

# Neuroimaging Meditation



Ranganatha Sitaram  
Wednesday, March 6, 13

# Overview of the presentation

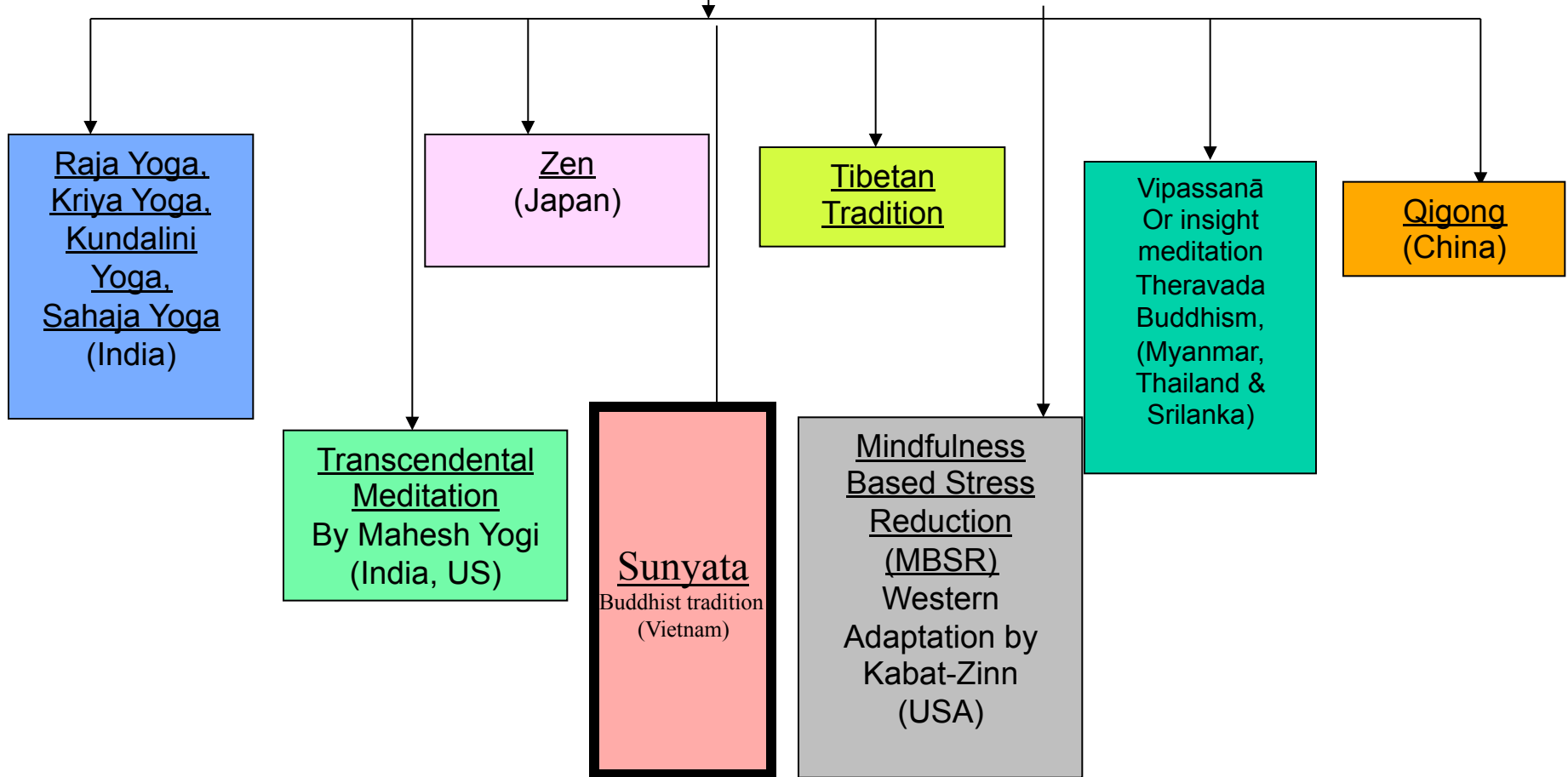
- Background
  - Meditation practices and methods
  - Current state of Neuroimaging studies
  - Research challenges
- Tuebingen Experiments on Sunyata Meditation
  - fMRI experiments
  - Combined EEG and fNIRS experiments
- Proposal
  - Unraveling the effects of meditation on consciousness

# Background

- The word *meditation* describes practices that self-regulate the body and mind.
- Indian scriptures mentioned meditation techniques more than 3000 years ago in Patanjali's *Yoga Sutras*.
- Buddha Sakyamuni, one of history's major proponents of meditation, first made his mark around 500 B.C.
- The sanskrit word for meditation is *dhyAna* -> chinese *chan* -> Japanese *zen*.



# Widespread Contemporary Meditation Practices





# Meditation is not just Relaxation!

- In Buddhist thought, over emphasizing samatha (stability or relaxation) is believed to lead to withdrawal, physical inactivity and depression.
- An ideal meditative state is one where there is neither dullness due to too much relaxation nor over-excitement.

# Meditative States & Traits

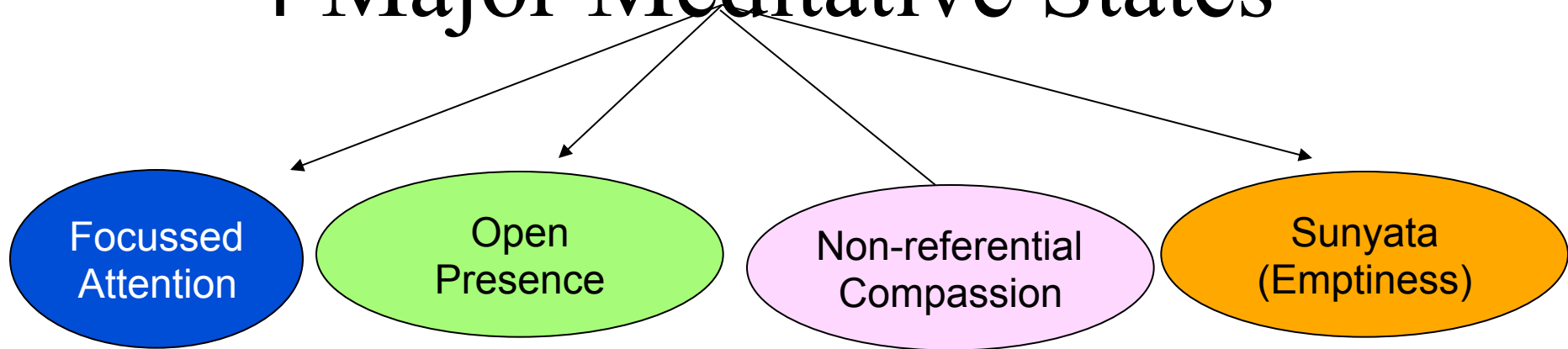
- **Meditative States**
  - Altered sensory, cognitive and self-referential awareness that occurs during meditation practice.
- **Meditative Traits**
  - Lasting changes in the above dimensions in the meditator that persist even when not engaged in meditation.
- Examples: Deep sense of calm and peacefulness, cessation of mind's internal dialog and experience of perceptual clarity.

# Meditation Studies

- Major groups of studies to-date:
  1. **1950s:** On yogis & students of Yoga in India  
(Das & Gastaut, 1955)
  2. **1960s:** On long-term Zen practitioners in Japan  
(Kasamatsu & Hirai, 1966)
  3. **1970s:** Transcendental meditation practitioners in the USA (Becker, 1981)
  4. **1990s onwards:** Various studies on Zen, Tibetan meditation, Yoga, etc. Neuroimaging studies...

PubMed search: more than 1,200 papers on meditation.

# 4 Major Meditative States



- A single practice may gradually progress through a number of meditative states.
- With increased practice, mental and physical effects are believed to gradually build.

# 1. Focused Attention

A *meta-awareness* is developed that surveys the meditative state for loss of focus or distraction.

Object of focus



## Objects of focussed attention

- An imaginary object
- A Mantra
- Breath

# Focussed Attention

## Important Points:

- 1. Sustained attention:** to maintain an awareness of the object in focus.
  - Thoughts, feelings and sensations can be detected as they arise.
- 2. Switching attention:** bringing attention back to the object once a thought, feeling or sensation has been acknowledged.
  - Switching involves flexibility of attention

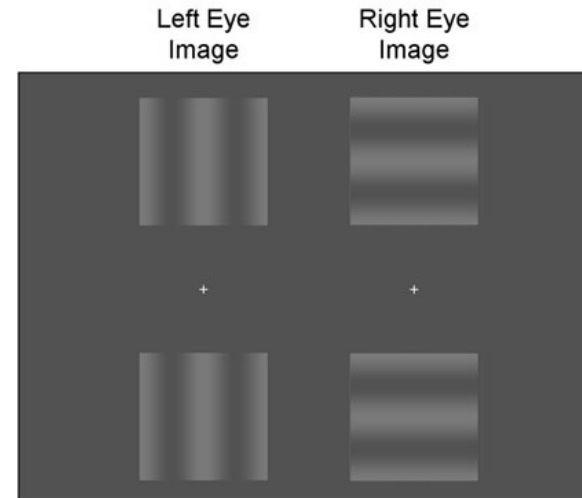


# Effects of Focussed Attention

- Greater ability to concentrate and a decrease in susceptibility to be perturbed out of concentration
- During meditation, the practice is said to induce a calming effect and a pleasurable sensation
- Reduced need for sleep
- Lightness and pliancy of mind and body

# Research Result: Focussed Attention Meditation on Binocular Rivalry Task (Carter et al., 2005, Current Biology)

- Tibetan monks were able to perceive a stable, superimposed percept of two dissimilar, competing images presented to separate eyes for a longer duration both during and after FA meditation and not ‘compassion’ meditation.



Stabilization of Perceptual Stimuli

## 2. Open Aware Meditation

- May start with initial attentional focus
- Does not rely on brain regions in engaging and sustaining attention on a specific object.
- But on **monitoring, vigilance and disengaging** attention from stimuli which distract attention from an ongoing stream of experience.

Awareness of ongoing experience from moment to moment

**Observe/label each moment**



# Open Aware Meditation

## Important Points:

- 1. Non-elaborative awareness:** not getting caught up in **ruminative** thought streams about one's experience.
  - Not a practice of *thought suppression*
  - All mental events are considered an object of *observation* and not *distraction*.
  - *Cognitive Inhibition*: This inhibits secondary elaborative processing of thought.

# Open Aware Meditation

2. **Releasing resources:** Attention has a limited capacity (Schneider & Shiffrin, 1977).

- When resources are released from **ruminative thought, more resources are available for processing information related to current experience.**
- Example: when one is less caught up in what happened yesterday would one be more aware of what is happening now.
- Avoiding the **,mental filter‘** of experiencing through our beliefs, assumptions, expectations and desires – **to enable direct observation.**

Research Result:  
Distributed attention in Open Aware  
Meditation

(Valentine & Sweet, 1999)

- This was a behavioral study
- Superior performance in Open Aware meditation when stimuli were unexpected
- Same performance in Focussed Attention meditation and Open Aware meditation when stimuli were expected.

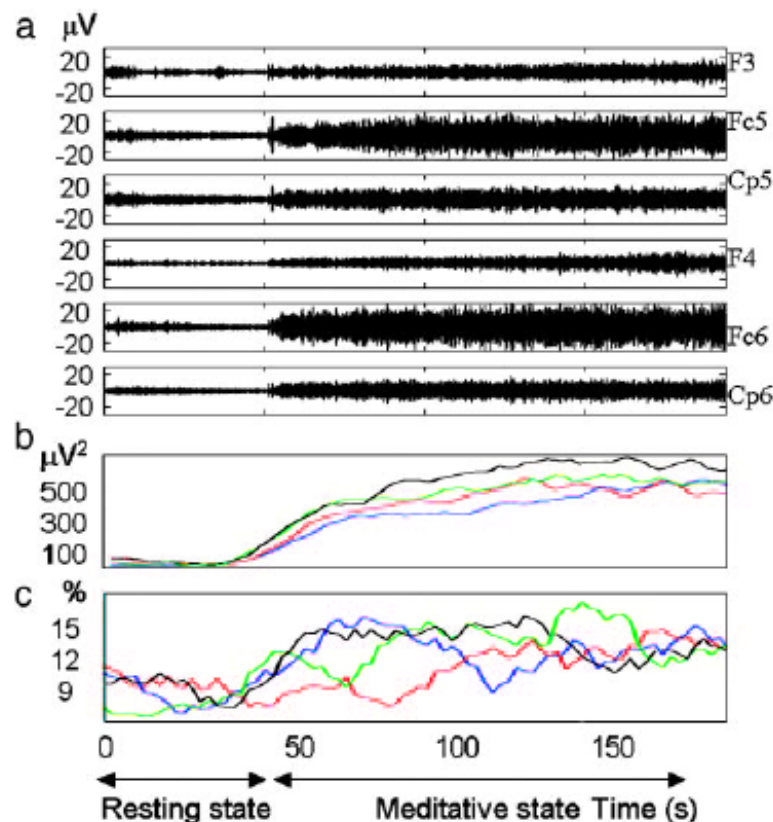


### 3. Non-Referential Compassion Meditation

- Mainly followed by Tibetan monks.
- This meditation produces a specific emotional state -> an intense feeling of „loving-kindness“ towards other beings by empathisizing with their happiness and sorrow.

# High-amplitude Gamma in Compassion meditation (Lutz et al., 2004, PNAS)

- High-amplitude gamma activity in long-term Tibetan buddhist meditators (raw signals after 45s of meditation).
  - Average time-course of gamma activity power over the electrodes (20s sliding window, averaged every 2s).
  - Time-course of cross-hemisphere synchrony.
- Colors show 4 blocks of data.



# Psychological & Clinical Effects of Meditation

## 1. On Attention:

- Longitudinal studies on children & adults reported improved performance on Embedded Figures Test requiring individuals to ignore distracting stimuli (Kubose, 1976).
- ADHD in adults: substantial improvement in symptoms after 6 week training of yogic concentrative meditation (Harrison, Manoch, 2004).

## 2. On Anxiety & Stress:

- Meditation decreases experienced stress load (Carlson et al., 2003) which appears related to cortisol & catecholamine levels (Carlson et al., 2004).

## 3. On depression

- Mindful meditation has been reported to be successful in treating depression (Ma & Teasdale, 2004).
- In conclusion, different meditative practices potentially produce different psychophysiological effects.

# Challenges of meditation research

1. Limited statistical evidence
2. Lack of control populations
3. Lack of scientific rigor in early studies
4. Heterogeneity of meditative states
5. Varying degree of expertise in meditators

# Neuroimaging Study on Sunyata Meditation

# 4. Sunyata

- Sunyata (Sanskrit noun from the adjective ‘Sunya’ meaning void).
- In Buddhist philosophy it signifies the **impermanent nature** of form; meaning that objects in the world do not possess essential or enduring properties.
- In Buddhist spiritual teaching, cultivating **insight** into the emptiness leads to wisdom and inner peace.



# Study Hypotheses

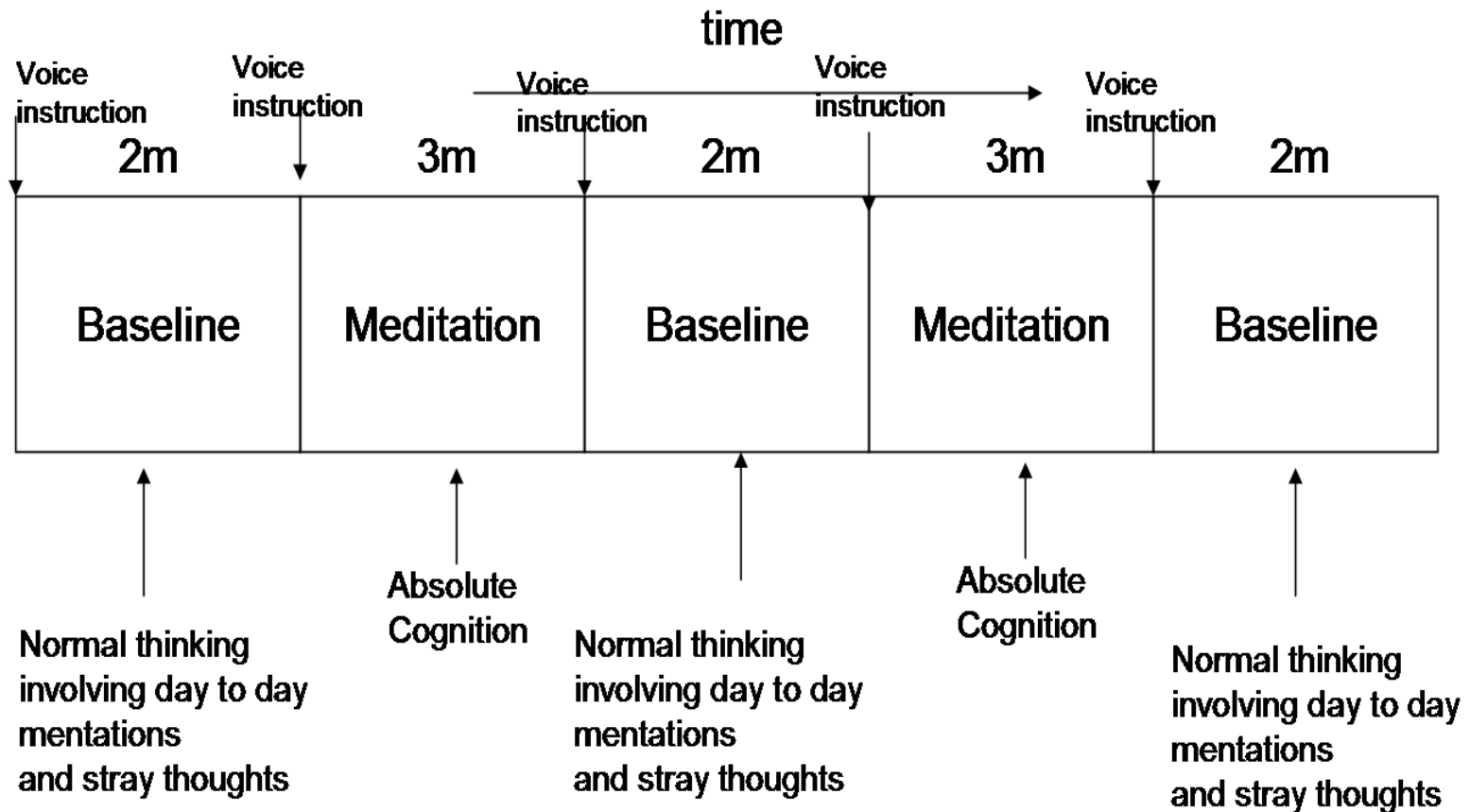
- Considering that Sunyata meditation practice is aimed to develop an ability to:
  - avoid *discursive* (wandering, long-winded) thought
  - instead acquire *insight* into the nature of reality through direct perception of the internal (bodily) and external (sensory) phenomena...
- we hypothesized that:
  1. Memory retrieval, planning and executive control areas of the brain will be deactivated.
  2. Brain areas related to interoception and sensory perception will be activated.

# 6 Participants

- 4 expert meditators: 2 monks, 2 nuns
- Master (male)
  - About 70 years of age
  - More than 30 years meditation experience
  - Meditates > 7 hours per day
- Other experts
  - 50-60 years of age
  - More than 15 years meditation experience
  - Meditate > 4 hours per day
- 2 intermediate practitioners

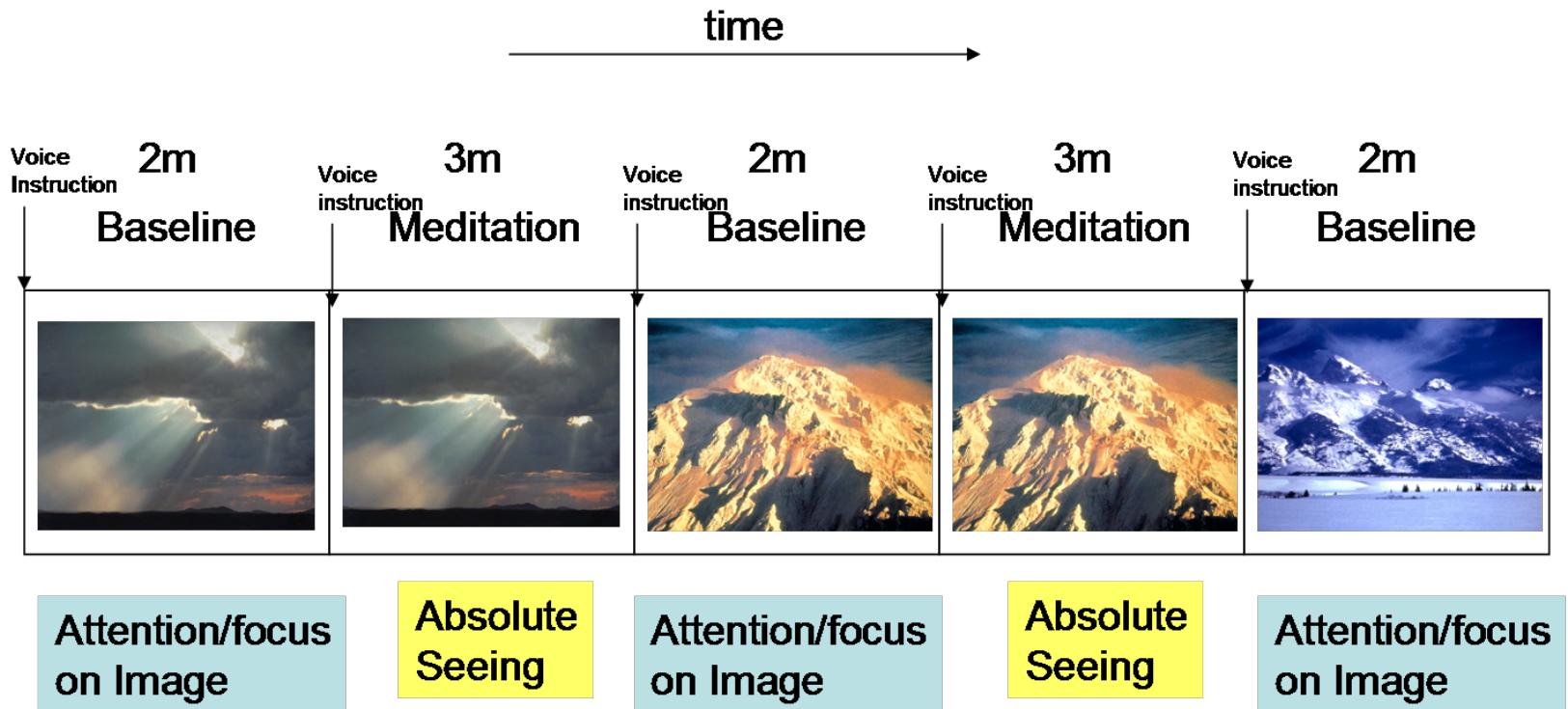
# Study Design

## 1. Absolute Cognition

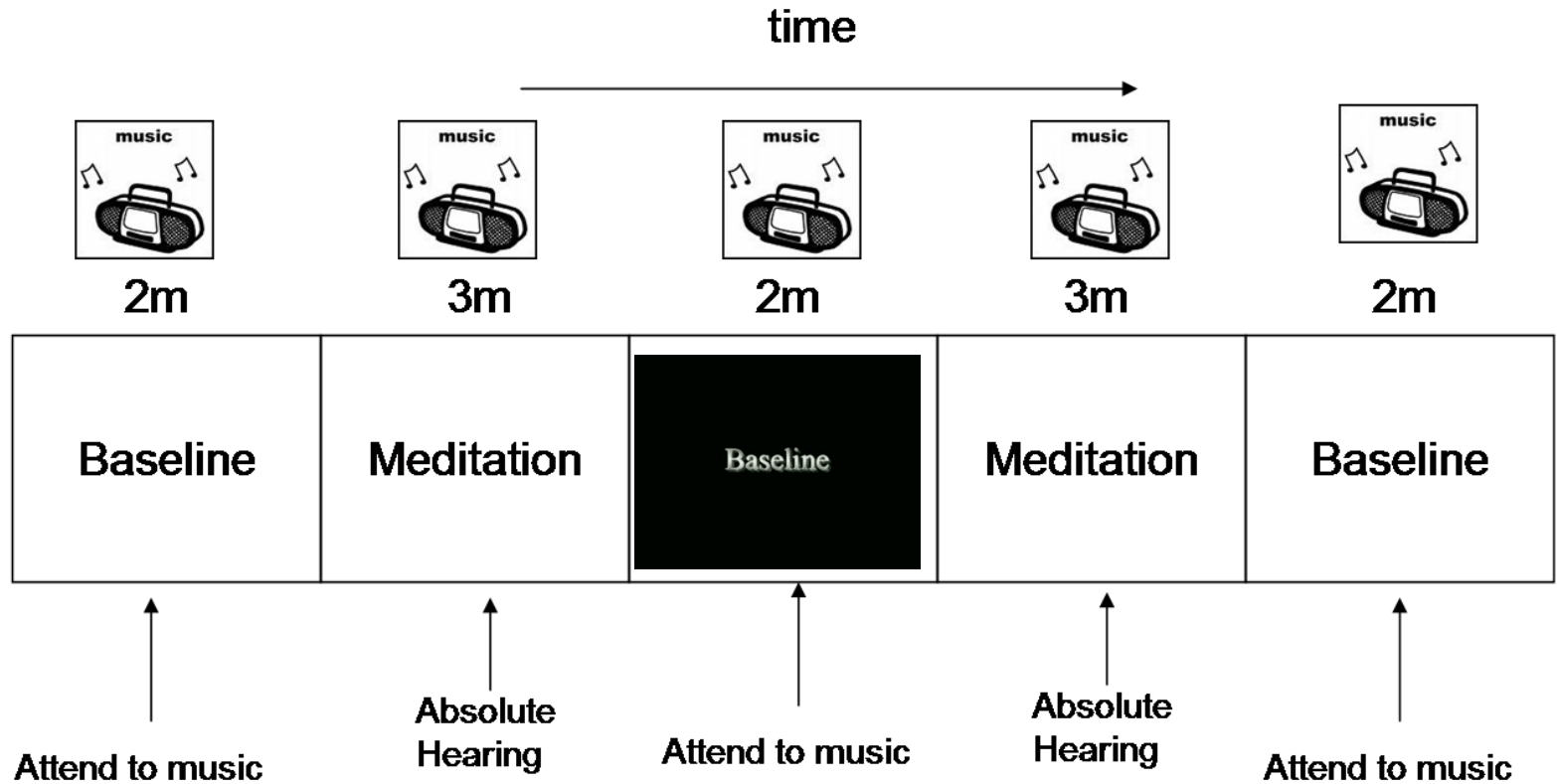


# Study Design

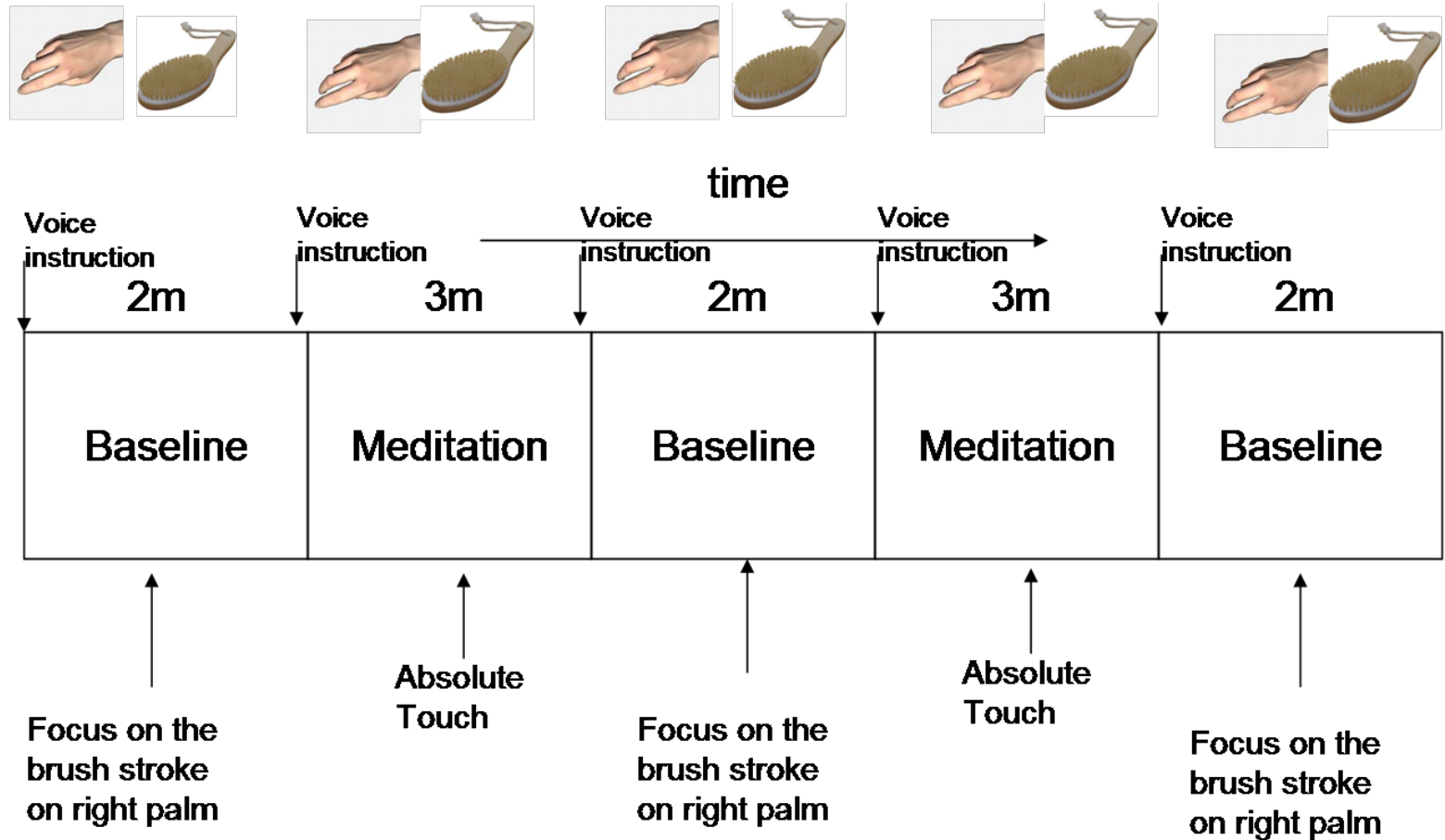
## 2. Absolute Seeing



# 3. Absolute Hearing



# 4. Absolute Touch





# Data Acquired

- fMRI
- Pulse
- Respiration
- Report of depth of meditation reached in each session, and subjective feelings.

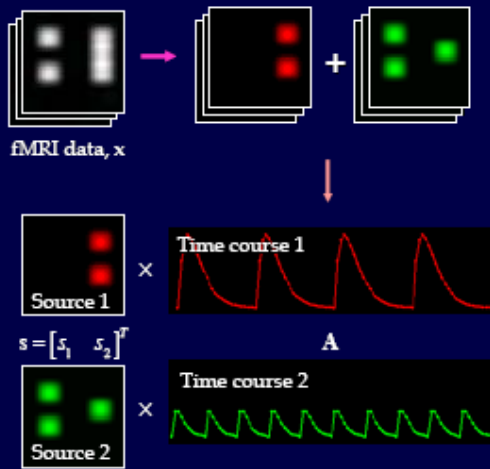
## ICA of fMRI

The ICA model assumes the fMRI data,  $x$ , is a linear mixture of statistically independent sources,  $s$ .

$$x = As$$

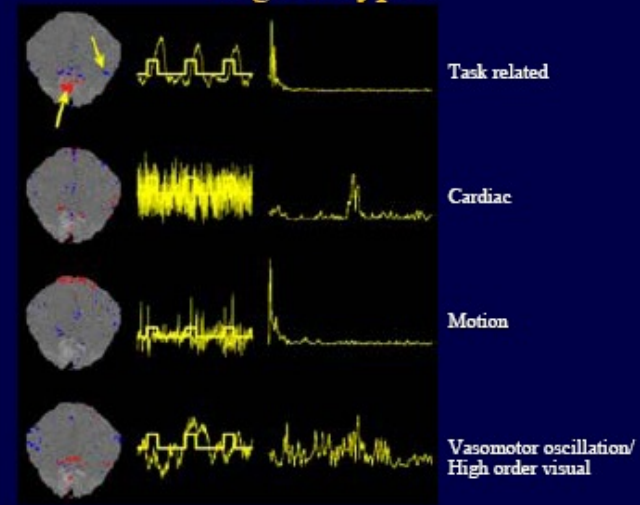
$$p(s_1, s_2) = p(s_1)p(s_2)$$

The goal of ICA is to separate the sources given the mixed data and thus determine the  $s$  and  $A$  matrices



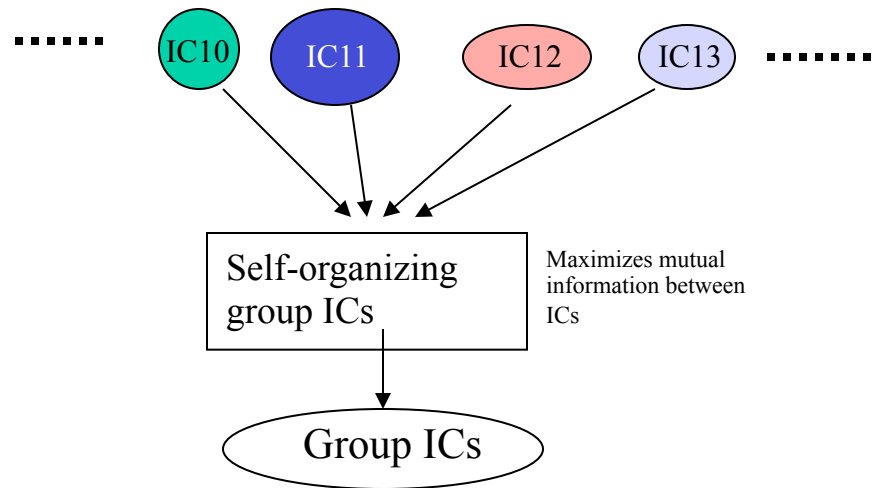
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## Signal Types



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## Group ICA



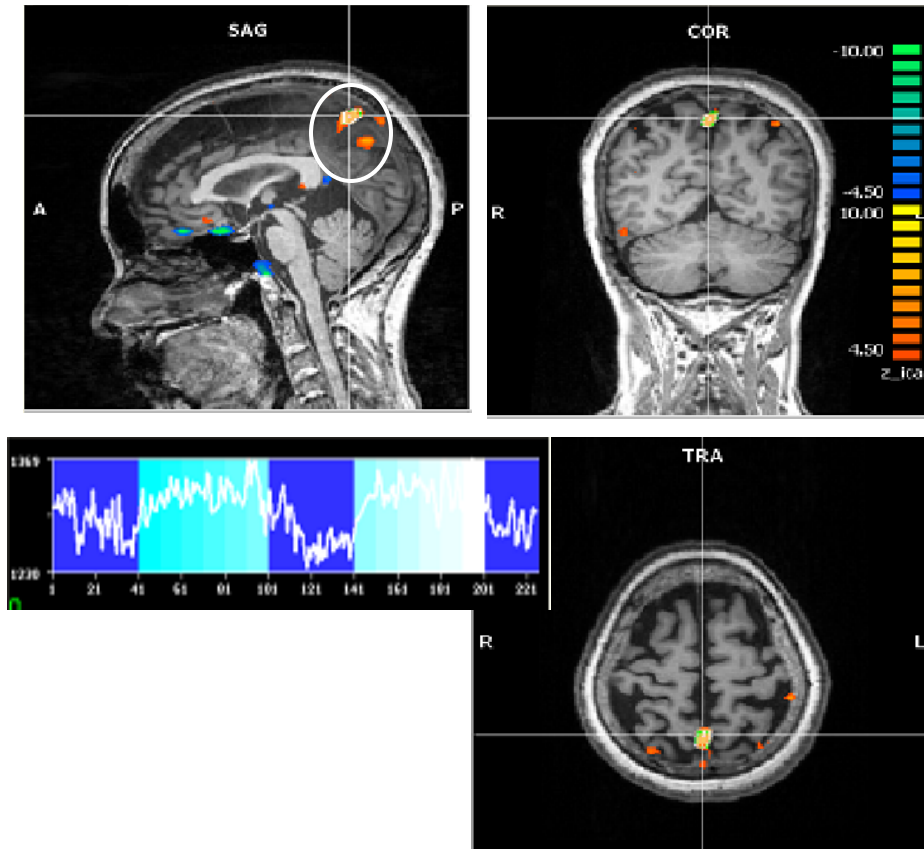
# Group ICA Results - 1

Common (de)activations across 4  
types of meditation

Note: Some (not all) of these areas were also identified in the SPM group analysis. But ICA was more consistent and noise free. So, SPM results are not repeated here for saving time.

# 1. Activation in Precuneus

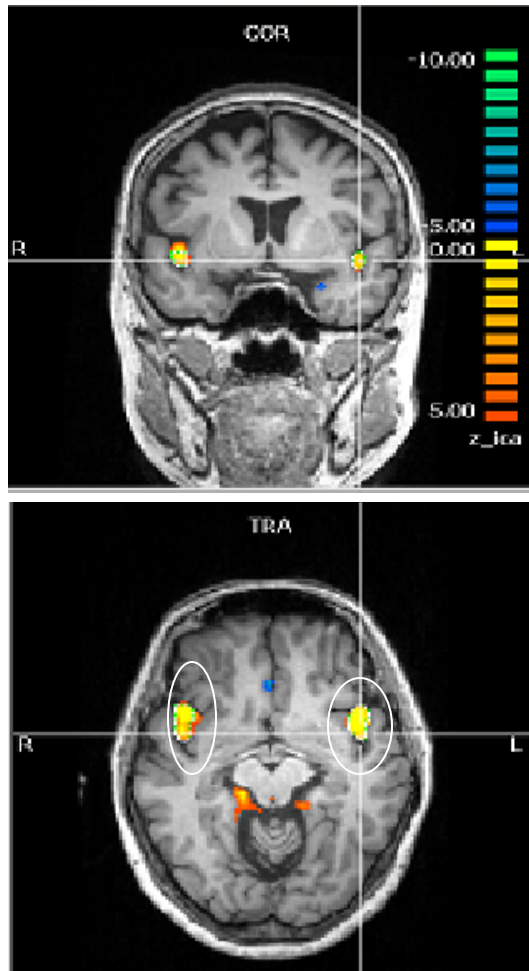
## Enhanced self-processing and conscious state



- Studies in healthy subjects indicate that the precuneus plays a role in **self-consciousness**.
- Lou et al. (1999) found a medial parietal prefrontal core in the **enhanced consciousness state** of yoga meditation with the PET technique in experienced yoga teachers.
- An interaction between precuneus and prefrontal cortex has been postulated in states of consciousness characterized by a high level of **reflective self-awareness** (Kjaer and Lou, 2000).
- Precuneus shows a profound deactivation in pathophysiological altered states of consciousness, such as slow-wave sleep (SWS) and rapid eye movement (REM) sleep, the hypnotic state, pharmacologically induced general anaesthesia and the persistent vegetative state

## 2. Activation in insula

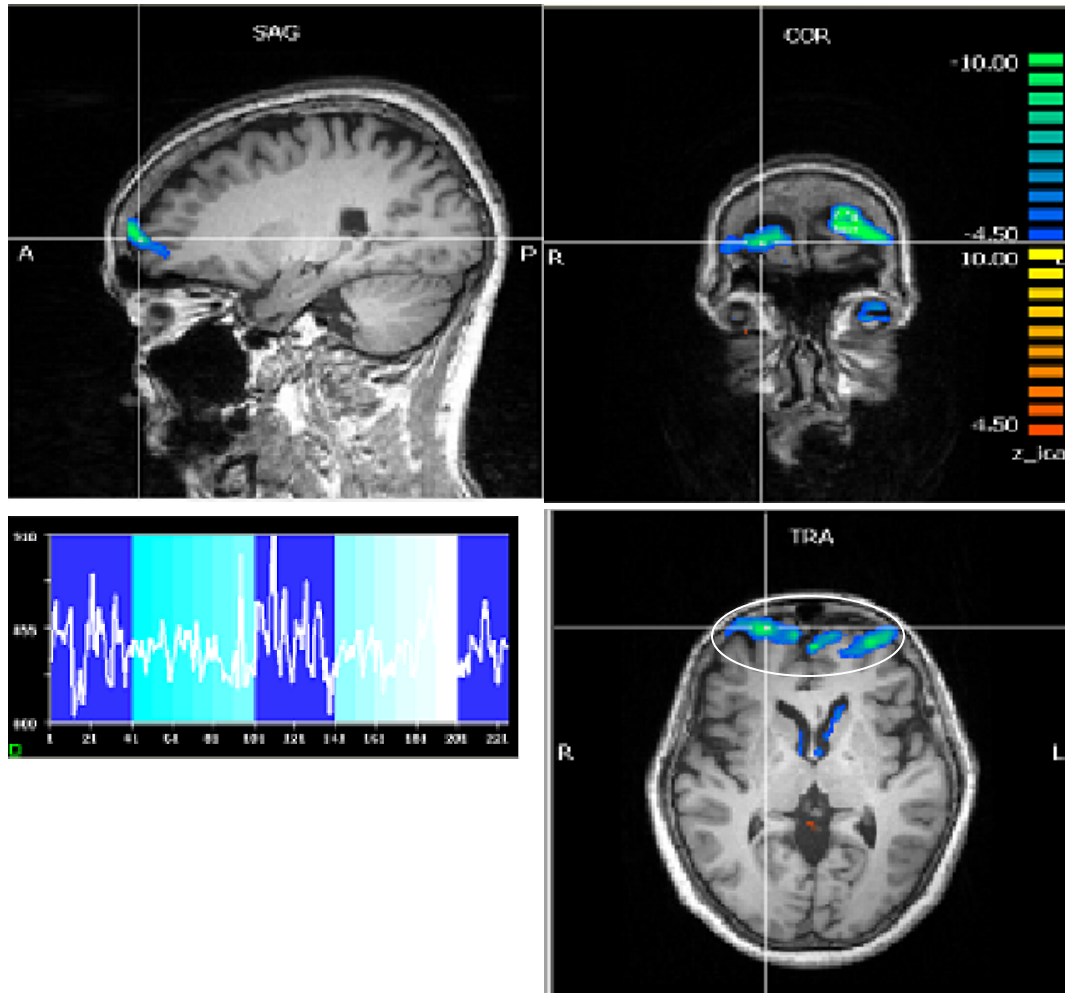
### Enhanced interoception



Insula is critical for the evaluation of the interoceptive awareness, including emotional states, through the functional representation of homeostatic changes (Reiman 1999, Craig 2002, 2003).

# 3. Deactivation of BA-10

## Reduced memory retrieval and executive function

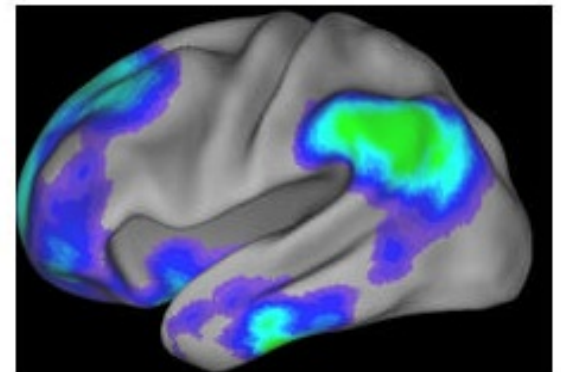
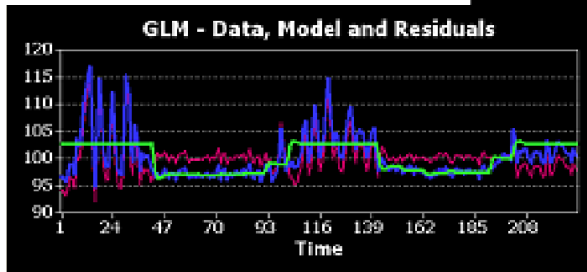
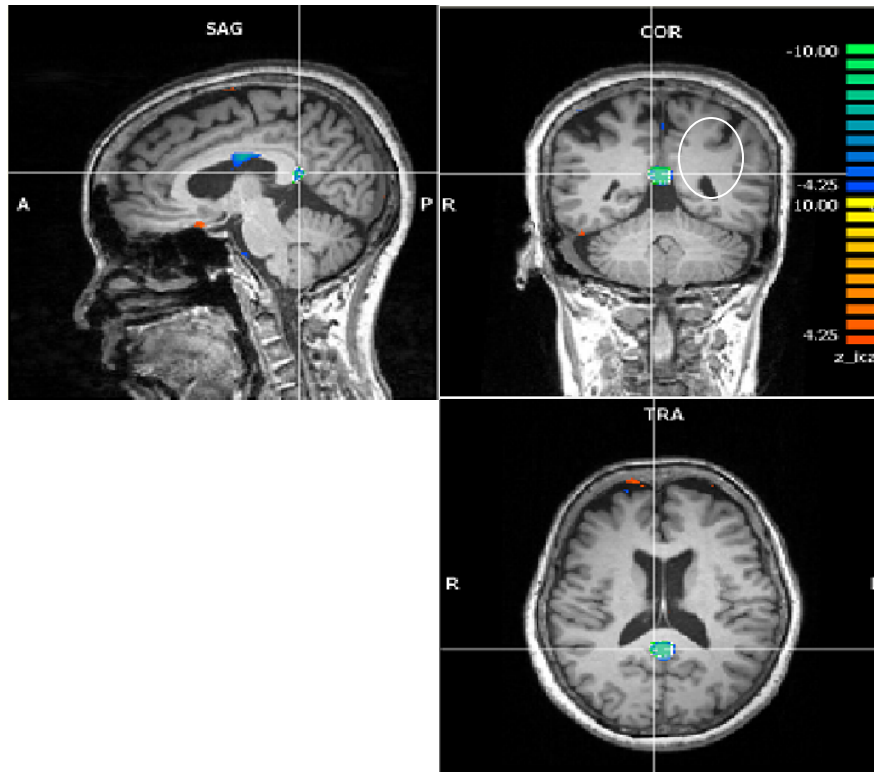


• **Brodmann area 10**, encompasses the most anterior part of the frontal cortex, known as the frontopolar region. This area is believed to play a part in strategic processes involved in memory retrieval and executive function.

# 4. Deactivation of the Posterior Cingulate

## Default Mode of Brain Function (Raichle 2001)

A *default mode* of functioning is described by Raichle et al., as the basis of two related observations: first, certain areas (**Posterior Cingulate**) of the brain **consistently decrease** activity when subjects engage in **goal-directed tasks** as compared to simply resting quietly with the eyes closed or visually fixating; and, second, this network of areas was not physiologically 'activated' in the resting state.



# Summary of Group ICA Results

- Common (de)activations across the 4 meditation types
  1. Activation in bilateral **Precuneus**, implicated in **self-processing** and **consciousness** (Cavanna 2007).
  2. Activation in the bilateral **insula**, implicated in **interoception**.
  3. Deactivation in frontopolar region of the brain, namely, **BA-10**, involved in strategic processes including **memory retrieval** and **executive function**.
  4. Deactivation in the **Posterior Cingulate**, implicated consistently in the **default** network of brain function (Raichle, 2000).

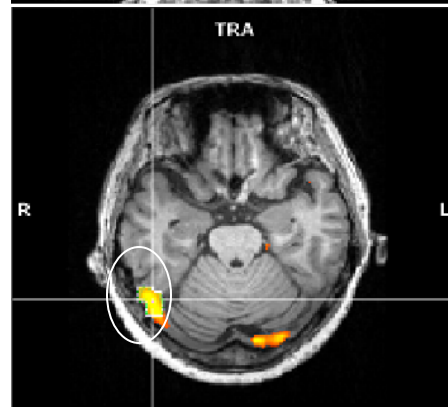
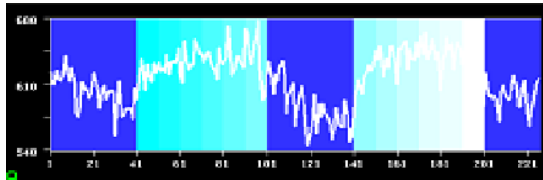
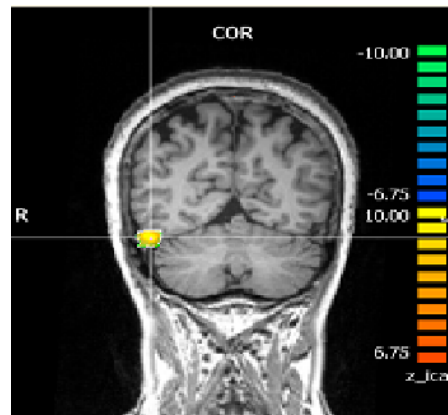
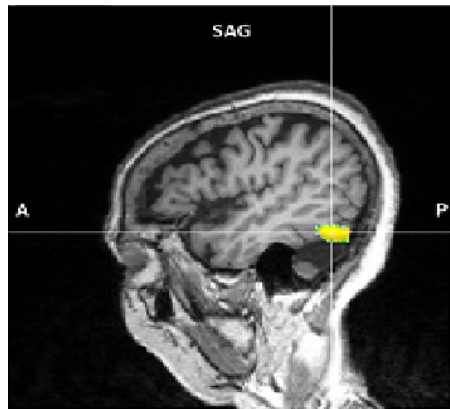


# Group ICA Results - 2

Meditation type specific activations

# Absolute Cognition

Activation in the Fusiform Gyrus: enhanced abstraction?



FFG is known to be involved in the following functions:

- processing of color information
- face and body recognition
- word recognition
- number recognition
- **abstraction**

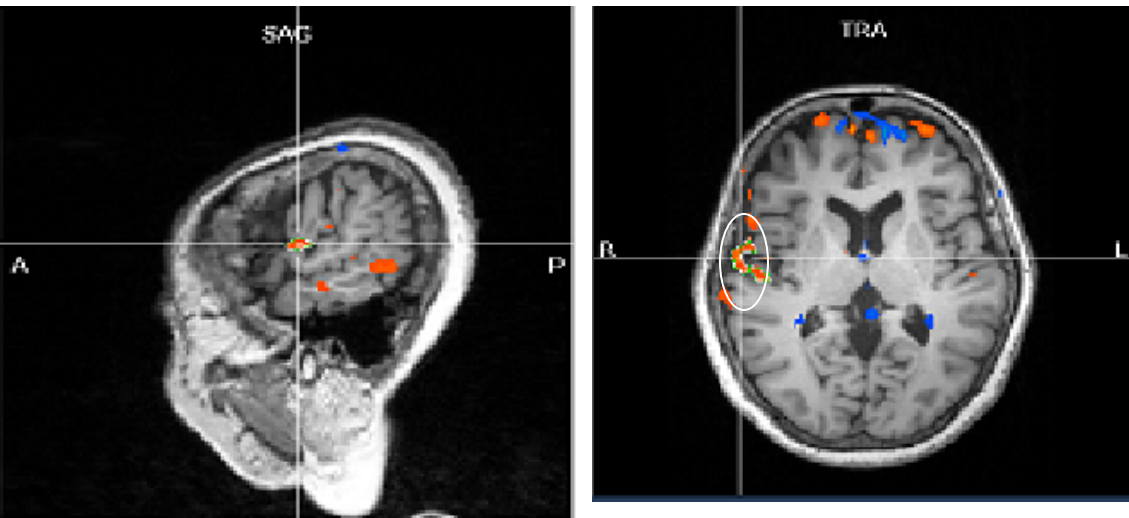
Considering that there were **no stimuli** presented during this meditation condition, could we hypothesize that FFG is involved in some sort of **abstraction** or a **direct recognition** of an internal state?

**Is there more to FFG?**

# Absolute Hearing

## Enhanced activation of the auditory area for tone processing

### Right Rolandic Operculum



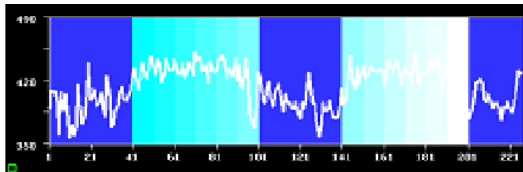
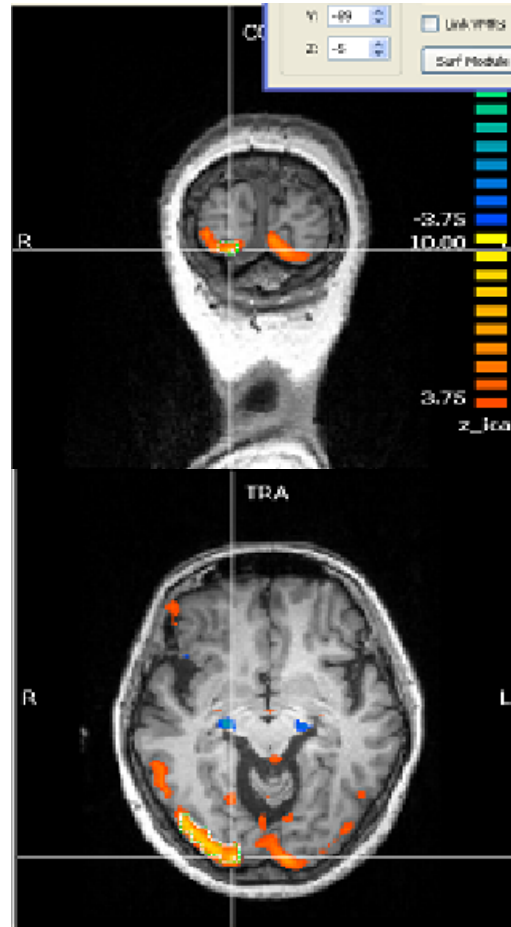
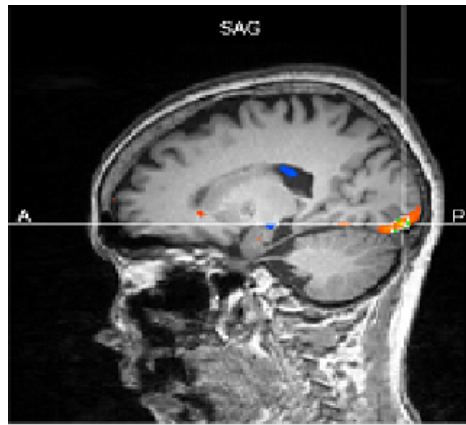
The **right** auditory cortex has long been shown to be more sensitive to tonality, while the left auditory cortex has been shown to be more sensitive to minute sequential differences in sound, specifically speech.

Our results suggest that compared to baseline condition, the meditation condition enhances the sensitivity to music.

This agrees well with the meditators self-report of improved experience of music during meditation.

# Absolute Seeing

Heightened activation in the visual cortex

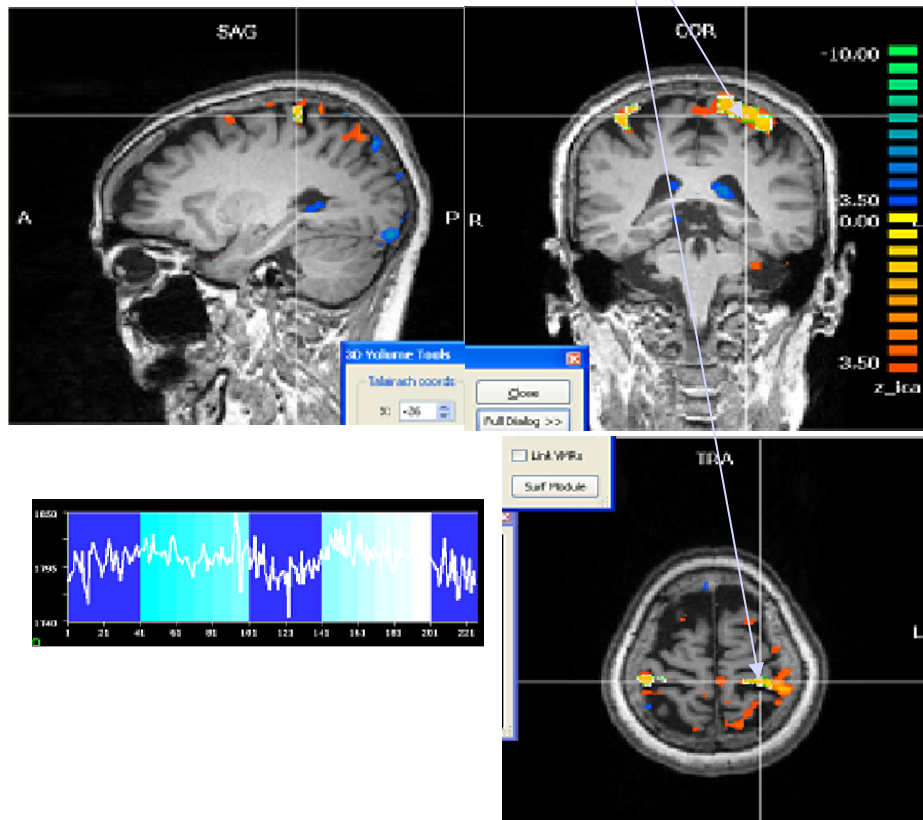


Considering that the same pictures are shown in both the baseline and meditation conditions, the increased activity in the visual cortex during meditation probably demonstrates the **heightened sensitivity to sensory perception** during meditation.

# Absolute Touch

## Enhanced somatosensation

Effect of brush stroke on the back of right hand

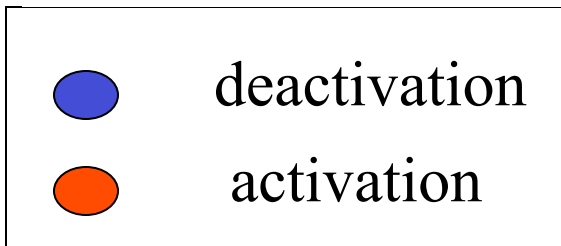
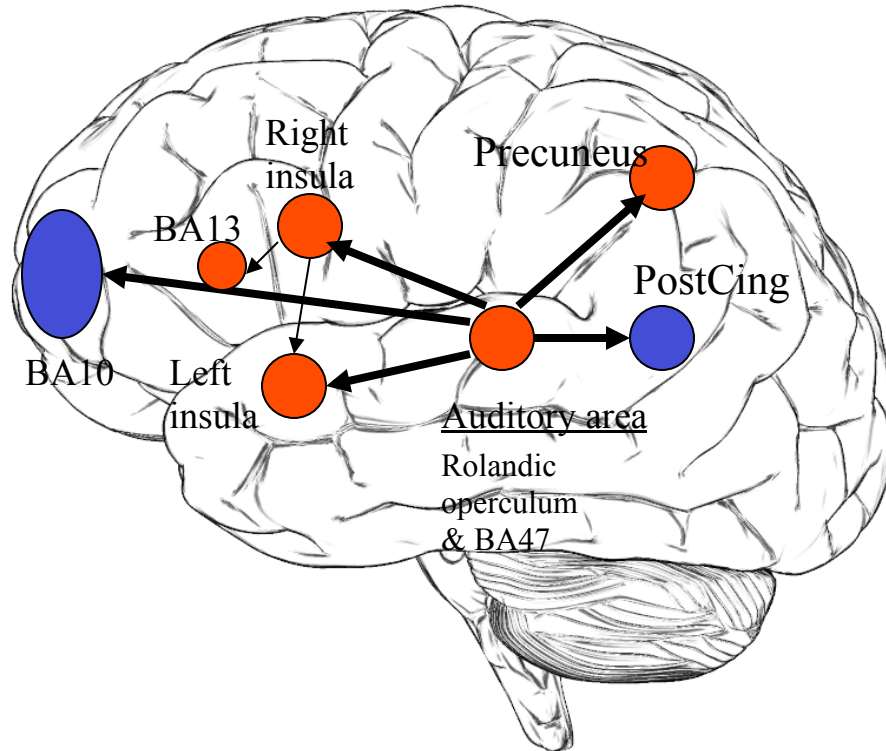


The **somatosensory system** is a sensory system that detects experiences labelled as touch or pressure, temperature (warm or cold), pain (including itch and tickle), as well as [proprioception](#).

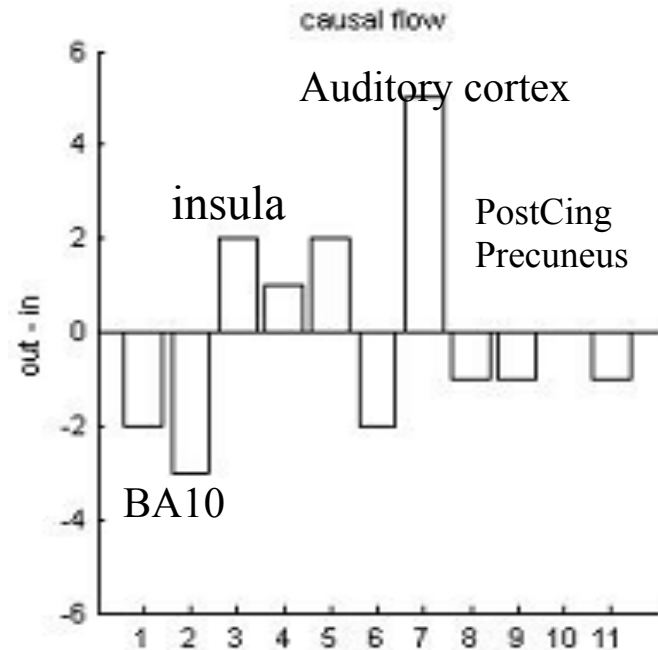
Touch may be considered one of five human senses; however, when a person touches something or somebody this gives rise to various feelings: the perception of pressure (hence shape, softness, texture, vibration, etc.), relative temperature and sometimes pain. Thus the term "touch" is actually the combined term for several senses.

# Effective Connectivity Analysis

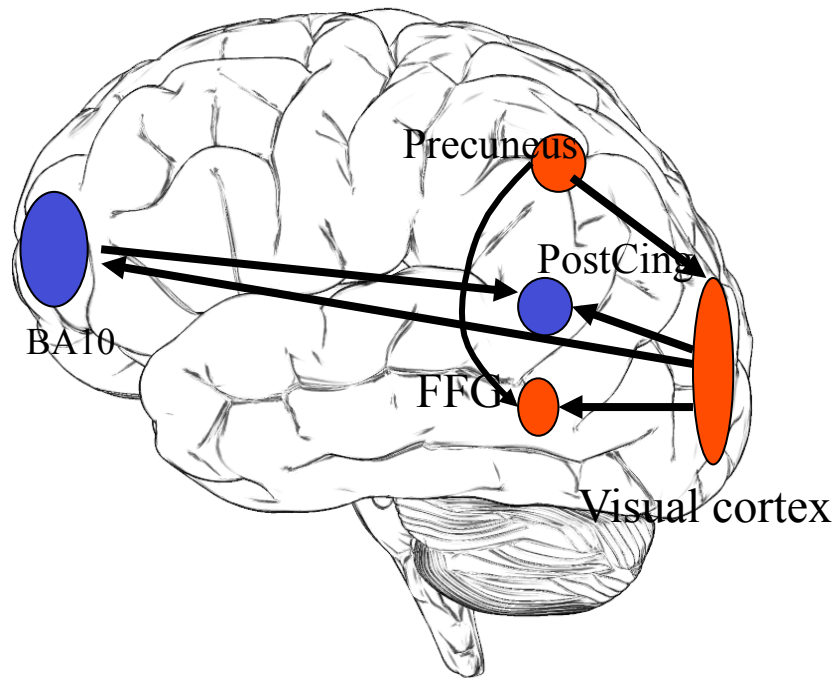
# GCM Analysis of Absolute Hearing



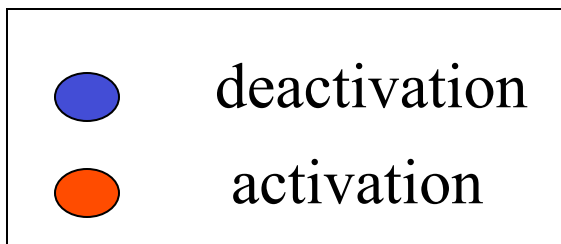
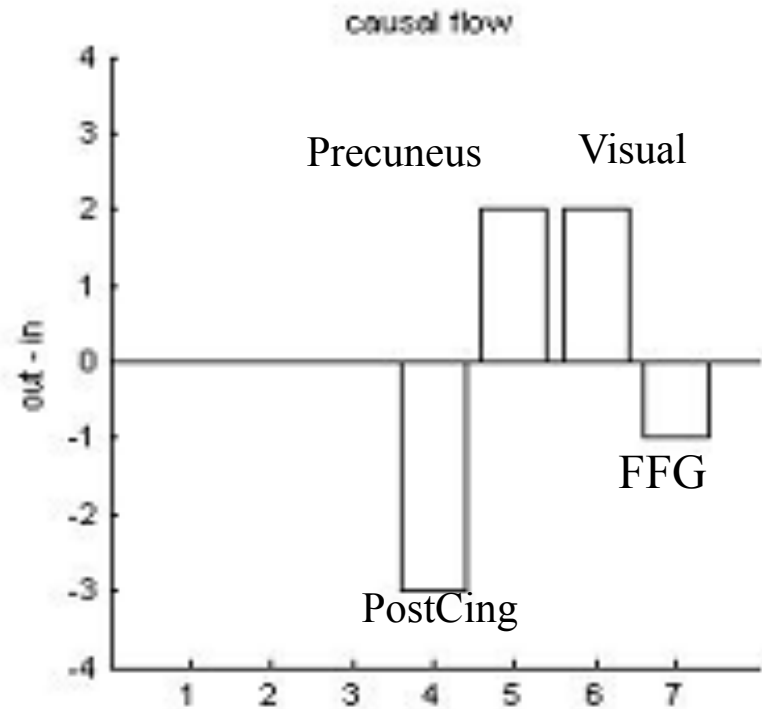
Differential outgoing and incoming connections



# GCM Analysis of Absolute Seeing



Differential outgoing and incoming connections





# Summary of Results

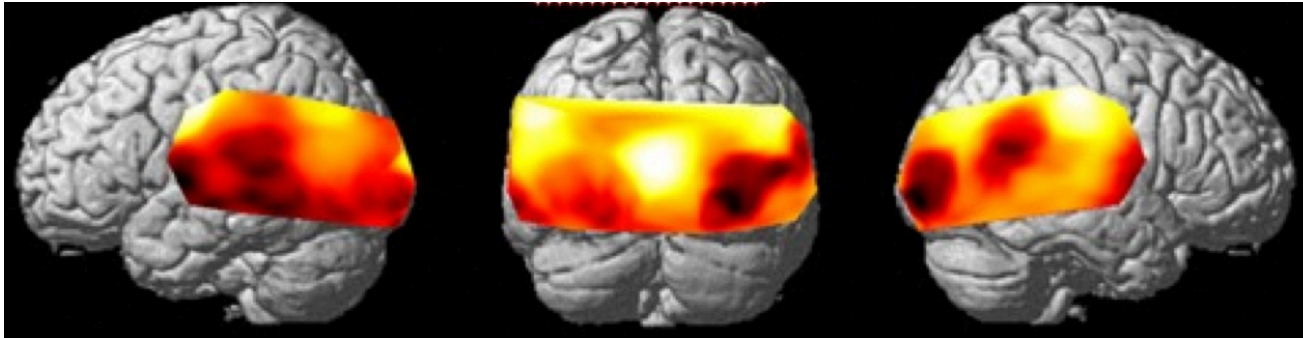
1. Sunyata meditation **enhances perception** of external stimuli and **interoception** (of internal bodily states) as shown by heightened activations in sensory areas and **insula** when compared to the baseline state.
2. It **reduces discursive** (long-winded, mentation) **thought** as shown by a consistent deactivation of the the BA-10 involved in memory retrieval, planning and executive function.
3. This experiment replicates the **default state** of brain function as shown by the consistent deactivation of the **Posterior Cingulate**.

# Discussion

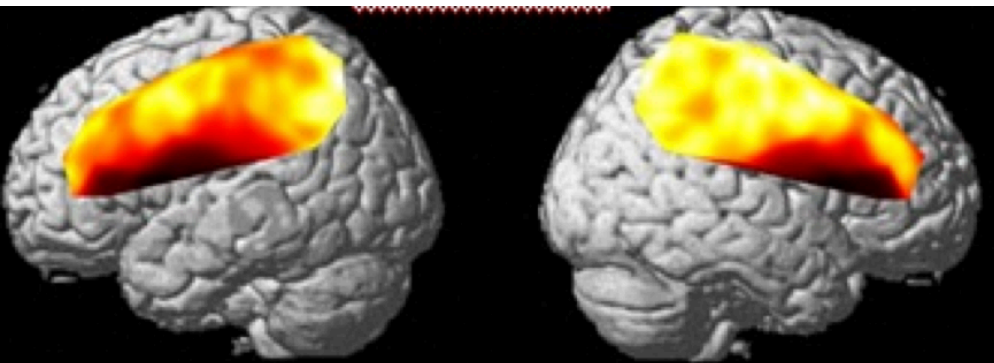
- Neuroelectric & neuroimaging correlates of meditation are not yet completely established.
- However, there is evidence that experienced practitioners are able to produce repeatable and reliable states and verbal reports of meditation.
- An important foundation for research is the sound understanding of variety & complexity of meditation practices.
- Meditation research can lead us to understand: neural correlates of subjective experience, neuroplasticity and mechanisms of mind-body interactions.
- Practically, meditation research may establish clinical therapy for psychophysiological ailments.
- **Future work should develop a theoretical framework of neuronal activations during different meditation practices.**

# Simultaneous EEG fNIRS Study

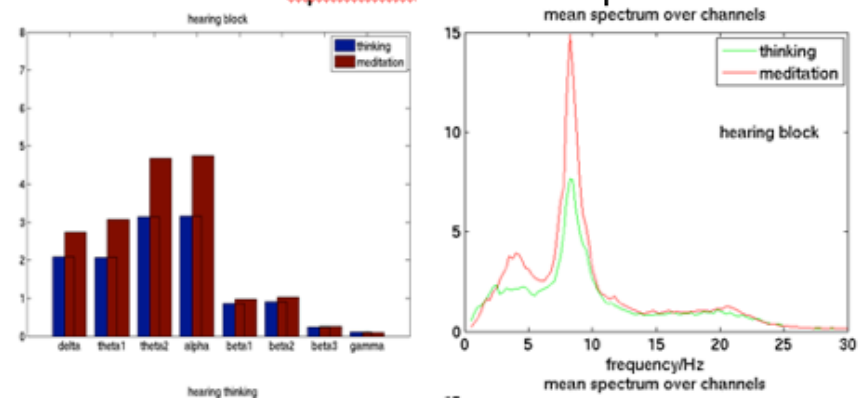
## Absolute Seeing Meditation



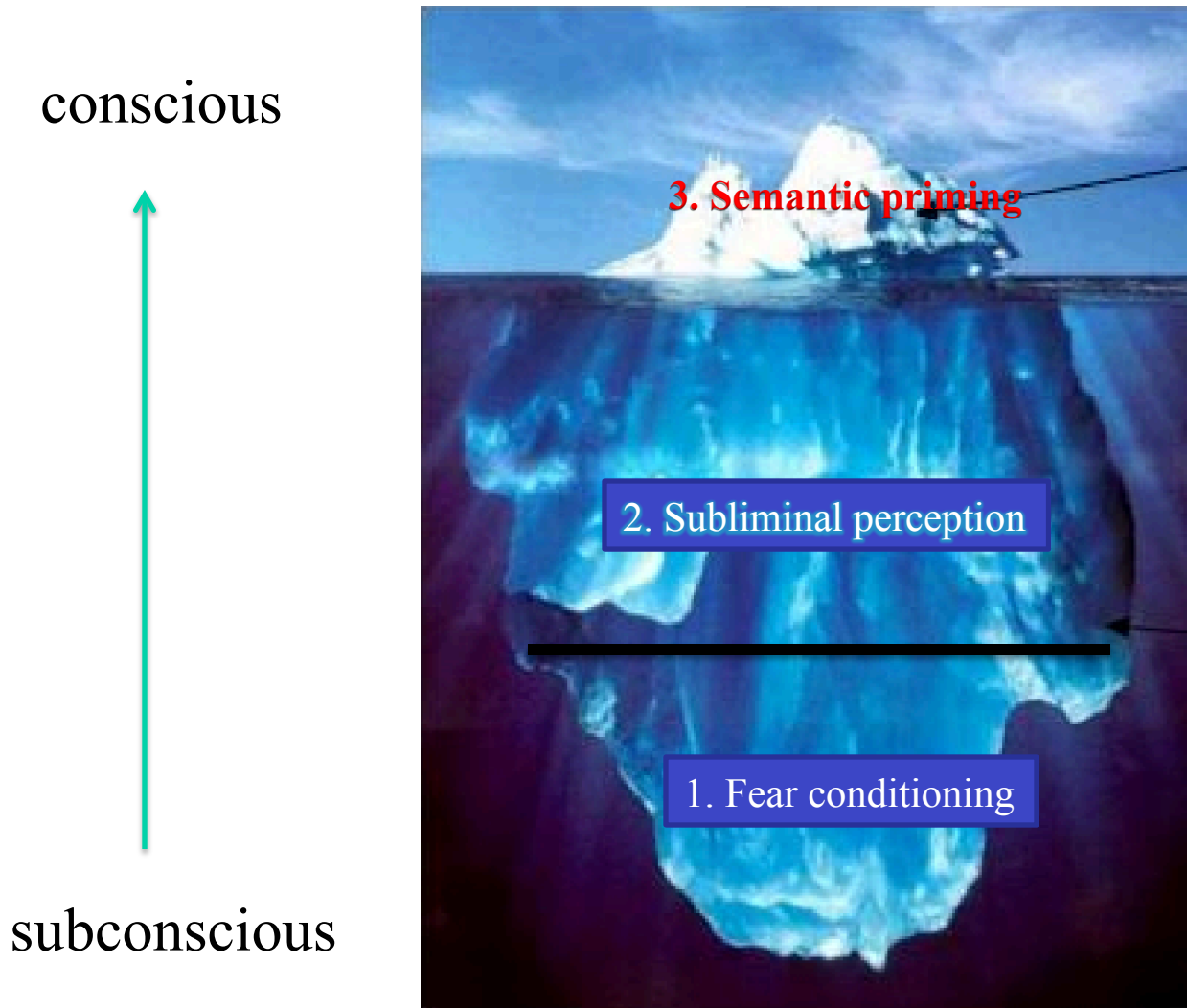
## Absolute Hearing Meditation



## EEG spectra and band power



# Does meditation change brain processes of consciousness?



# 1. Classical Fear Conditioning

conscious



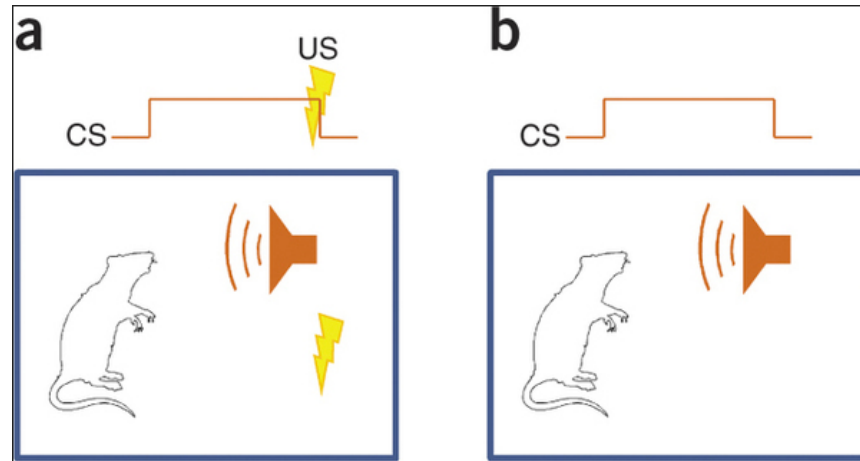
subconscious



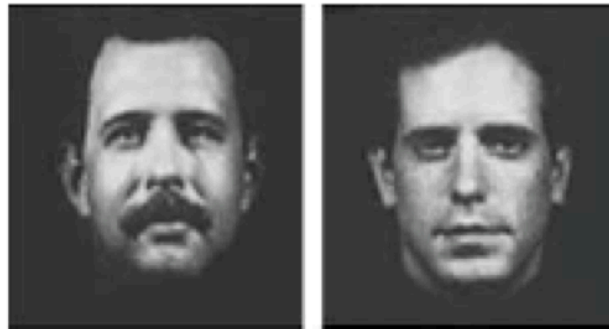
1. Fear conditioning

# Classical Fear Conditioning

Veit, Birbaumer et al., (2002, 2005)

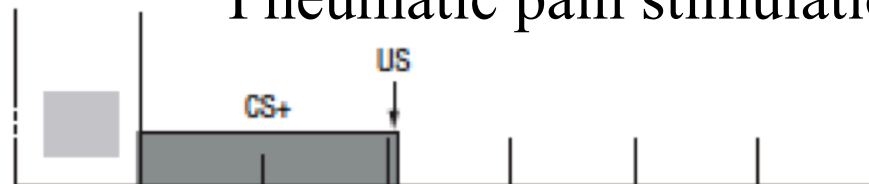


CS +/-



Human Experiment

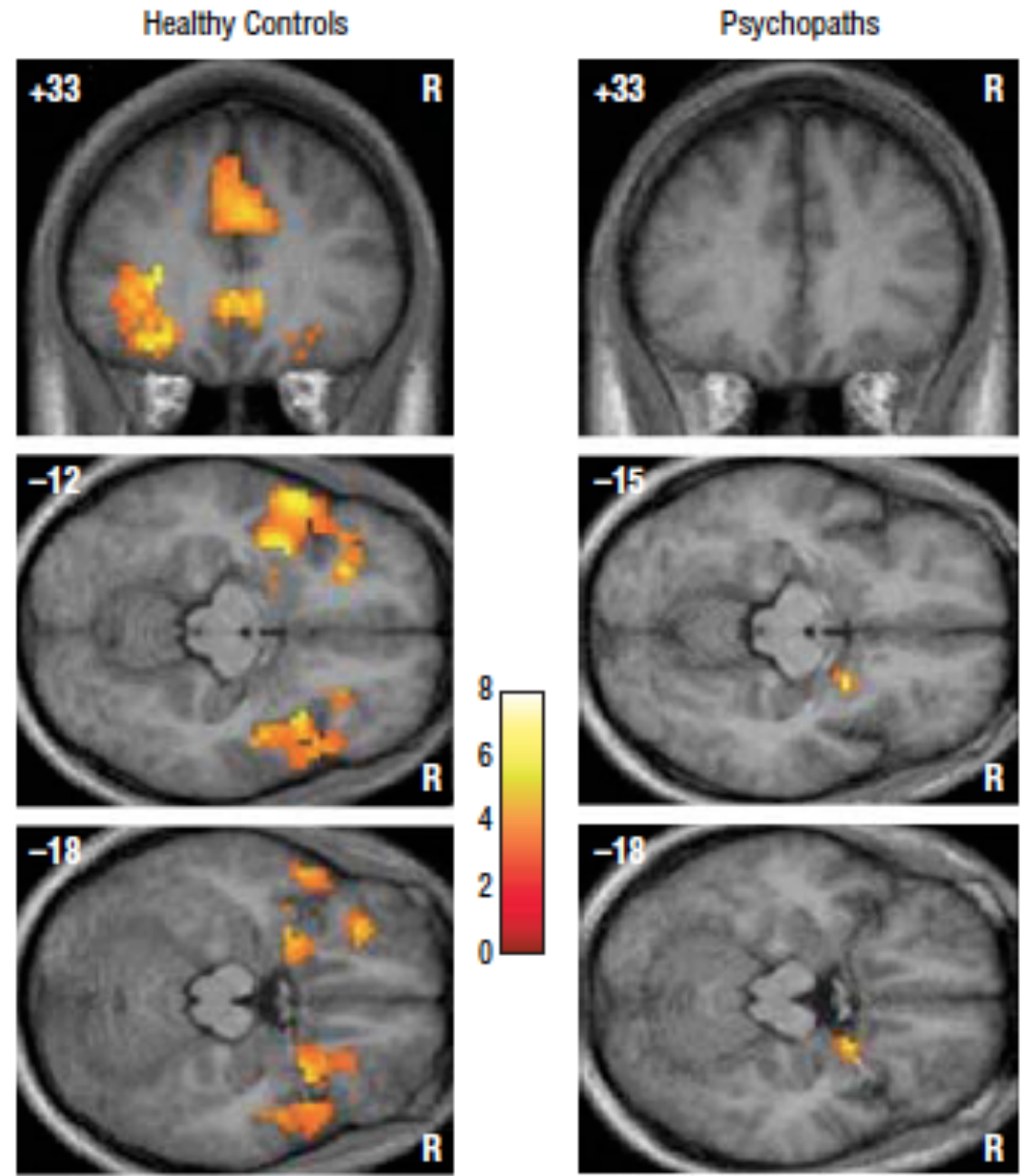
Pneumatic pain stimulation on finger

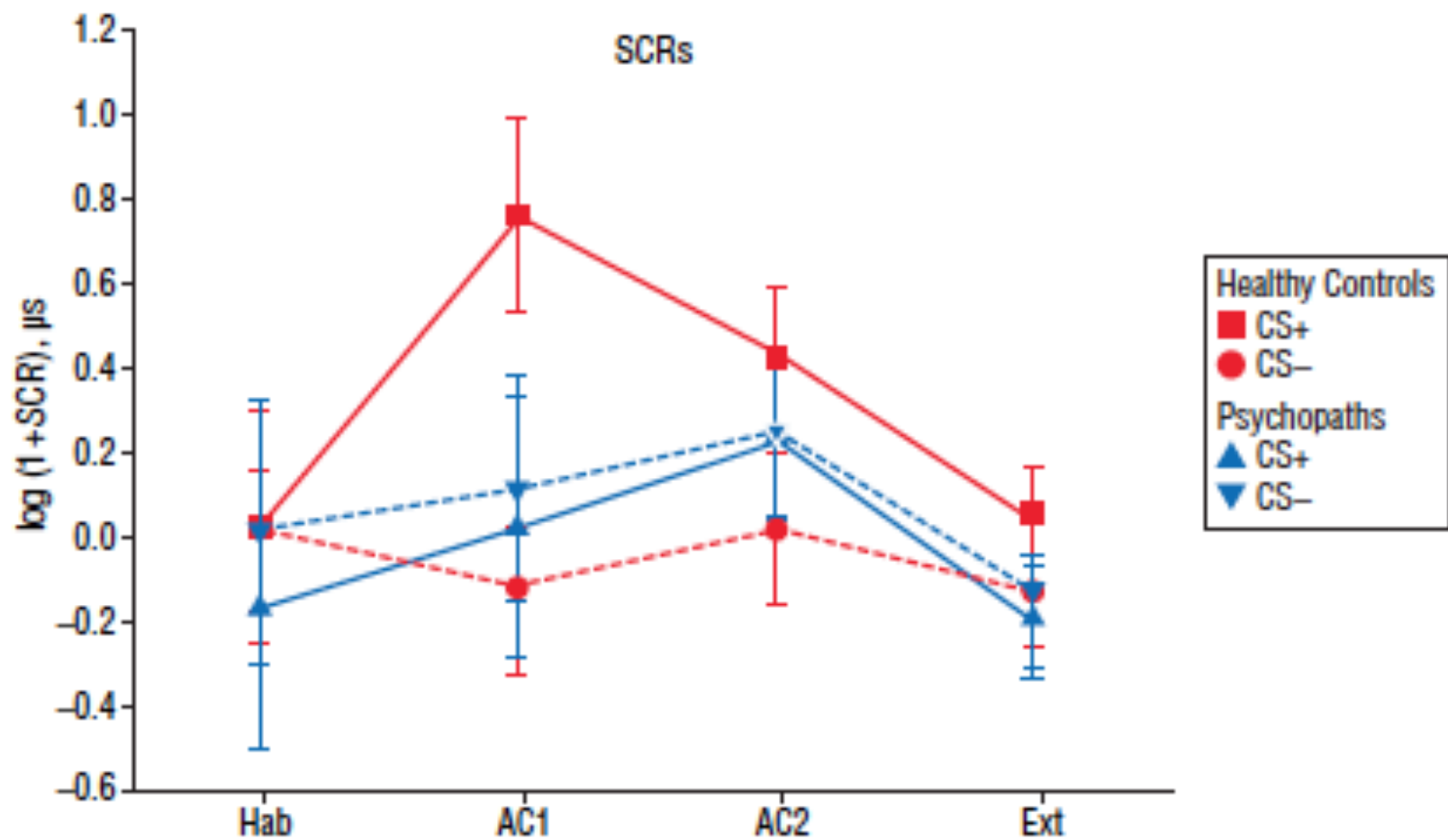


Anterior Cingulate

Insula

Amygdala







# Meditation and fear conditioning?

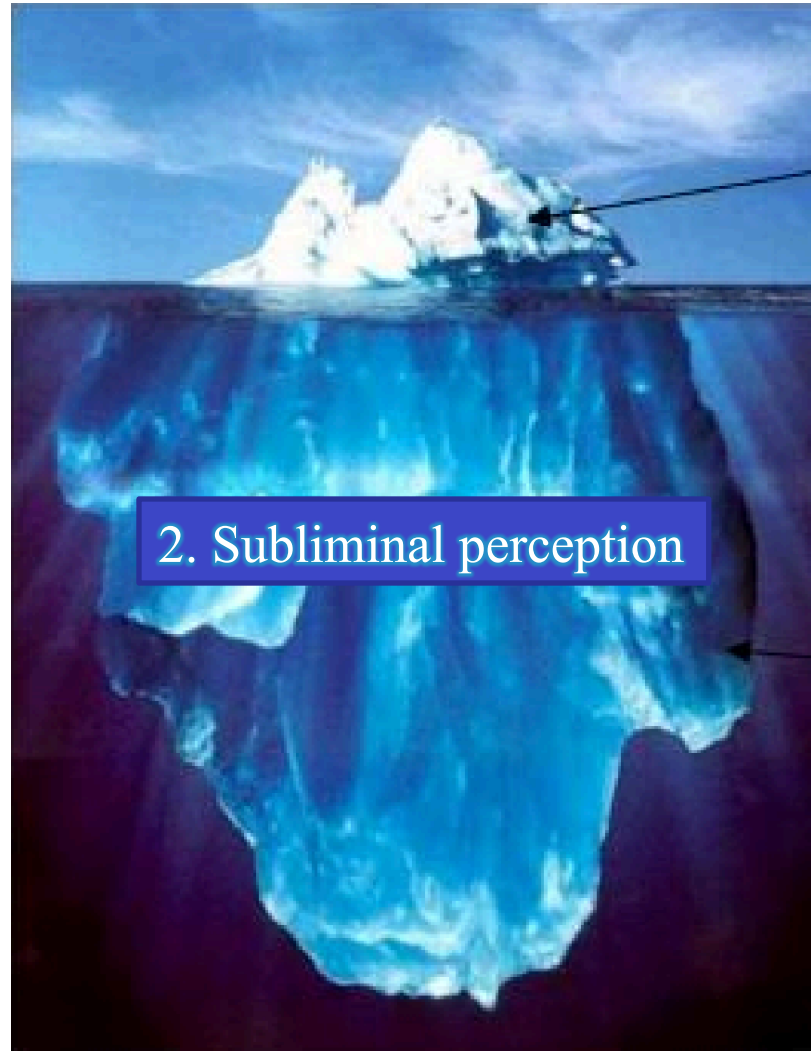
1. Meditation leads to rapid “extinction” of fear conditioning and fear memories.
  - Scientific and clinical implications: understanding the brain circuits of rapid extinction
  - Extinction of phobias and traumatic stress disorder.

# 2. Meditation and Subliminal Perception

conscious

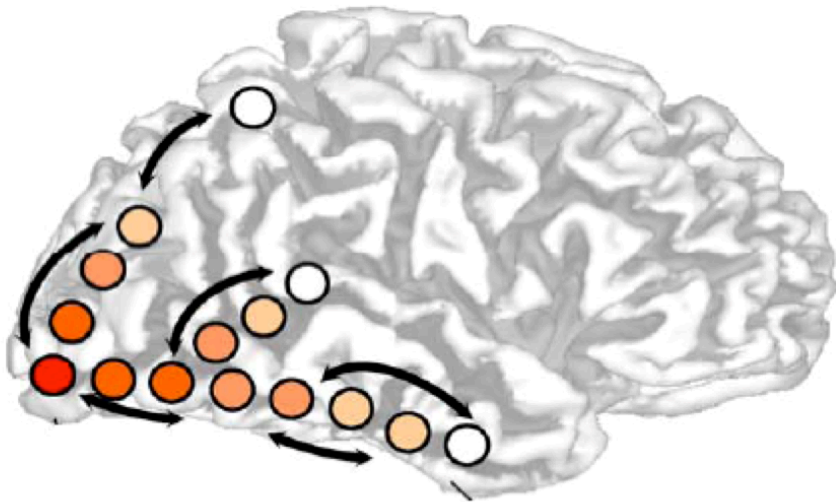


subconscious



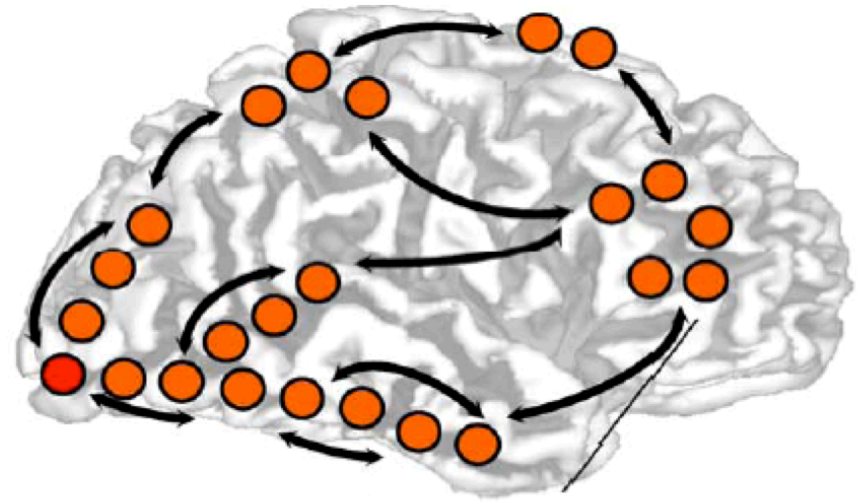
## Subliminal Processing

- Local processing



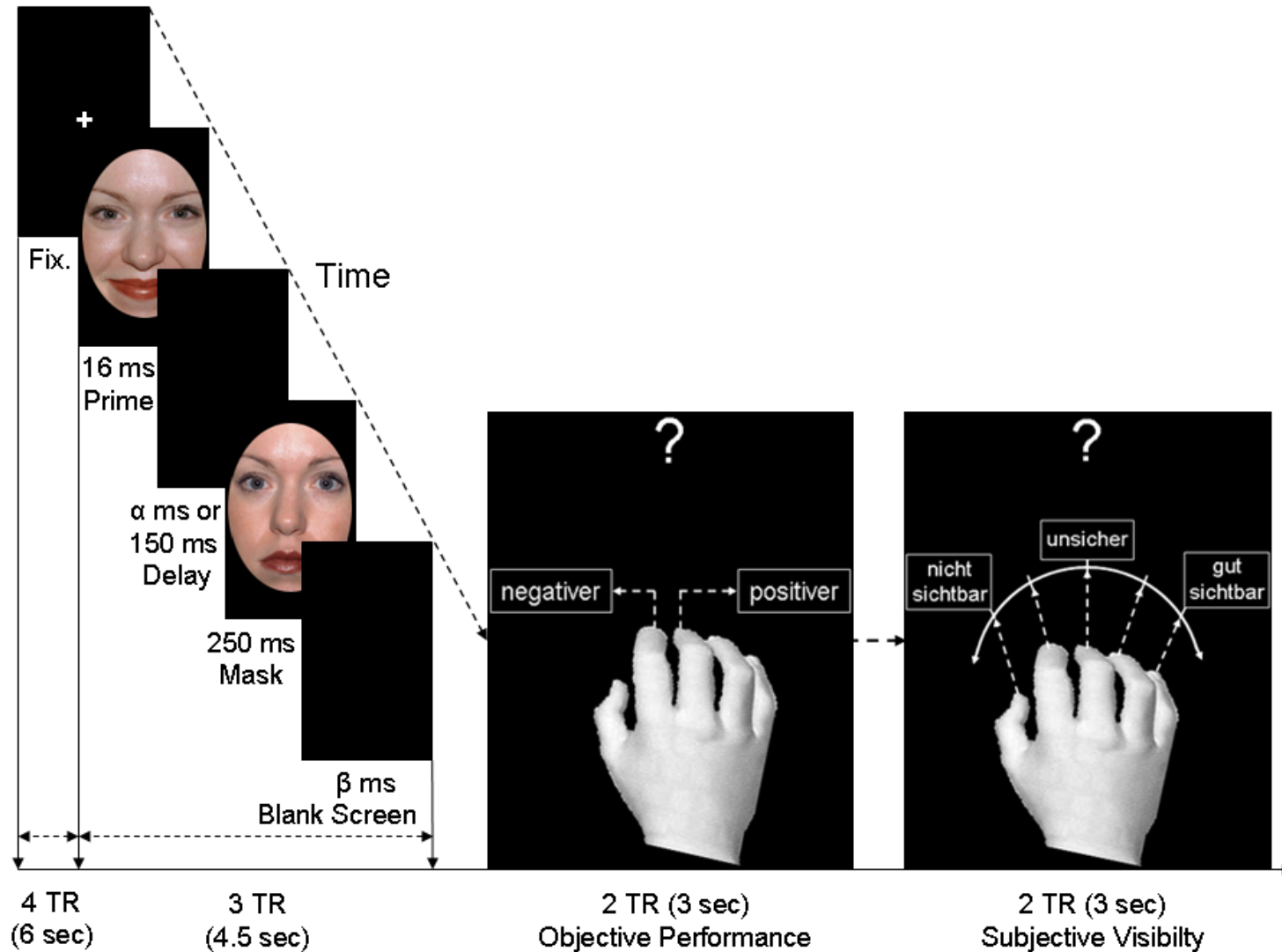
## Supraliminal/Couscious Processing

- Long-range **occipito-parieto-frontal** functional connections

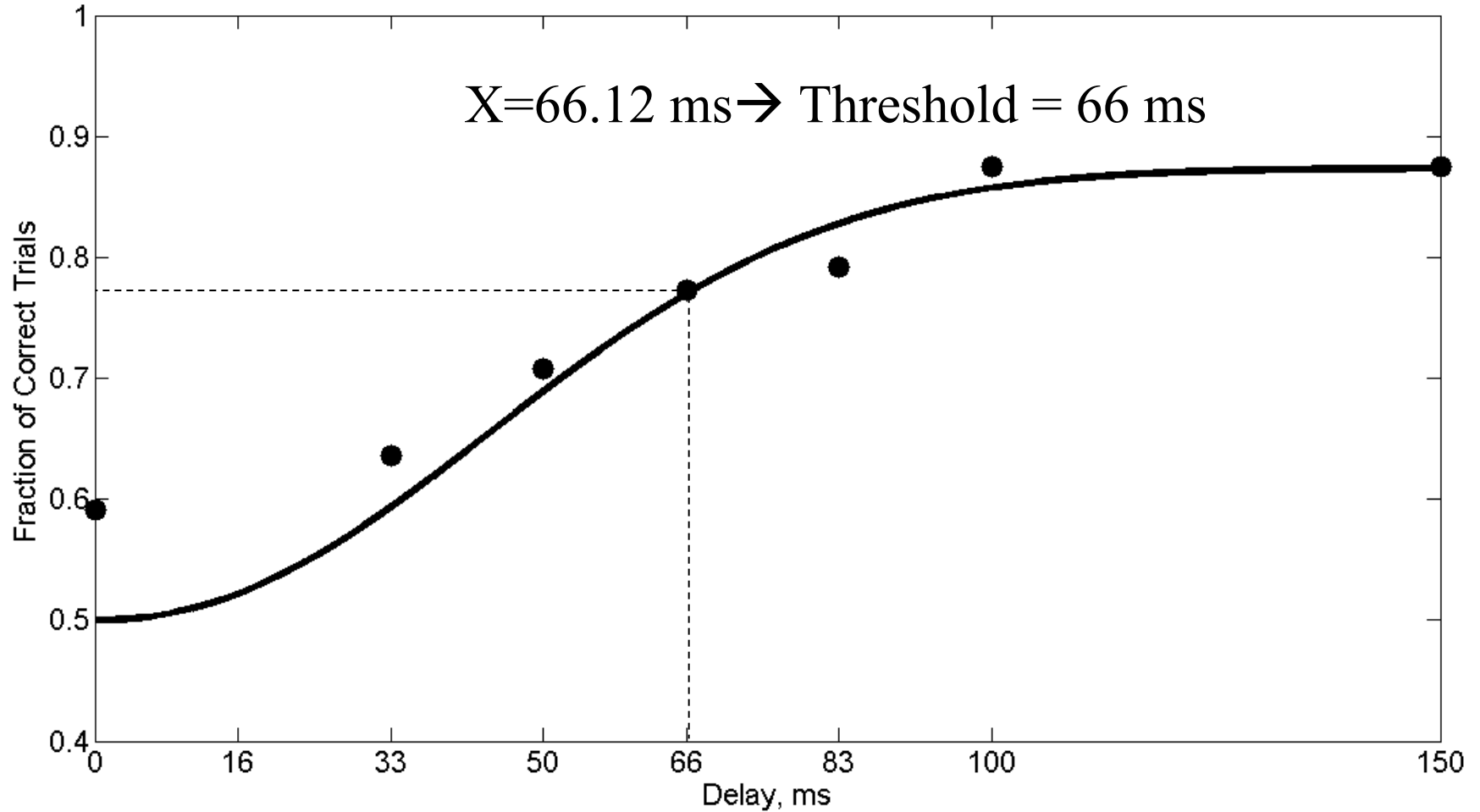


(Del Cul, Dehaene et al., 2007)

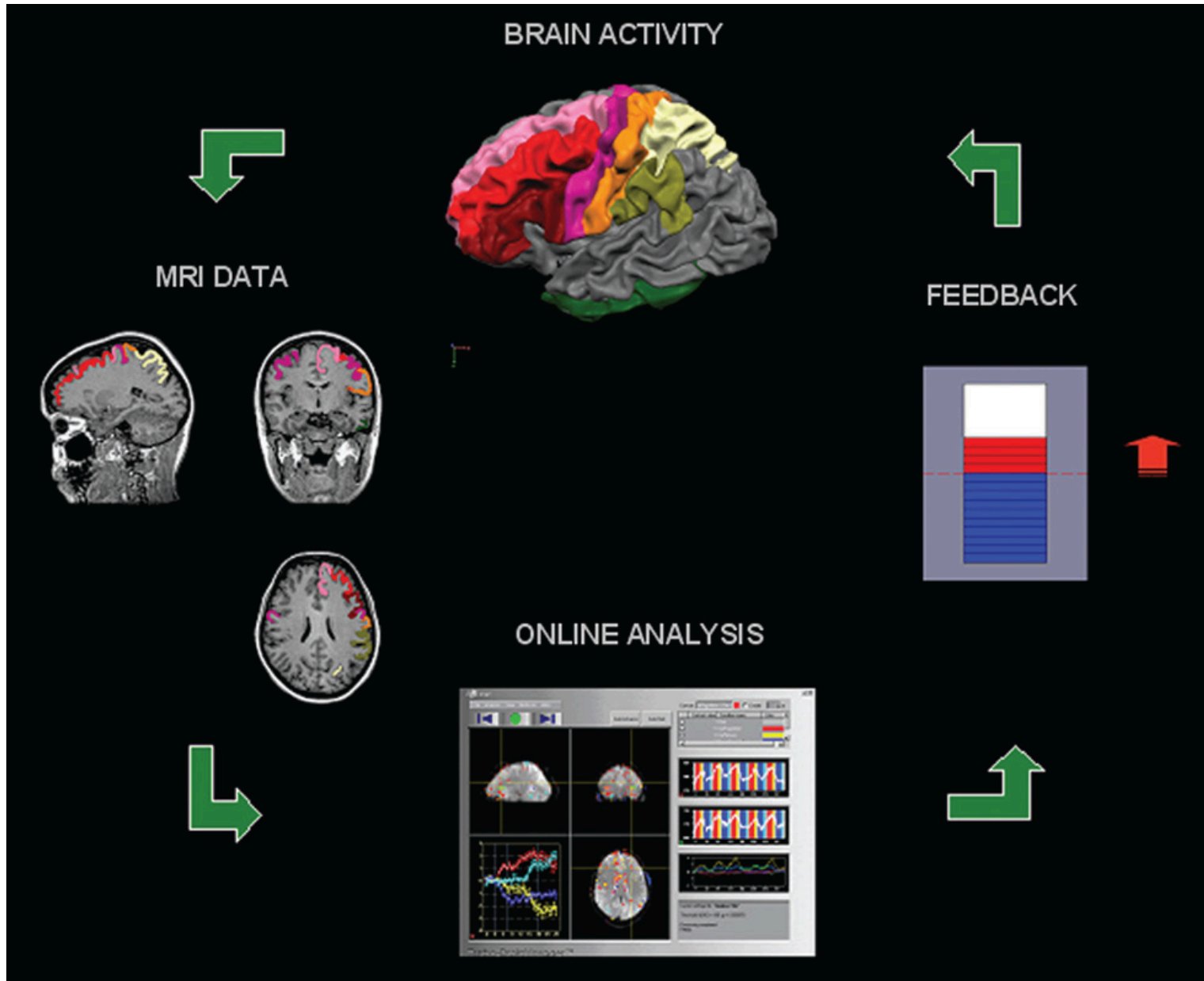
# Subliminal Perception of Emotion



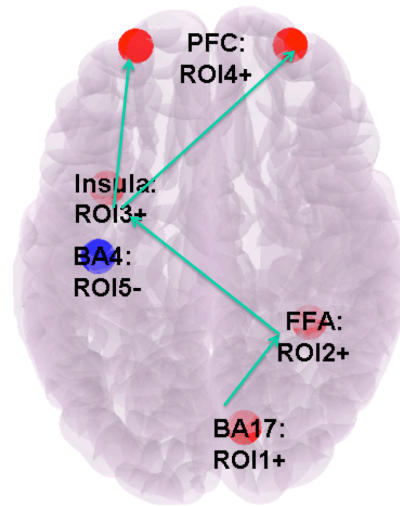
# Threshold to perception



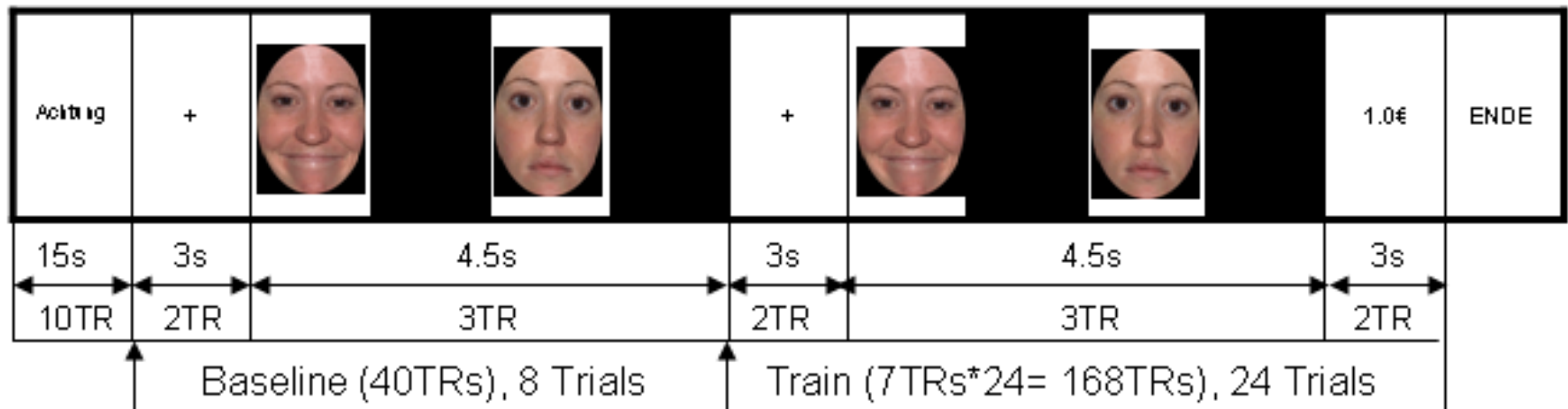
# Real-time fMRI Brain-Computer Interface



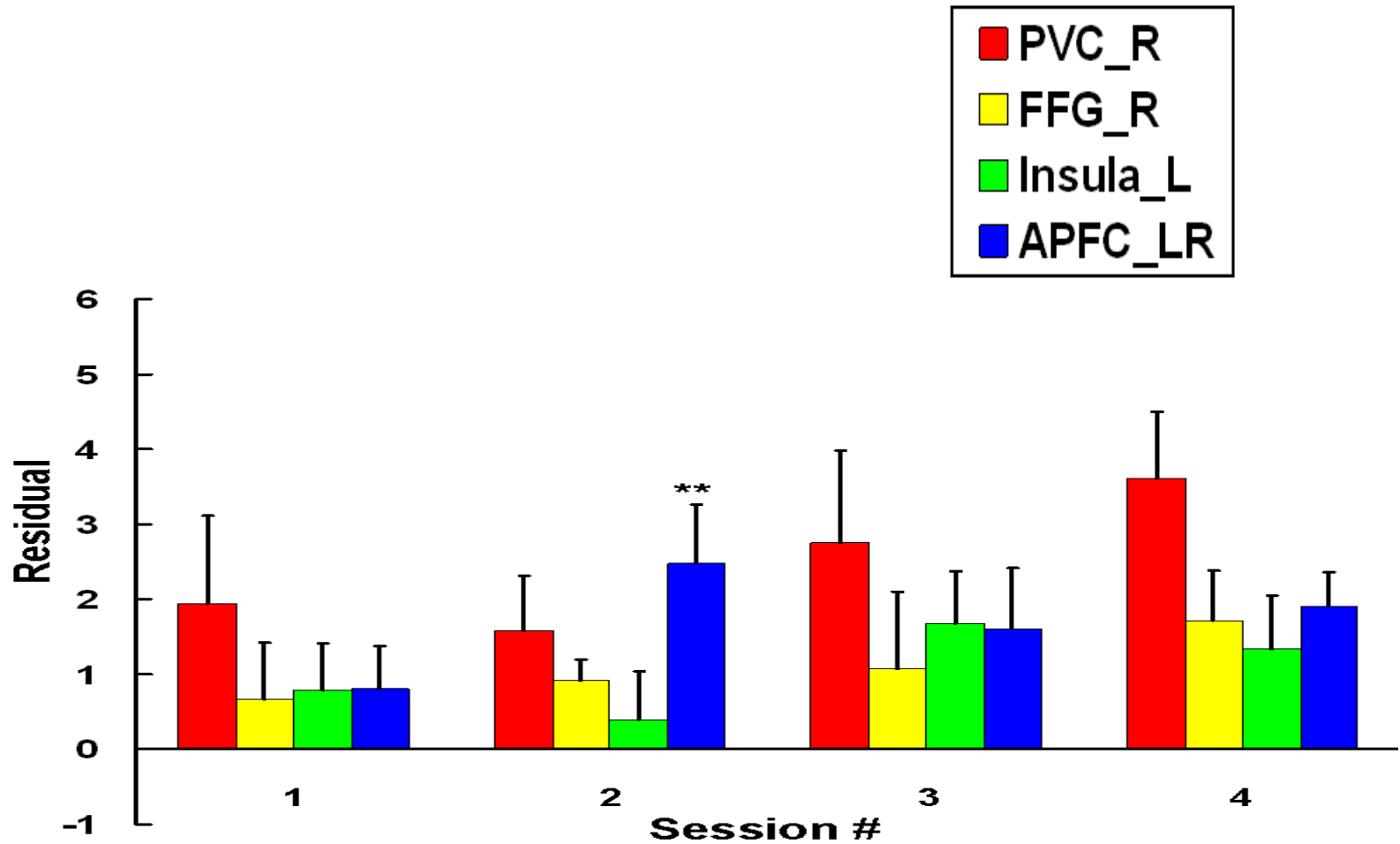
# Real-time fMRI Up-regulation of Fronto-parietal Network of Conscious Perception



## Neurofeedback Training Protocol

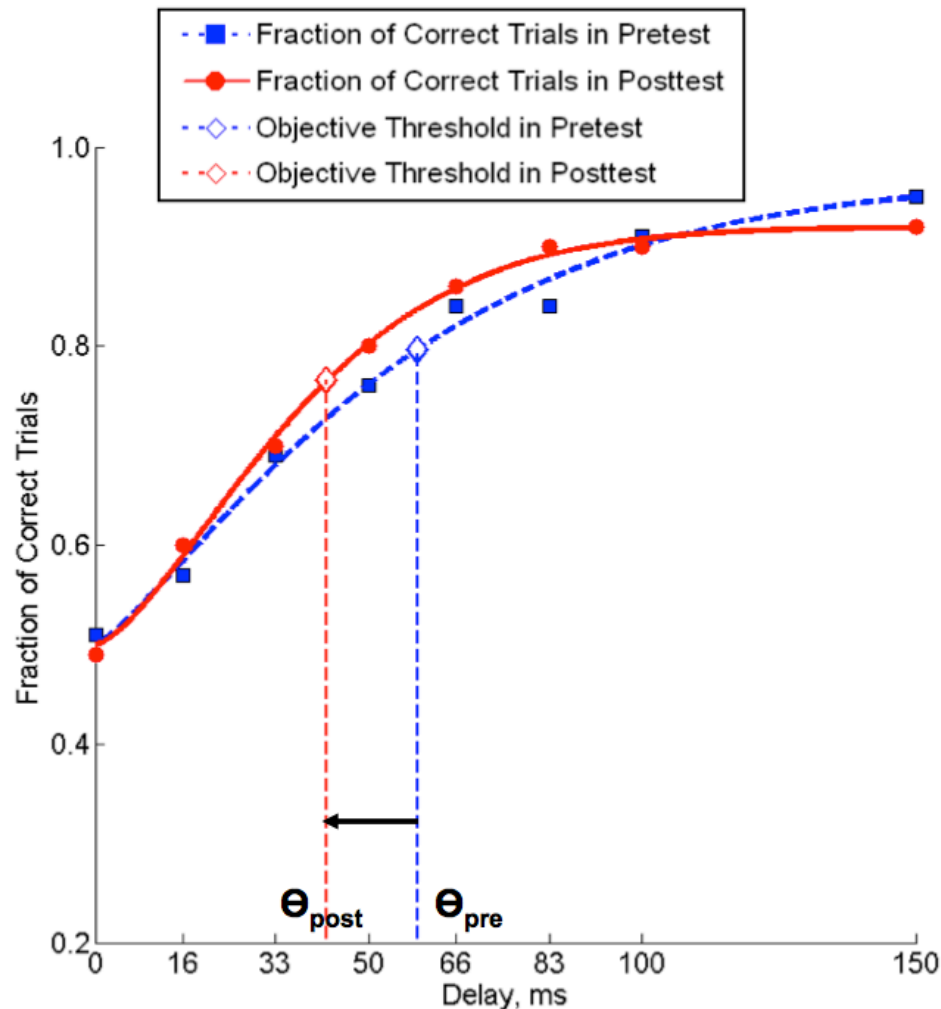


# Increase in brain activation with neurofeedback training





# Change in threshold to conscious perception due to up-regulation



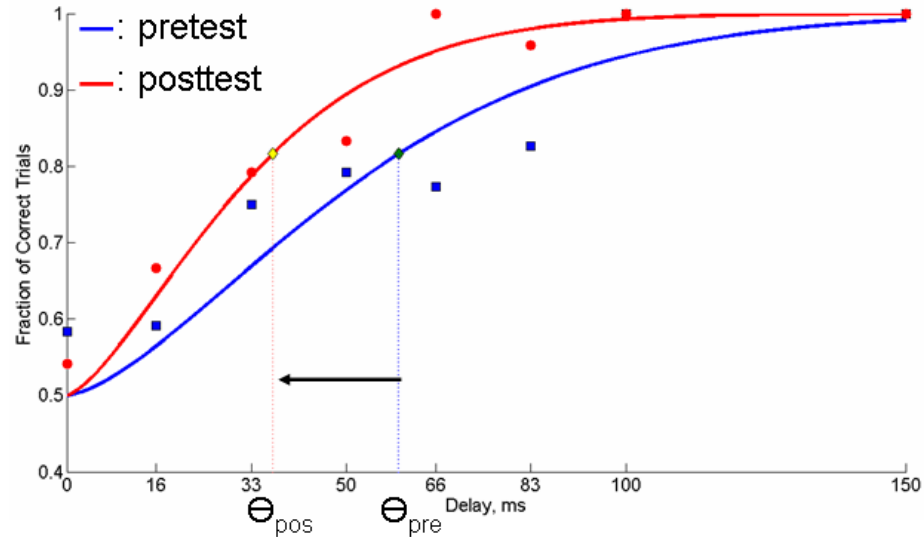
## Group Average

	Mean	N	StDev
Pretest	59.80	10	19.62
Posttest	44.00	10	16.94

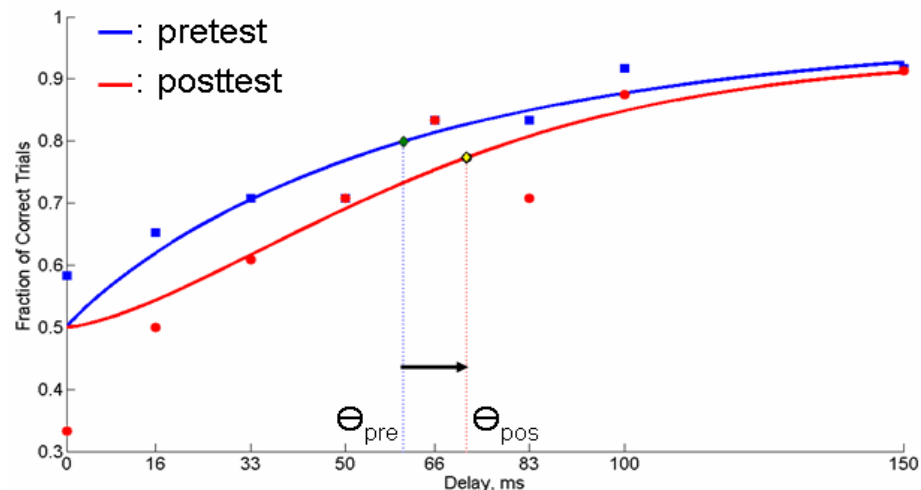
A significant threshold improvement occurred ( $t(9) = 4.22, p = .002$ ) in the posttest compared to the pretest.

# Effects of up- and down-regulation of the perceptual network

UP-  
REGULATION



DOWN-  
REGULATION



# Meditation and subliminal processing?

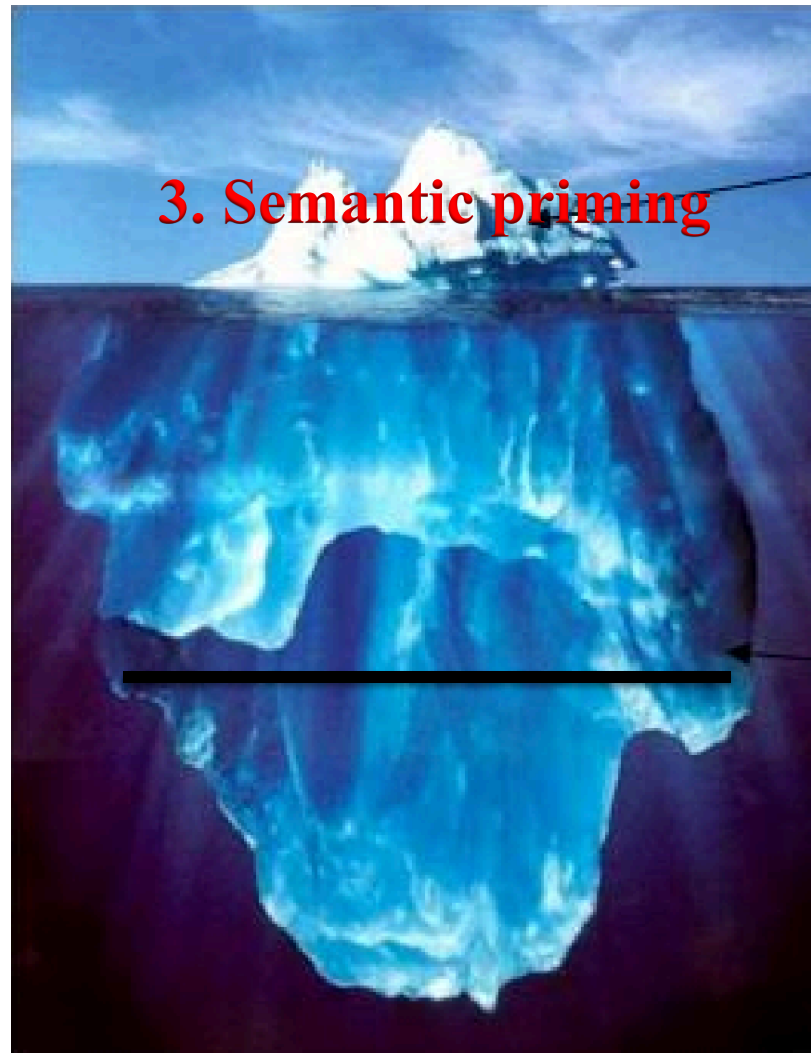
- Does meditation lower the perceptual threshold?
- Can long-term meditators learn to modulate the fronto-parietal network more readily?

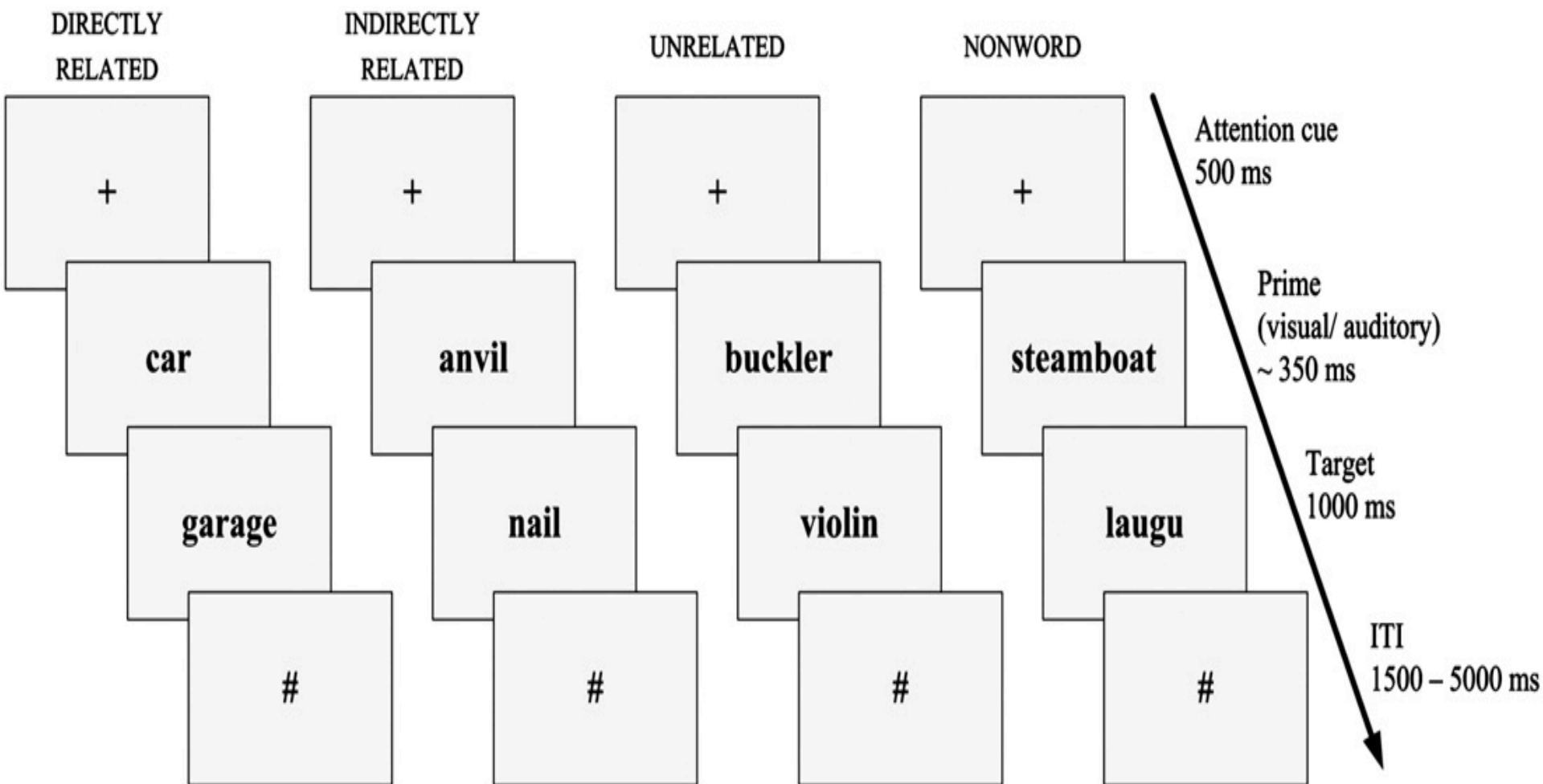
# 3. Semantic Priming

conscious

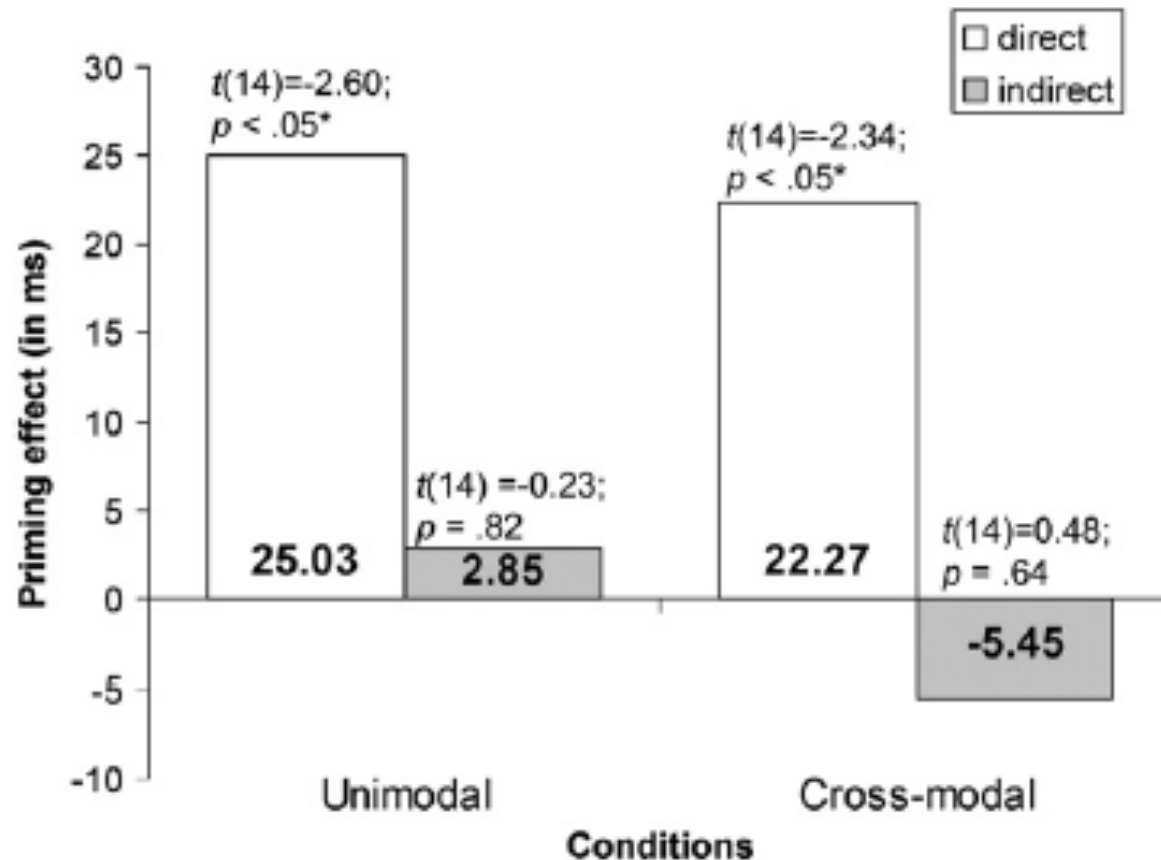


subconscious



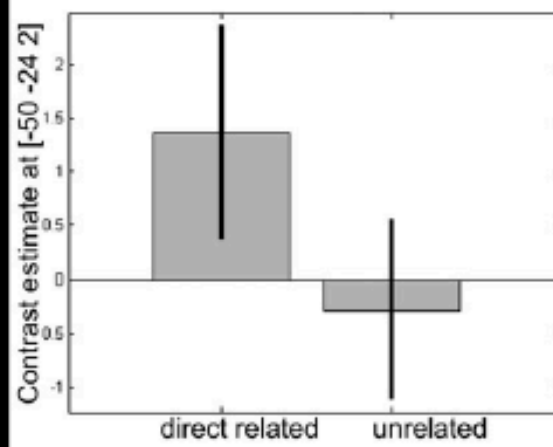
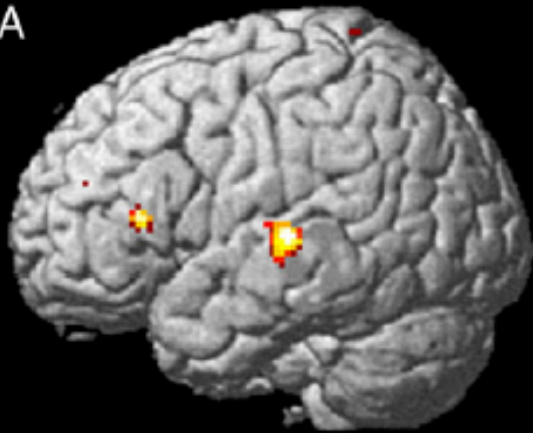


Priming Effect = ResponseTime<sub>UnrelatedWords</sub> - ResponseTime<sub>RelatedWords</sub>

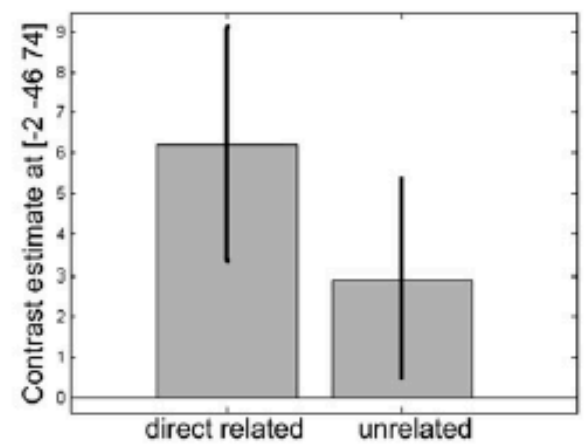


**Fig. 2.** Behavioral priming effects. For the semantic priming effect the related condition was subtracted from the unrelated condition. Subjects were faster if the words were directly related in comparison to unrelated word pairs (irrespective of modality) whereas there was no difference between indirectly related and unrelated words.

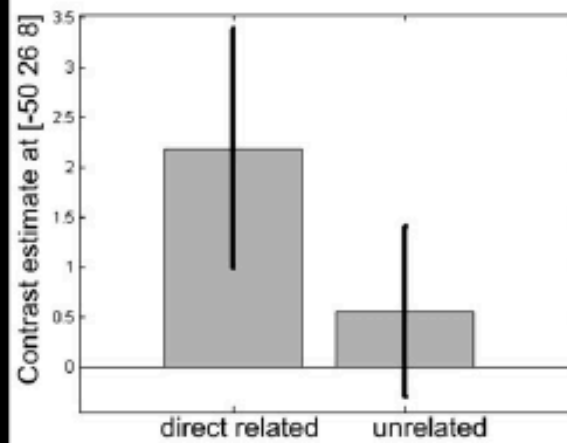
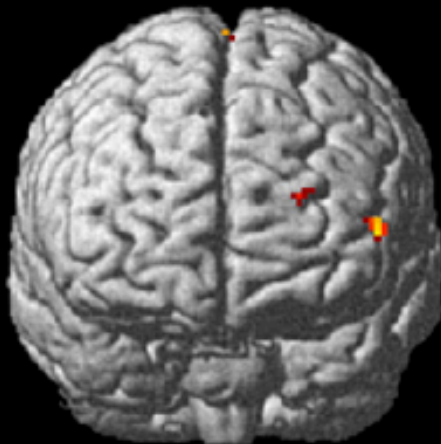
A



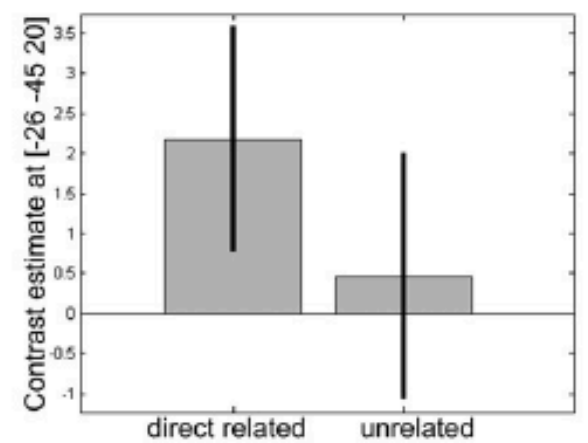
Left STG



Precuneus



Left IFG



Left MFG

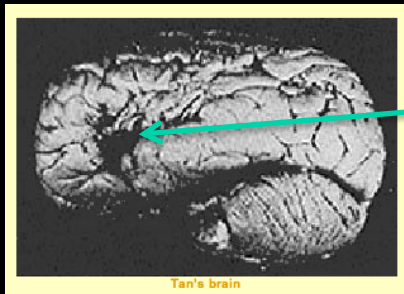
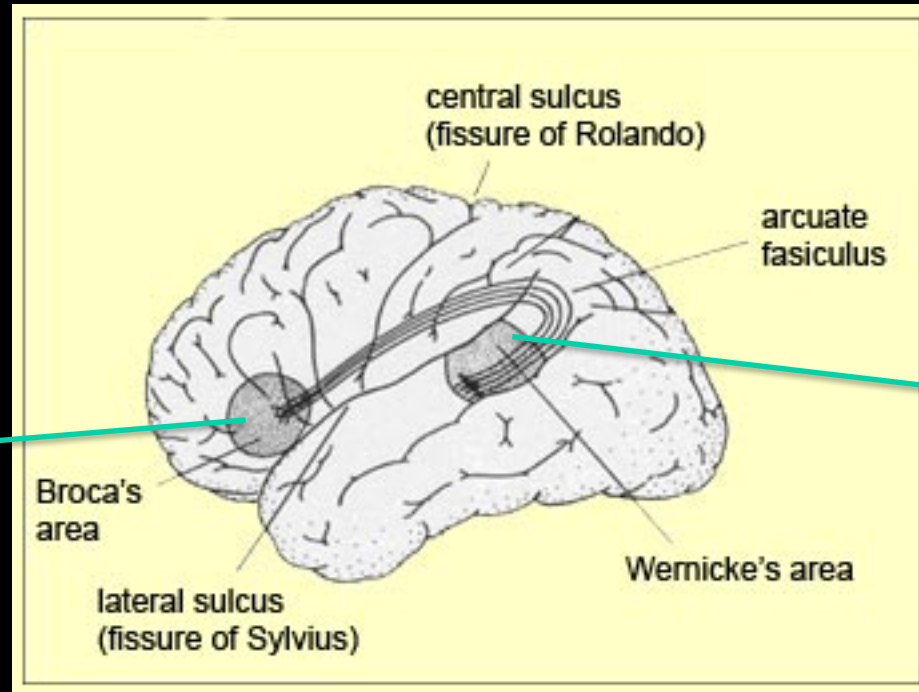
# Broca and Wernicke brain regions in language production and understanding



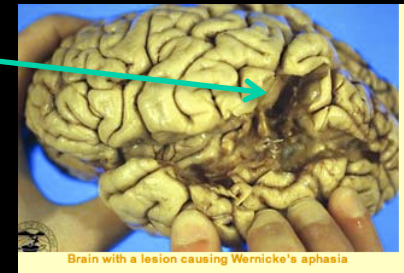
Paul Broca



Carl Wernicke



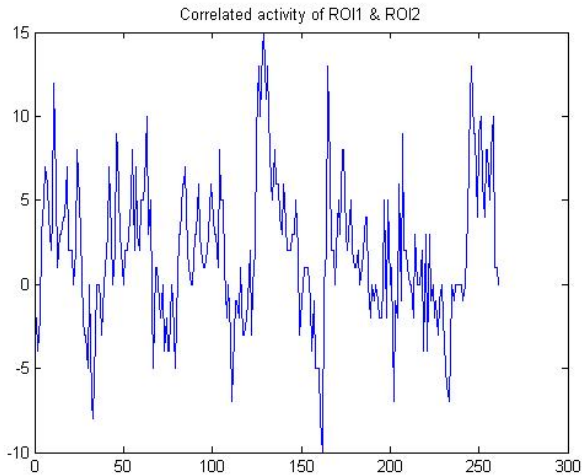
Tan's brain



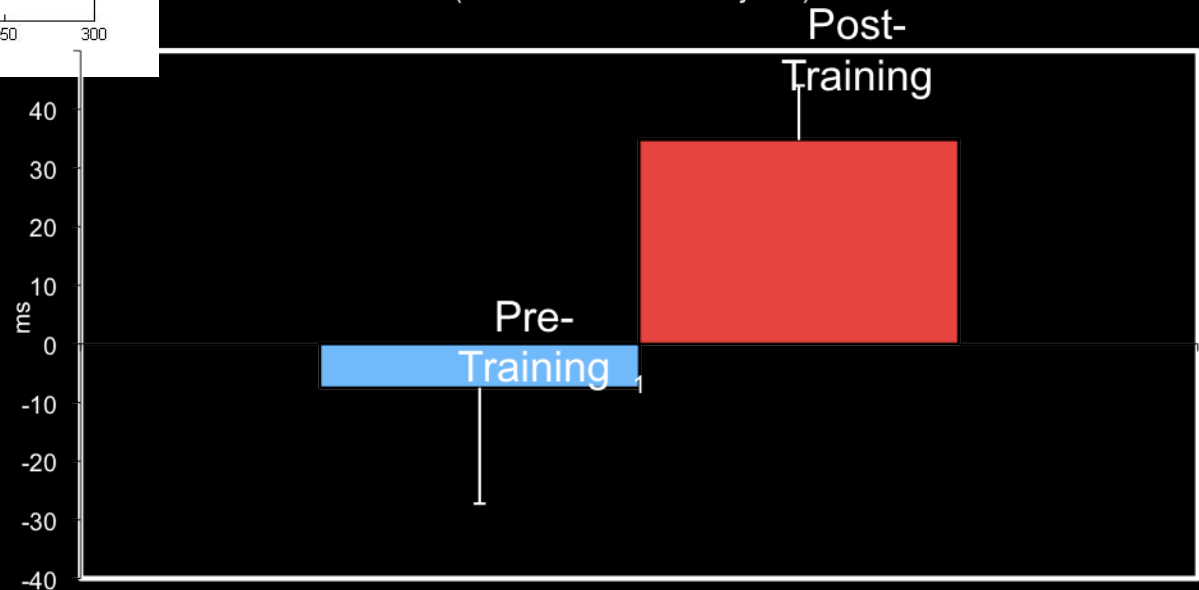
Brain with a lesion causing Wernicke's aphasia



# Real-time Functional connectivity enhancement by feedback training



Enhancement of the priming effect  
(Mean  $\pm$  SE of 8 subjects)



# Meditation and Semantic Priming

- We know that certain meditation practices emphasize “non-verbal” mental states and de-emphasize stereotypical conceptualization.
- In light of this, does meditation lead to reduced priming effects?
- How does that influence cognition and perception without causing ‘Aphasic’ symptoms?

# Summary

- Meditation's effect on the consciousness has not been well studied.
- Such studies not only enhance our understanding of meditation *per se*, but also the brain processes delineating conscious and subconscious perception/experience.
- Meditators present themselves as special “models” for studying brain processes in altered states of consciousness.
- We believe that such studies would expand our own “consciousness” 😊