


Northeastern University



Massachusetts Institute of Technology



McGOVERN INSTITUTE  
FOR BRAIN RESEARCH AT MIT



The Center for Precision Psychiatry




Massachusetts General Hospital  
Founding Member Mass General Brigham

## Cultivating Calm: The Science of Mindfulness

Summer Academy 2024:  
Cultivating Hope and Kindness in Your School Nursing Practice


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## Outline

- What is Mindfulness
- Magnetic Resonance Imaging
  - Bases, Mechanisms, Functional in cognitive tasks and at rest
  - Functional Brain Connectivity
- Neural Networks involved in Mindfulness
- Neuroplastic effects of meditation on:
  - Healthy Adults and Children
  - Adolescents with a history of major depression
  - Patients with schizophrenia and drug-resistant auditory hallucinations
- Neural Flocks and Neurophenomenology
  - Isomorphism: Patterned Process and Consciousness
  - Auditory Hallucinations and the Patterned Process
  - Mental Mirror or the Consciousnesscope
  - Towards a Neurophenomenology research program

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### **What is Mindfulness?**

- It is the ability to consciously pay attention to the present moment.
- It involves observing our thoughts, emotions, bodily sensations, and environment with acceptance and without judgment.
- It allows us to distance ourselves from automatic thought patterns and respond with greater awareness.
- It promotes calm, mental clarity, self-awareness, and emotional well-being.

Bishop et al. (2004, 232)

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### **What is Mindfulness?**

- Brief exercise to identify a state of mindfulness

Bishop et al. (2004, 232)

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## Mechanisms of Mindfulness

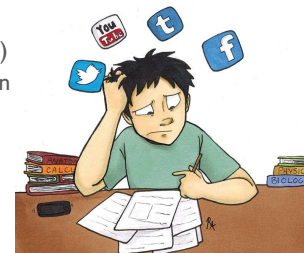
- Intention
- Attentional control
- Specific attitude towards experiences marked by acceptance and non-judgment or kindness.

(Shapiro et al., 2006)

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## The Distracted or Un-mindful Mind

- In contrast to much of our daily experience where:
- functioning on autopilot (Bargh & Chartrand 1999)
- Immersed in thoughts different from what is happening in the current moment (Killingsworth & Gilbert 2010)
- or suppressing unwanted experiences (Kang et al. 2013)



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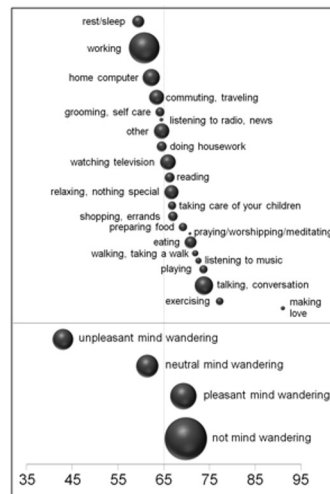
## The Distracted or Un-mindful Mind

- It has been shown that:
- Our minds wander approximately 47% of the time and that a distracted mind predicts subsequent unhappiness (Killingsworth and Gilbert 2010).
- On the other hand, the ability to be present in each moment is associated with greater well-being in daily life (Brown & Ryan 2003).



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## The Distracted or Un-mindful Mind



(Killingsworth &amp; Gilbert 2010).

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## Mindfulness and the Brain



100 billion stars



100 billion **neurons**

- + Each neuron > 5000 synapses with other neurons

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## Magnetic Resonance Imaging (MRI) modalities for Neuroscientific study

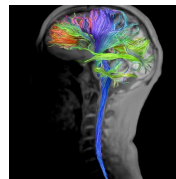
### Structural MRI

- Brain anatomy
- White/Gray matter
- Pathology



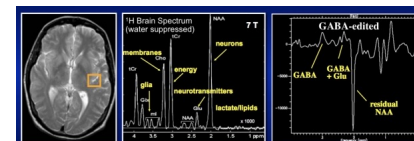
### Diffusion tensor imaging

- White matter connectivity
- Tracts and fiber



### Magnetic Resonance Spectroscopy

- Metabolite concentration
- Neurochemistry

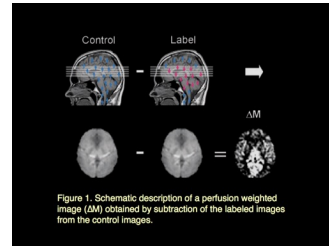


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## Magnetic Resonance Imaging (MRI) modalities for Neuroscientific study

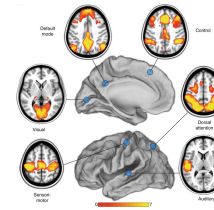
### Arterial Spin labelling

- Blood flow



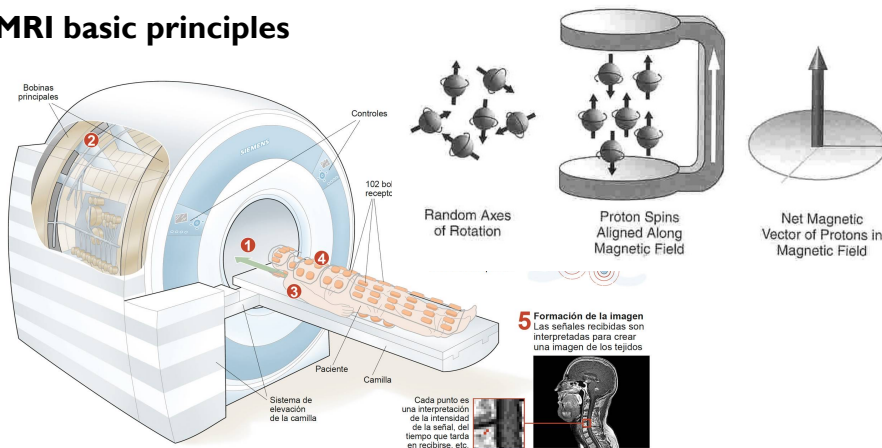
### Functional Magnetic Resonance Imaging

- Activation patterns
- Cognitive tasks
- Functional connectivity

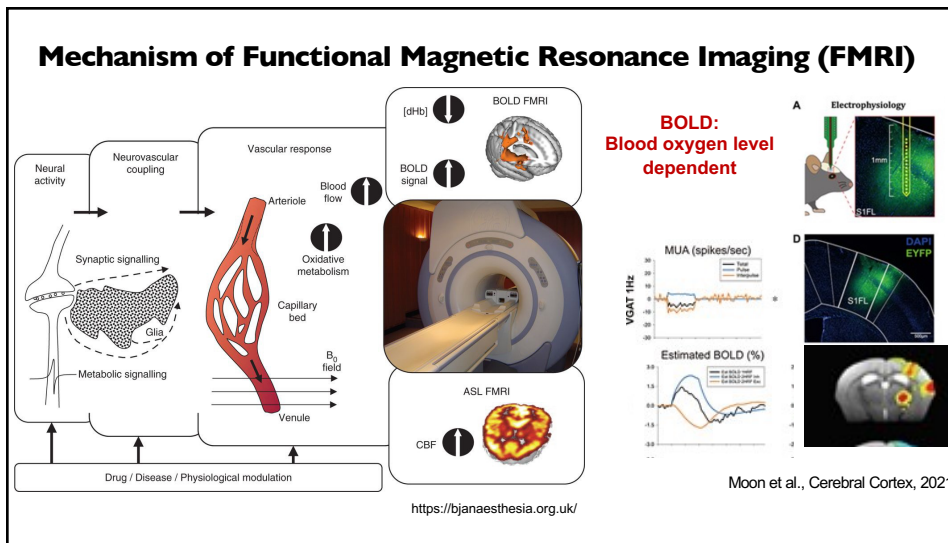


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## MRI basic principles

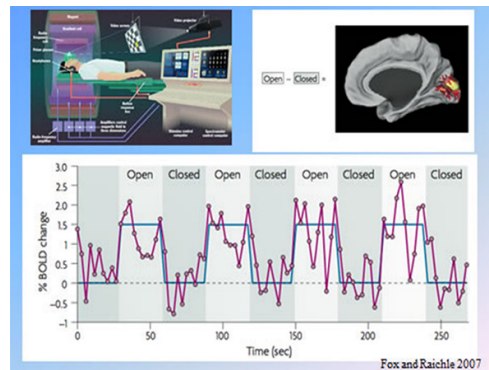


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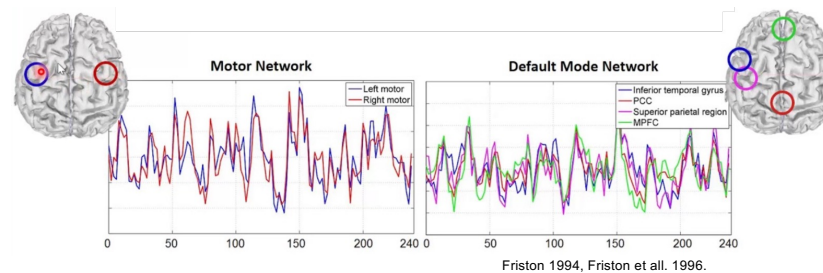
### Functional Magnetic Resonance Imaging (fMRI) in cognitive tasks



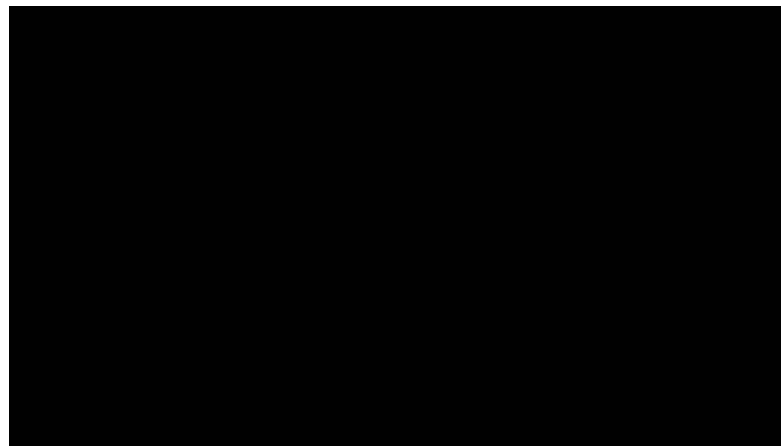
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## Functional Magnetic Resonance Imaging (fMRI) at rest

- Asociación o dependencia estadística entre dos o más series temporales BOLD anatómicamente distintas



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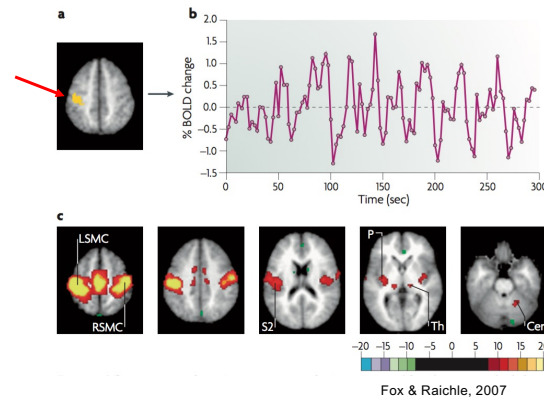


## Seed based analysis

Motor cortex  
Based on hypotheses.

based on an a priori definition of seed regions (regions of interest).  
measure of the temporal correlation between this signal and the passage of time

- a) all other voxels
- b) other seed regions

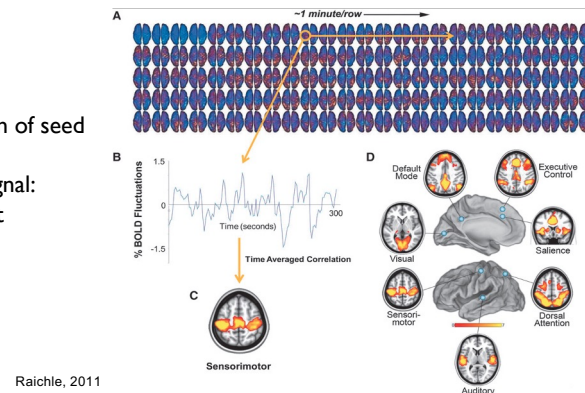


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## Independent Component Analysis (ICA)

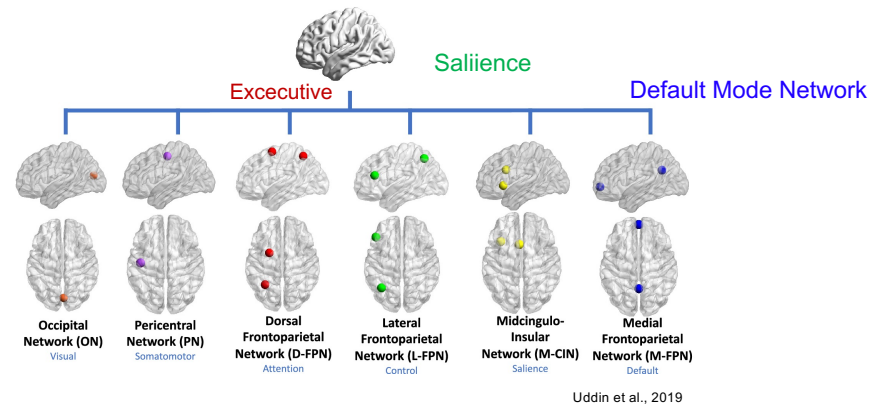
### Data-driven:

There is no a priori definition of seed regions.  
analyzes the entire BOLD signal:  
decompose into independent components  
and associated spatial maps



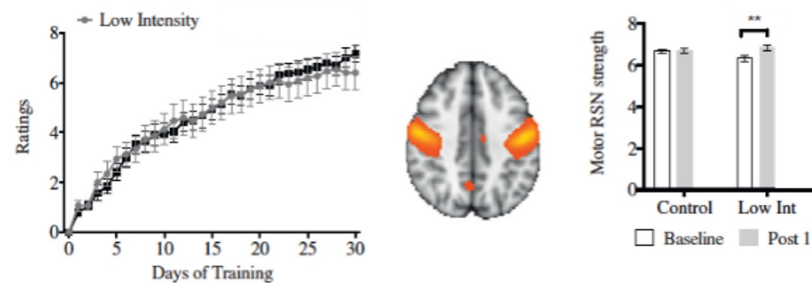
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## Taxonomy of functional brain networks



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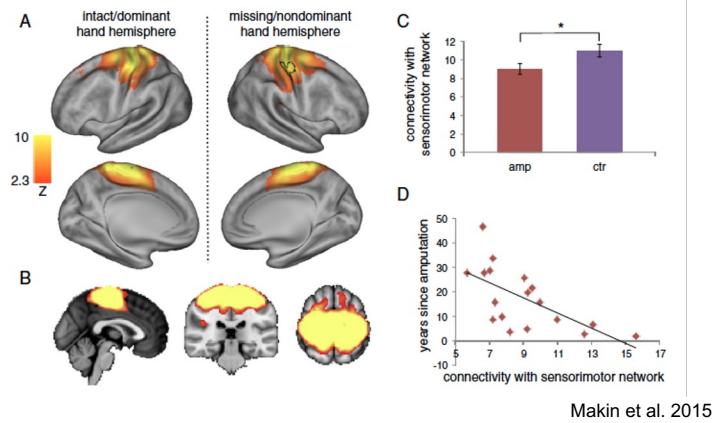
## Learning to Juggle and the Motor Network



Sampaio-Baptista et al. 2017

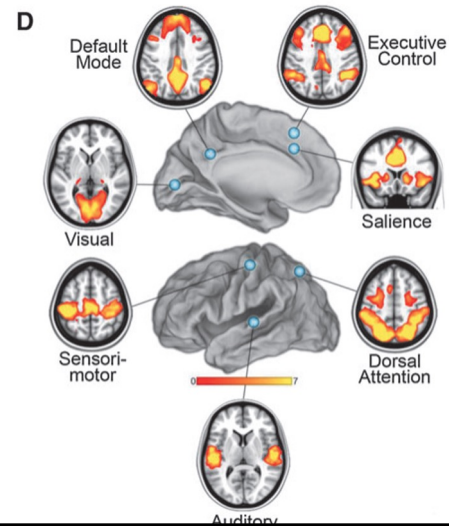
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## Re-organization of Networks in Amputee Patients



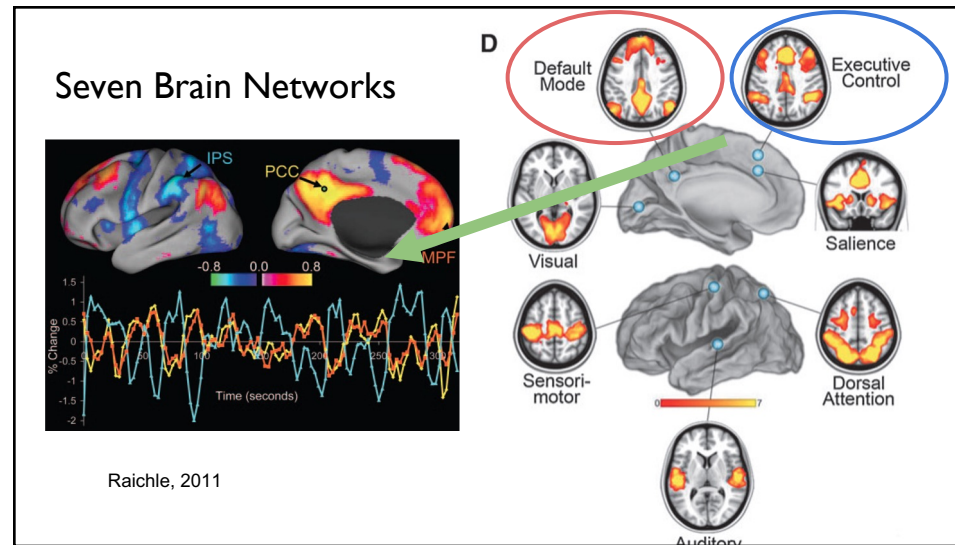
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## Seven Brain Networks

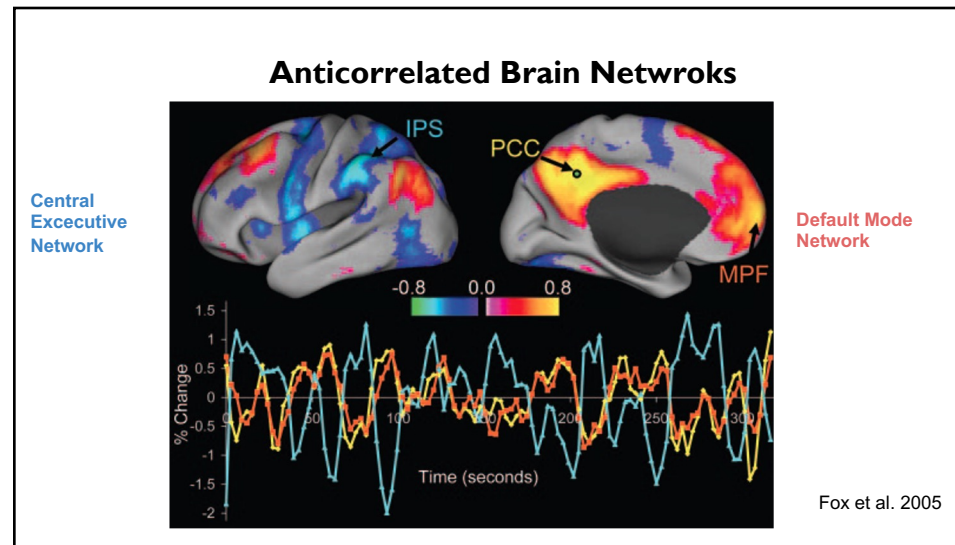


Raichle, 2011

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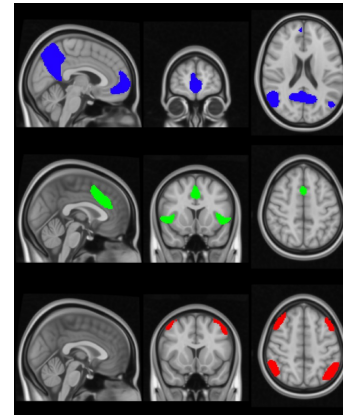
## Brain networks involved in Mindfulness

### Triple network model

Consists in:

- **Default Mode Network (DMN)**
- **Salient Feature Network (SN)**
- **Central Executive Network (CEN)**

Fox et al., 2005, Buckner et al., 2008, Christoff et al., 2009, Menón et al. 2011, Hellyer et al., 2014.



Triple networks. Default-mode network, in blue; Salience network, in green; Central executive network, in red.

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## Default Mode Network (DMN)

Associated with mental wandering and lack of attention to the present moment. Disabled during tasks that require attention

Key regions include

Precuneus/posterior cingulate cortex (PCC)

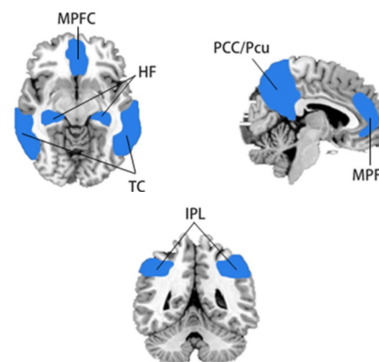
inferior parietal lobe

medial prefrontal cortex (MPFC)

Formations of the hippocampus

temporal cortex

Raichle et al., 2001; Gusnard and Raichle, 2001; Kelley et al., 2002; Northoff et al., 2006; Saxenz et al., 2010



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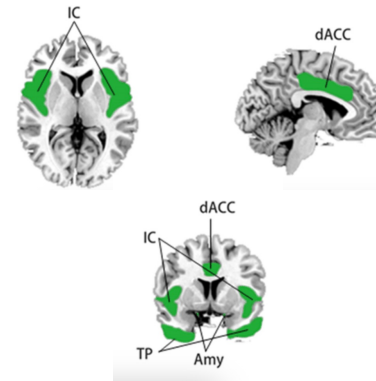
## Salience Network (SN)

Involved in stimulus-driven attention and the detection of salient features.

It is a switch between: internally focused attention mediated by the DMN and externally focused attention mediated by the CEN

Composed of: insula, mediodorsal-cingulate regions, Amygdala, Temporal poles

Seeley et al., 2007; Corbetta et al., 2008



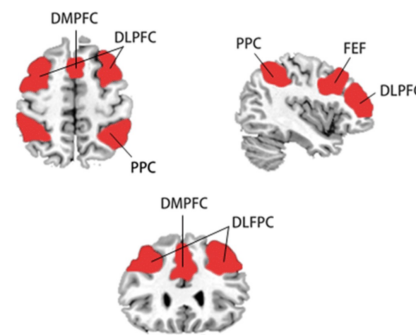
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## Central Executive Network (CEN)

Engaged in sustained externally focused and goal-directed attention.

Composed by:  
Dorsomedial and lateral prefrontal cortices  
posterior parietal cortices  
Frontal eye field

Seeley et al., 2007



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## Mechanistic model of mindfulness that involves triple networks.

During an active meditation practice:

**CEN:**

Maintains attention on the object of focus  
breathing, sensations, thoughts, etc.

**DMN:**

when the mind moves away from the object of attention

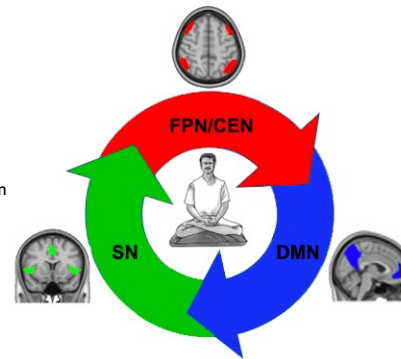
**SN:**

when the participant realizes that his mind  
Ramble

Resumption of **CEN:**

Divert attention back to the object of the practice.

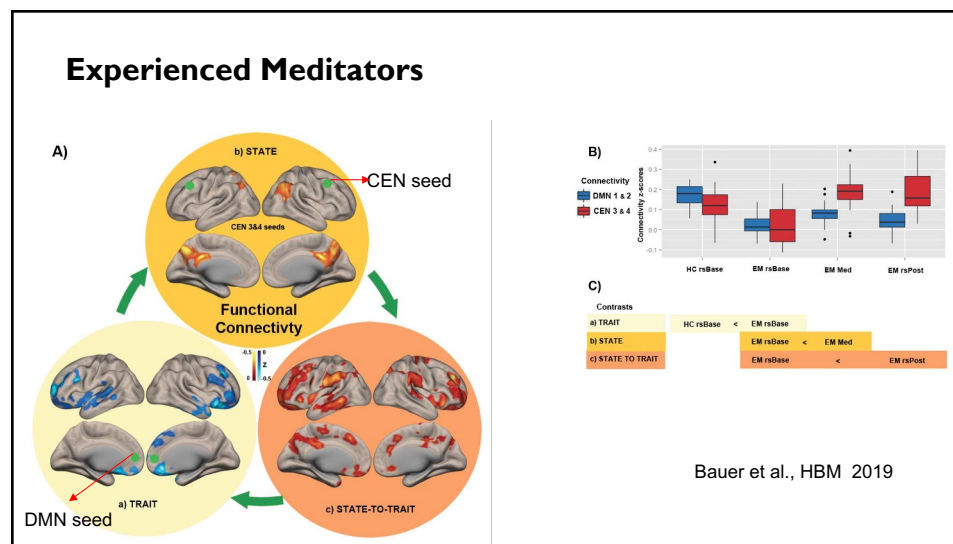
Hasenkamp et al., 2012



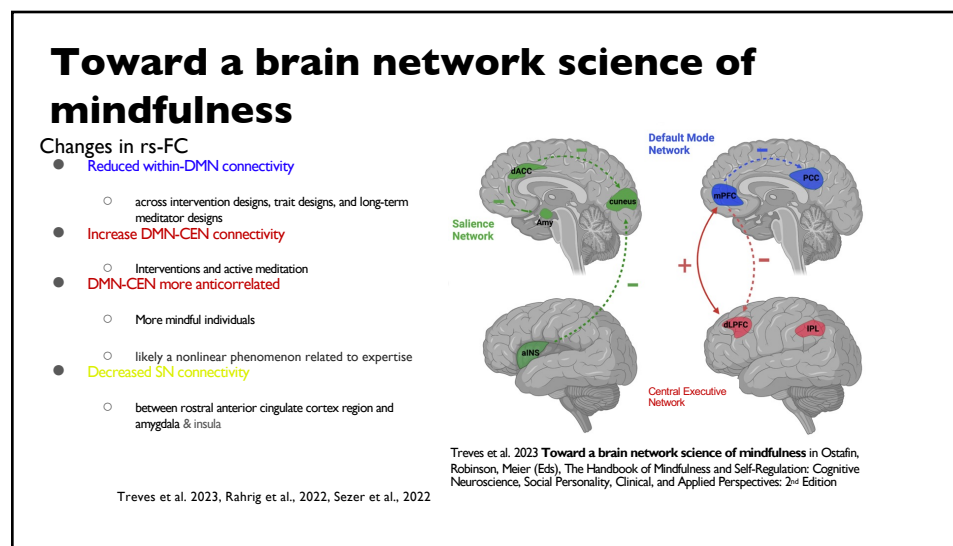
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## Neuroplastic Effects in Adult Meditators

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## Neuroplastic Effects in Healthy Children

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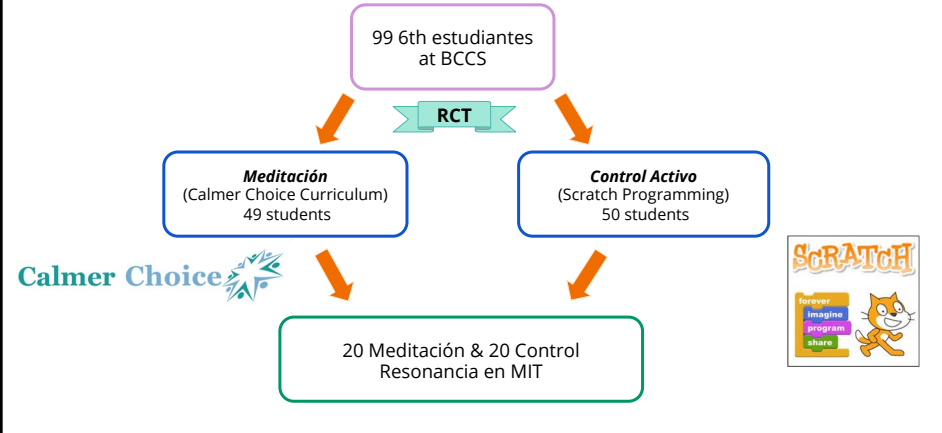
### The Participants



- 99 6th grado (12-13 años de edad)
- 70% niñas
- 47.5% Nivel Socioeconómico bajo
- 10% were Latinos, 32.5% AfroAmericanos, 52.5% Caucásicos, and 5% otros.

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## Randomized Controlled Trial



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This collage features the McGovern Institute for Brain Research at MIT and the Massachusetts Institute of Technology logos. It includes a photograph of a person lying in a Siemens MRI scanner, two sagittal brain scan images showing red highlighted areas in the brain, and a photograph of a child sitting at a desk using a computer. A list of 15 questions is also present, likely related to the study or research being conducted.

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Institute of  
Technology

1. In the last month, how often have you been upset because of something that happened unexpectedly? 0 1 2 3 4  
2. In the last month, how often have you felt that you were unable to control the feelings that came over you? 0 1 2 3 4  
3. In the last month, how often have you been nervous or worried? 0 1 2 3 4  
4. In the last month, how often have you felt confident about your ability to handle what life threw at you? 0 1 2 3 4  
5. In the last month, how often have you felt that things were going your way? 0 1 2 3 4  
6. In the last month, how often have you found that you could not make up your mind about things? 0 1 2 3 4  
7. In the last month, how often have you felt that you were at the top of the world? 0 1 2 3 4  
8. In the last month, how often have you felt that you were not at the top of the world? 0 1 2 3 4  
9. In the last month, how often have you been engaged because of something that happened unexpectedly? 0 1 2 3 4  
10. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4  
11. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4  
12. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4  
13. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4  
14. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4  
15. In the last month, how often have you felt that you were not engaged because of something that happened unexpectedly? 0 1 2 3 4

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## Perceived Stress Scale

**Tabla 1.** EEP-10 y calificación.

Durante el último mes:	Nunca	Casi nunca	De vez en cuando	A menudo	Muy a menudo
1. ¿Con qué frecuencia ha estado afectado por algo que ha ocurrido inesperadamente?	0	1	2	3	4
2. ¿Con qué frecuencia se ha sentido incapaz de controlar las cosas importantes en su vida?	0	1	2	3	4
3. ¿Con qué frecuencia se ha sentido nervioso o estresado?	0	1	2	3	4
4. ¿Con qué frecuencia ha estado seguro sobre su capacidad para manejar sus problemas personales?	4	3	2	1	0
5. ¿Con qué frecuencia ha sentido que las cosas le van bien?	4	3	2	1	0
6. ¿Con qué frecuencia ha sentido que no podía afrontar todas las cosas que tenía que hacer?	0	1	2	3	4
7. ¿Con qué frecuencia ha podido controlar las dificultades de su vida?	4	3	2	1	0
8. ¿Con qué frecuencia se ha sentido que tenía todo bajo control?	4	3	2	1	0
9. ¿Con qué frecuencia ha estado enfadado porque las cosas que le han ocurrido estaban fuera de su control?	0	1	2	3	4
10. ¿Con qué frecuencia ha sentido que las dificultades se acumulan tanto que no puede superarlas?	0	1	2	3	4

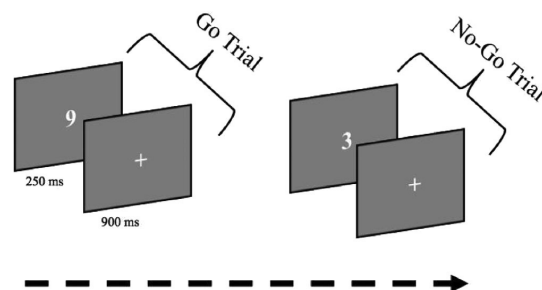
Fuente: autores.

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## Sustained attention

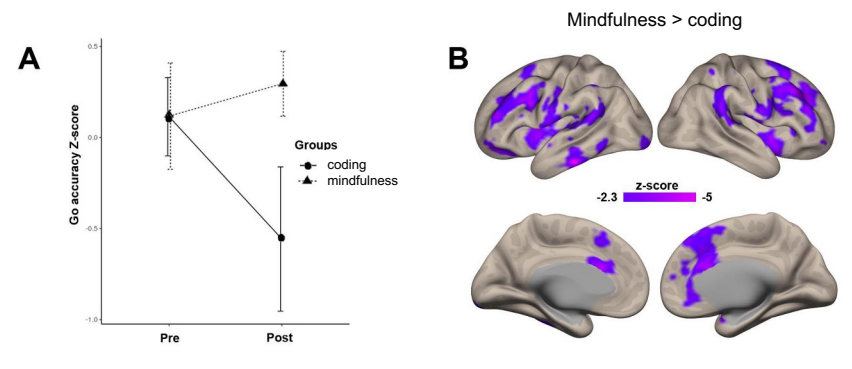
The Sustained Response Attention Task (SART)

It is an attention task that requires participants to retain the behavioral response to a single, infrequent target (-5%) (number 3) presented in a context of frequent non-targets (0-2, 4-9).



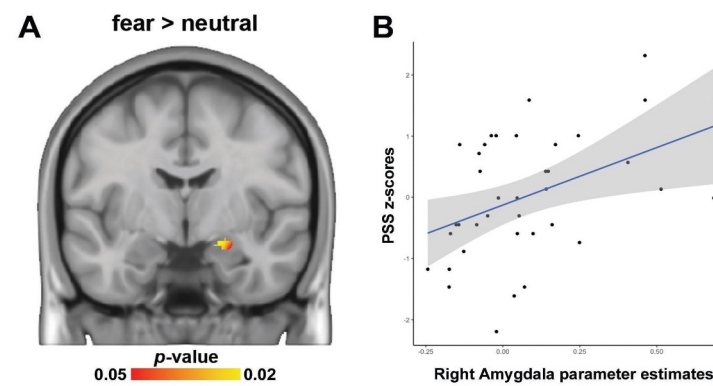
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## Sustained attention



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## Amygdala and Perceived Stress



Bauer et al., Behav Neurosci 2019

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### Emotional Regulation

- Simple perceptual task
- Participants see three images on the screen and are asked to select which of the two images in the bottom row is identical to the top image.

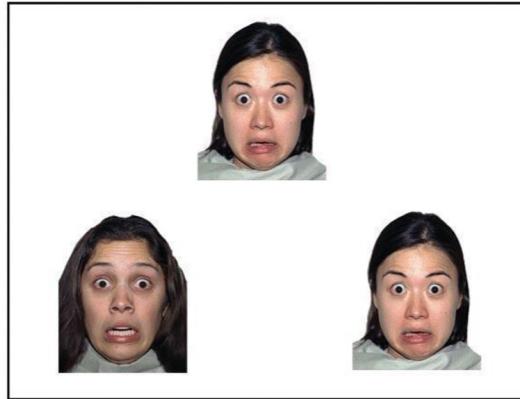
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Neutral faces



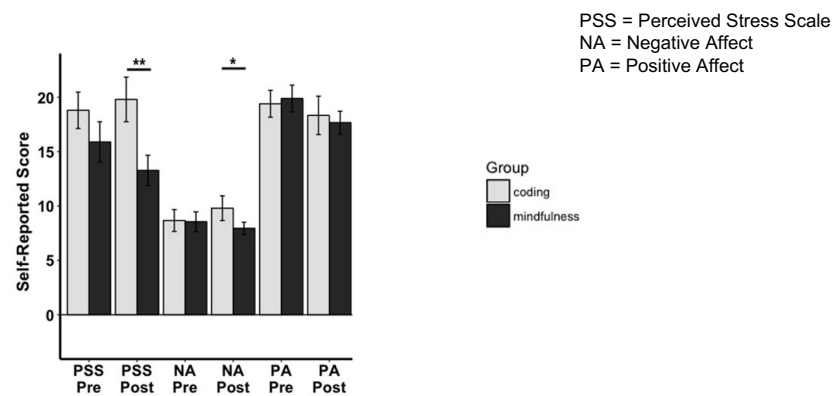
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### Fearful Faces



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### Perceived Stress and Affect Scale



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## Amygdala Activation to fearful faces

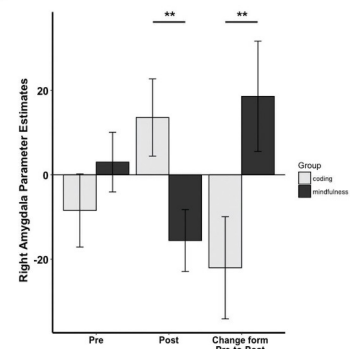
**A**

fear > neutral



0.05  $p$ -value 0.01

**B**

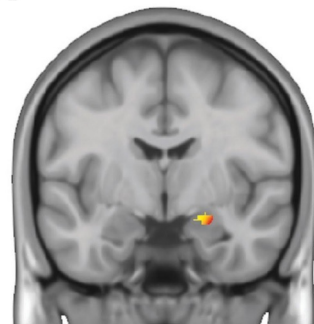


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## Correlation between Activity Changes and Stress

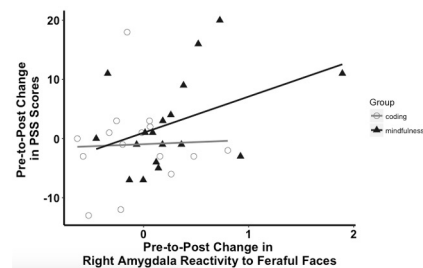
**A**

fear > neutral

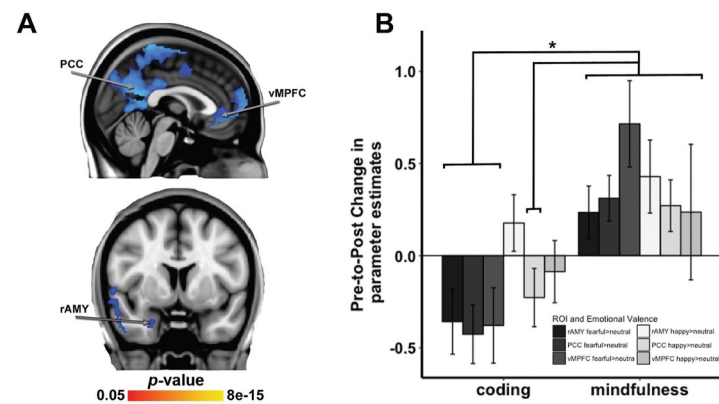


0.05  $p$ -value 0.02

**B**

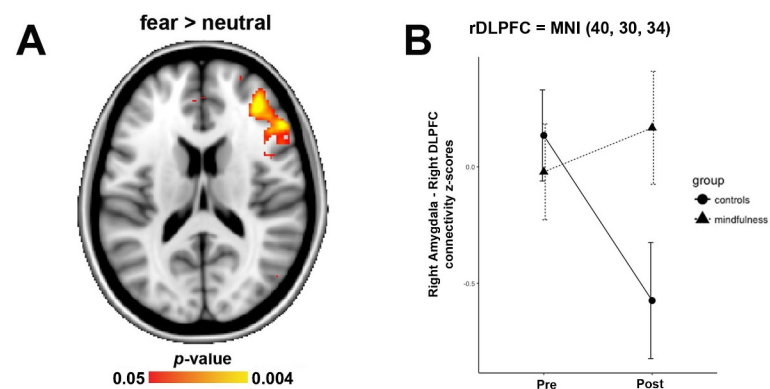


## Default Neural Network



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## Control over the Amygdala



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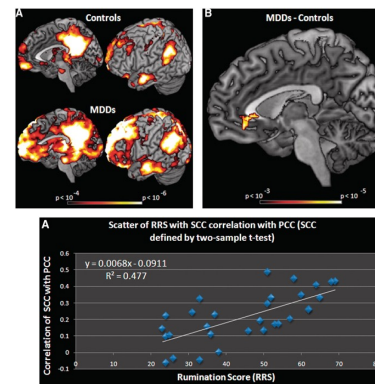
## Neuroplastic Effects in Adolescents with Major Depression

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Research on depression has consistently shown:

- Elevated connectivity within the midline Default Mode Network (DMN) centers (MPFC and PCC) in depressed adolescents, adults, and young people with a family risk of Major Depressive Disorder (MDD).
- This may reflect and facilitate persistent reflective tendencies.
- DMN hyperconnectivity correlates with depression
- Self-referential processing and increased focus on negative emotional states.
- Rumination has been linked to DMN hyperconnectivity in young people at risk for MDD and in currently depressed individuals
- Correlating it with subjective rumination scores

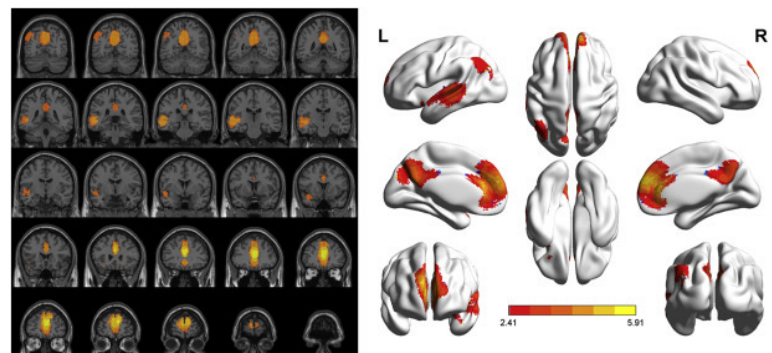
### Rumination, DMN connectivity and depression



Zhou et al 2020, Bergman et al, 2011

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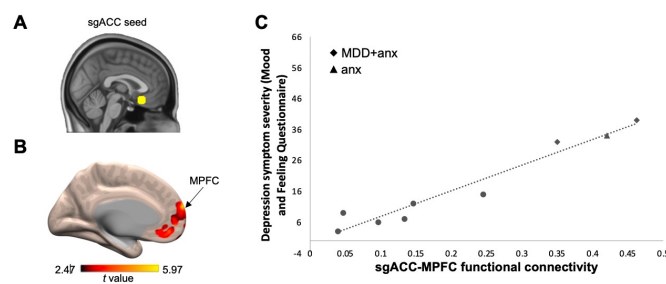
## Hyperactivity in rumination and depression.



Hui-XiaZhou et al 2020

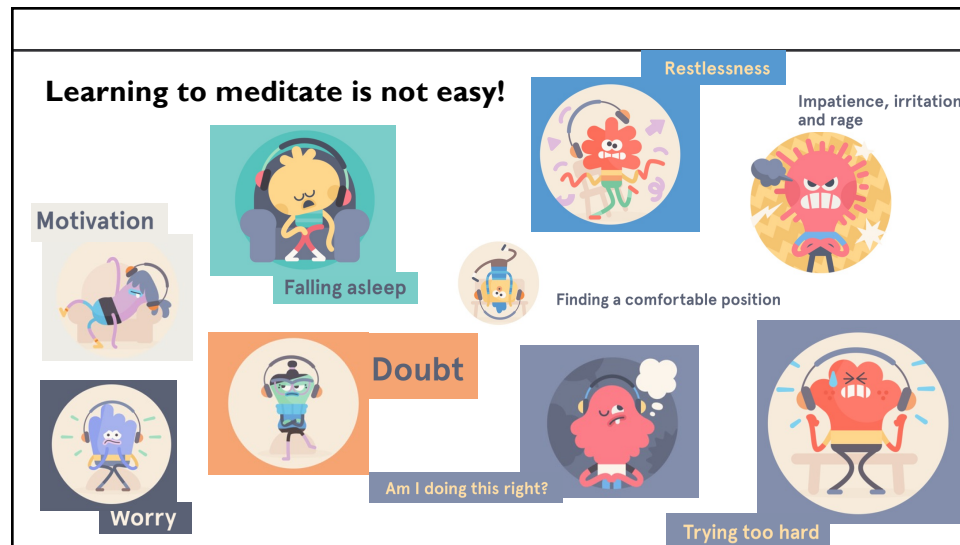
Meta-analytical results showing regions with significant increases in the rumination condition compared to distraction/control condition

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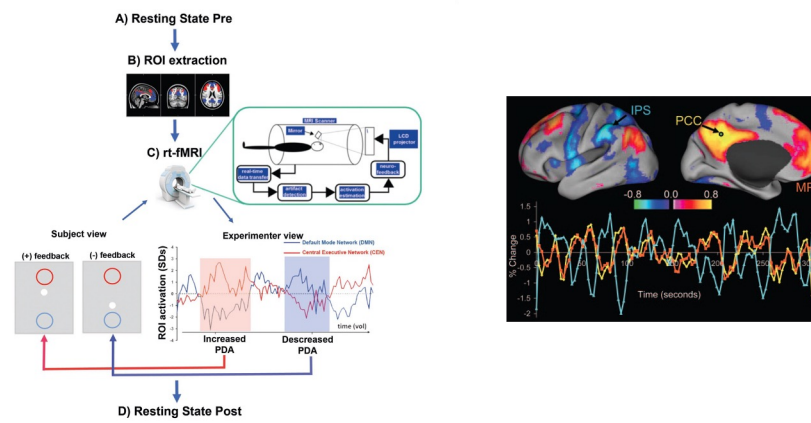
Higher: DMN functional connectivity is associated with more severe depression symptoms at baseline. A) We used a 8mm spherical seed in the sgACC. B) Functional connectivity between the sgACC seed and the MPFC positively correlated with symptom severity. C) Scatterplot illustrates the correlation between baseline MFQ and baseline sgACC-MPFC functional connectivity.

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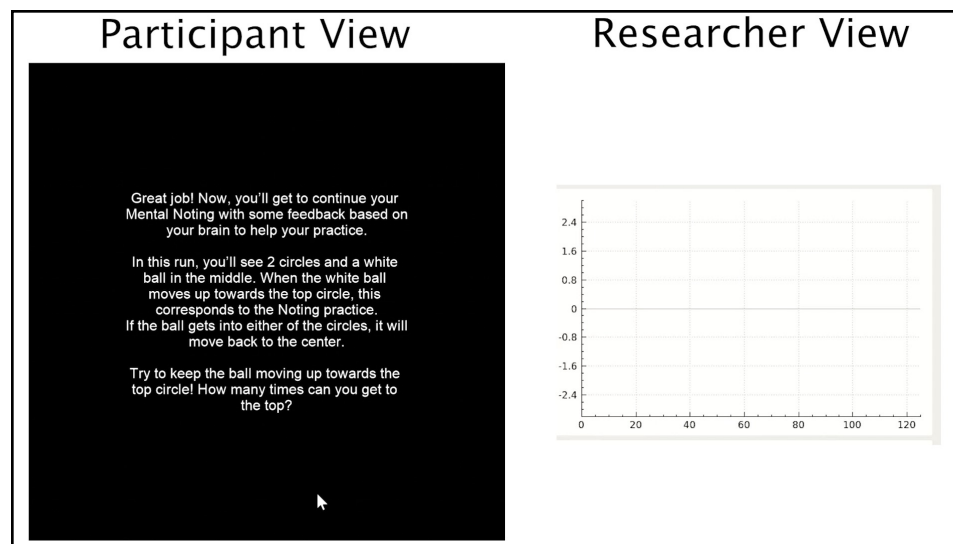


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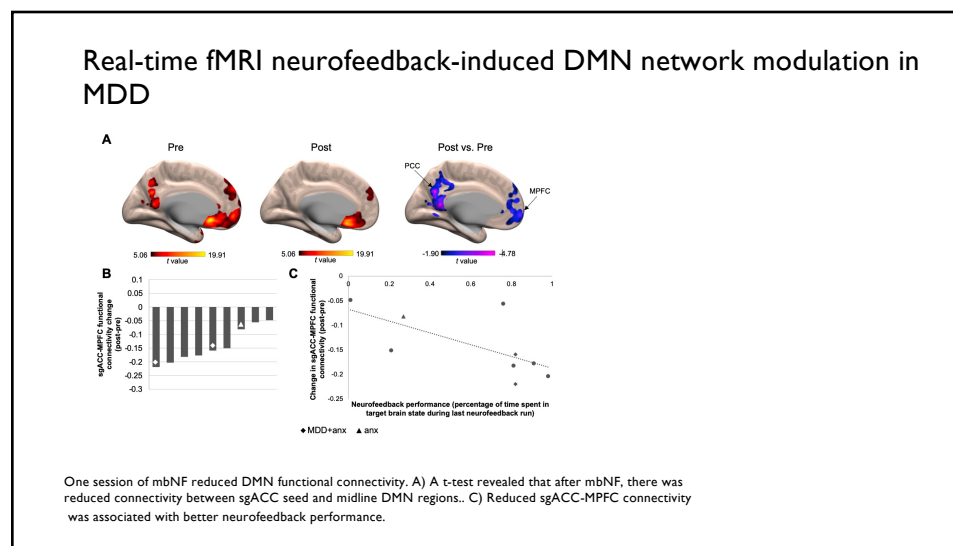
## Meditation reinforced by Neurofeedback



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## Neuroplastic effects in patients with schizophrenia and treatment-resistant auditory hallucinations

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### Schizophrenia

Schizophrenia is a serious mental disorder.

It is characterized by significant alterations in perception, thoughts, mood and behavior.

Experiencing positive symptoms such as hallucinations and/or delusions.

Negative symptoms such as dullness of affect, apathy, anhedonia, etc.

Many cognitive symptoms with alterations in verbal fluency, memory, reasoning, problem solving, processing speed, etc.

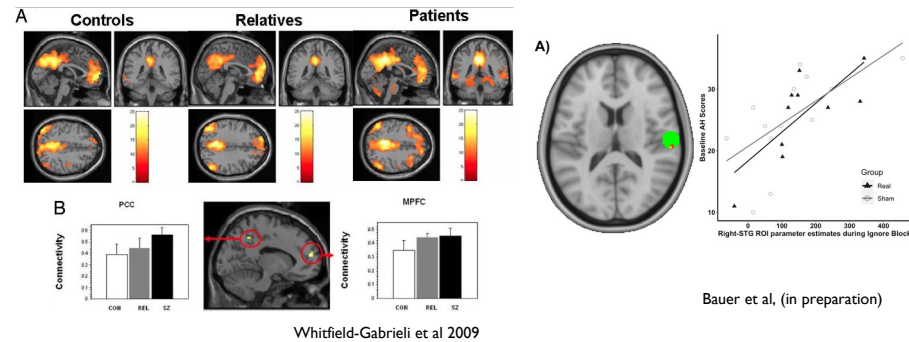
Lifelong treatment.

Treatment resistance



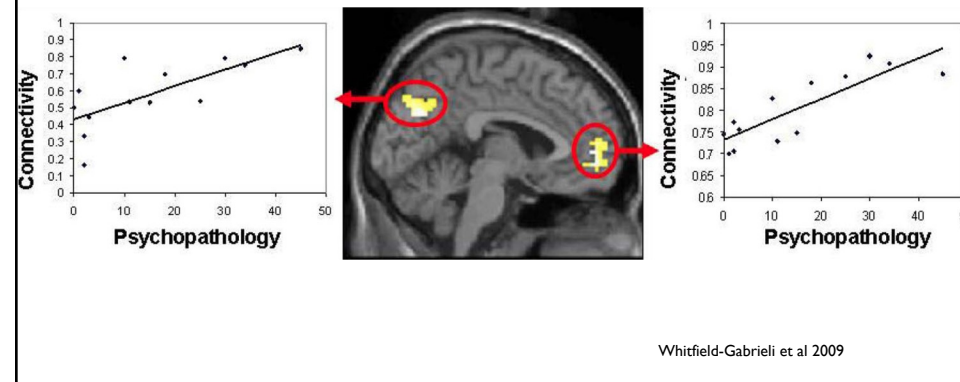
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## Default mode network (DMN) and auditory cortex



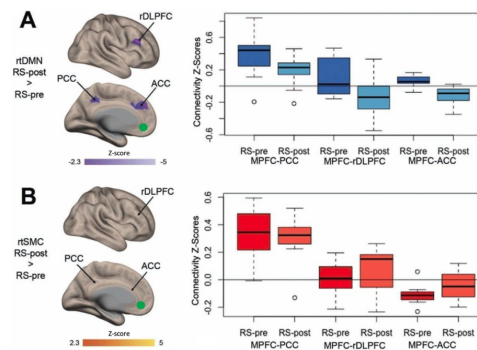
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## Default Mode Network (DMN)



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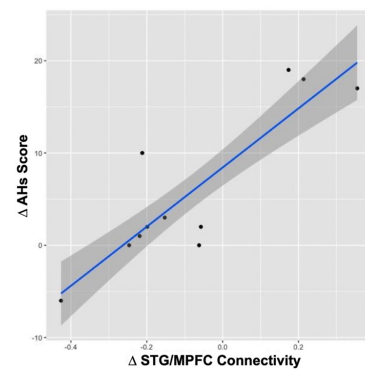
## Real-time fMRI neurofeedback-induced DMN modulation in schizophrenia



Regiones que muestran un cambio significativo en la conectividad funcional en estado de reposo (rsFC).

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## Real-time fMRI neurofeedback-induced DMN modulation in schizophrenia



Significant reduction (pre-publication) of AH auditory hallucinations ( $\Delta$ AH score) with a reduction (pre-publication) in STG-MPFC connectivity ( $\Delta$ STG/MPFC) for the resting state after network neurofeedback in default mode in real time.

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Thanks for your attention

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**Northeastern  
University**




Rt-fMRI Feedback



SUSAN WHITFIELD-GABRIELI



John Gabrieli



Margaret  
Nazzari



Randy Auerbach



Ann Shinn



David Pagliaccio



Kiana D. Greene



Setra  
Ghosh



Kana  
Okano



Jiahe Zhang



Paul Bloom



Isaac Treves



Nickolas Ford




Experience Sampling



Clare Shaffer



Aaron Kucyi



Christian Webb  
(MIT Neuroscience)



Alfonso Nieto Castañón

Connectivity





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