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MRI IN MOOD DISORDERS

NIH National Institute of Mental Health

Outline

- What are mood disorders?
- How do we treat mood disorders?
- What can imaging teach us about mood disorders and their treatment?

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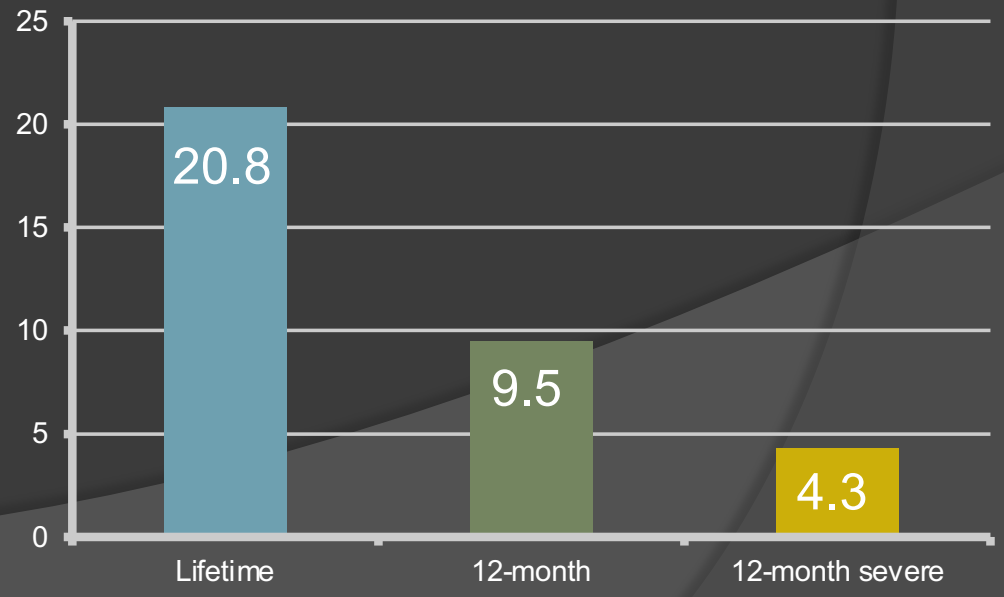
Mood Disorders

- Disorders featuring a disturbance in mood as the primary feature
- Disorders of depressed mood
  - Major depressive disorder, etc.
- Disorders cycling between depressed and elevated moods
  - Bipolar disorder, types I and II
- Highly prevalent



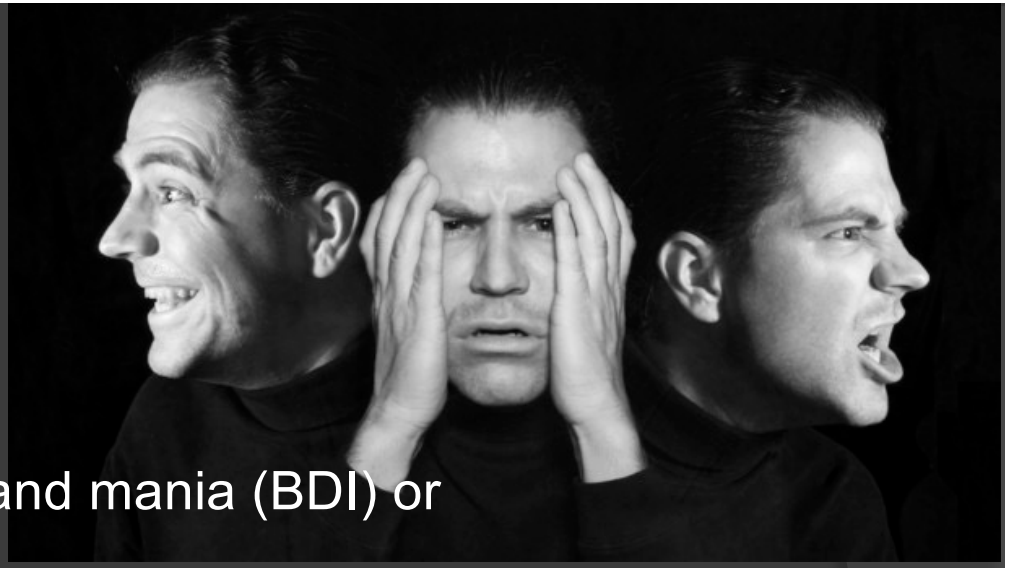
Major Depressive Disorder

- Either depressed mood or anhedonia
- 4 of 7 additional symptoms
  - Weight loss or gain
  - Insomnia or hypersomnia
  - Psychomotor agitation or retardation
  - Fatigue
  - Feelings of worthlessness or guilt
  - Cognitive problems
  - Recurrent thoughts of death or suicide
- Symptoms must have lasted more than 2 weeks, cause impairment, and not be due to a medical condition or medication

Major Depressive Disorder

- Highly Heterogeneous
  - Two patients with MDD could overlap on only one symptom
- Heritable, but no clear genetic pattern
- In 2012, 6.9% of US adults had at least one episode in the past year – 16 million

Bipolar Disorder



- Alternating periods of depression and mania (BDI) or hypomania (BDII)
- Manic episode: elevated, expansive, or irritable mood
- 3 of 7 symptoms (4 if only irritable)
  - Inflated self esteem
  - Decreased need for sleep
  - Talkative, pressured speech
  - Racing thoughts
  - Distractibility
  - Increased goal-directed activity
  - Excessive involvement in pleasurable activities
- Present for at least a week, causes impairment, and not due to a medical condition or medication
- Psychosis, requiring hospitalization, and severe impairment are exclusionary for BDII

Bipolar Disorder

- Twelve month prevalence of 2.6%, 82.9% of these cases are severe
- Highly heritable, but no clear genetic pattern
- Frequently disabling, with high prevalence of suicide

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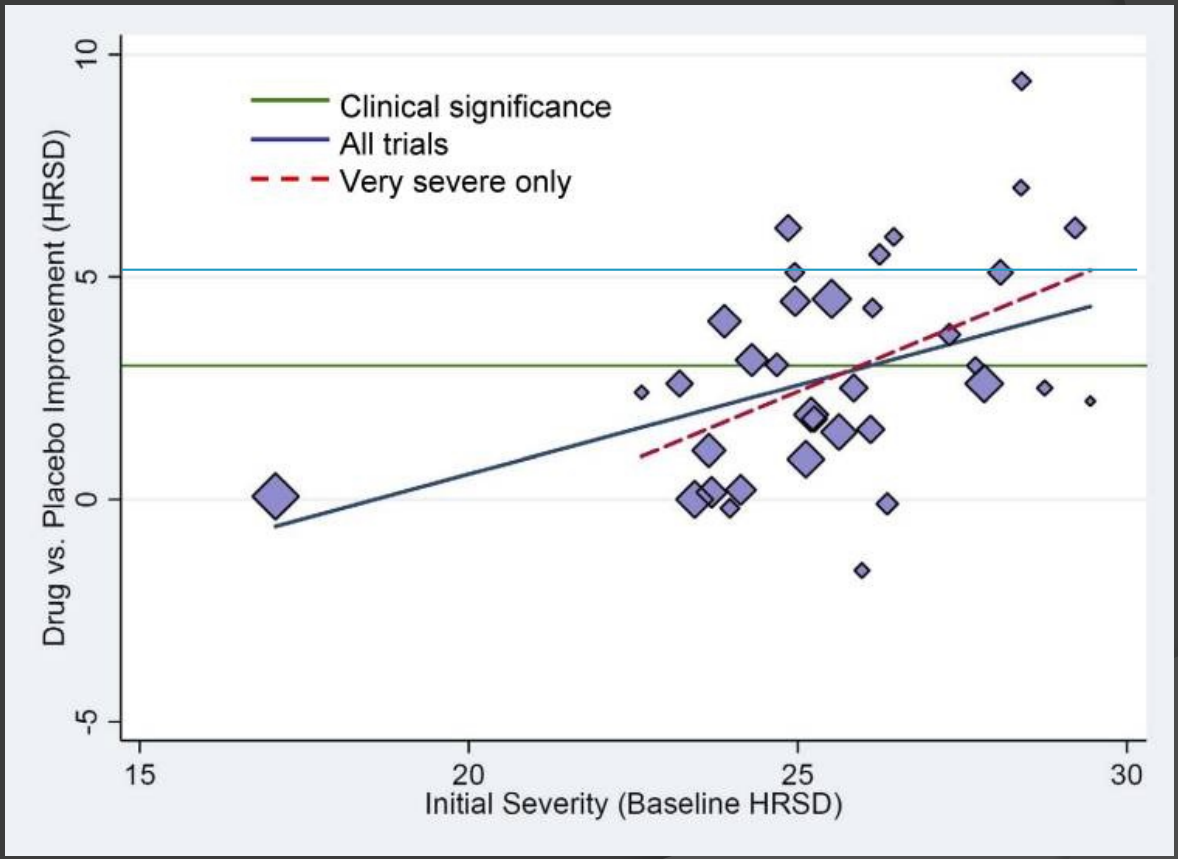
How Do We Treat Depression?

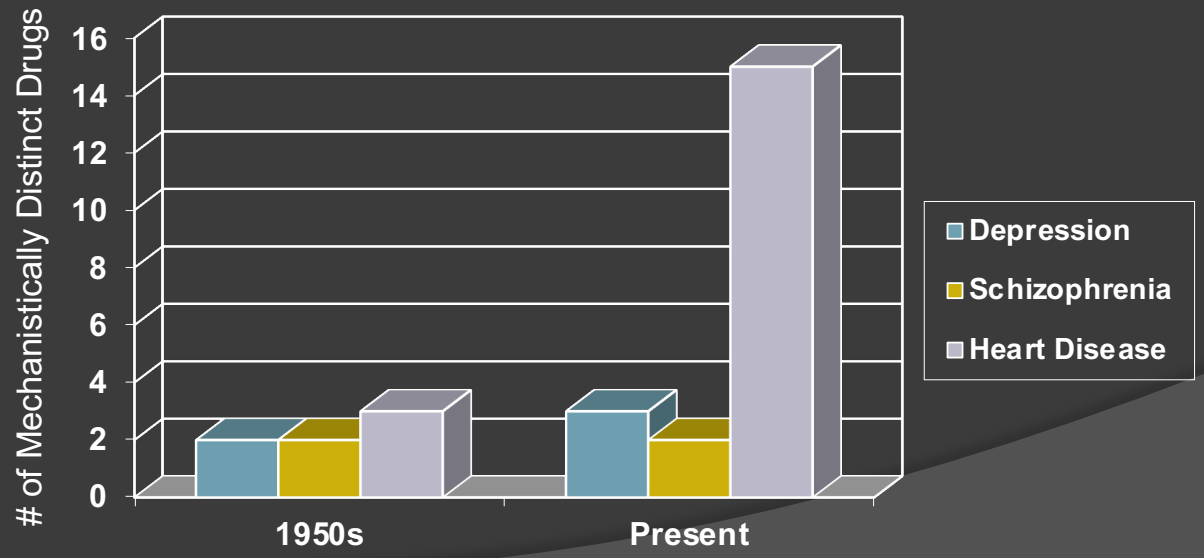
- Not very well
- MDD:
  - SSRI
  - SNRI
  - TCA
  - MAOI
  - ECT, TMS, DBS



Kirsch, et al. PLoS Med (2008) 5(2):e45

How Do We Treat Depression?

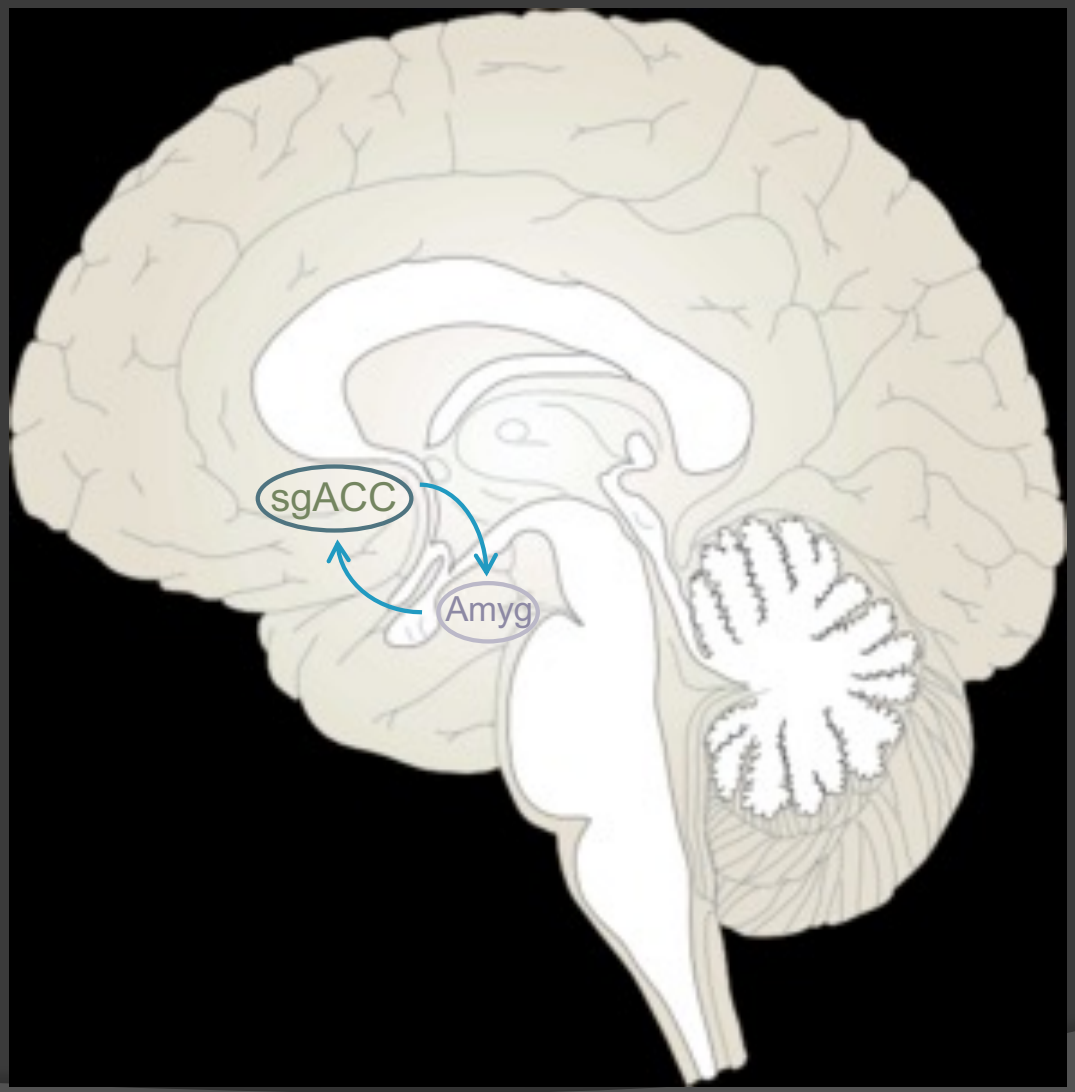
- Only ~35% of patients with depression will respond to the first drug
- Full response is not evident for 6-8 weeks
- There are no markers to guide choice of treatment
- There are no drugs specifically developed to treat depression in the context of BD



How Do We Treat Mania?

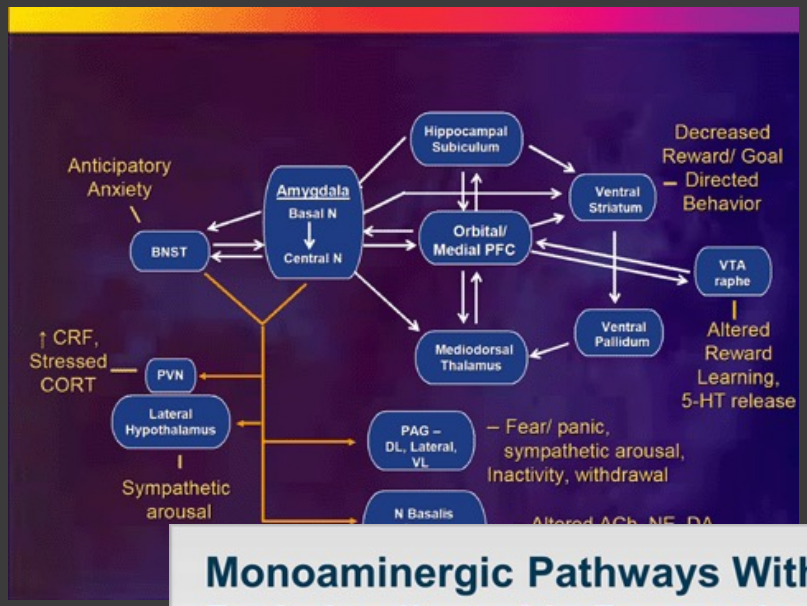
- Only one drug ever developed to treat BD: Lithium
- Alternatively treated with antipsychotics or anticonvulsants
- Frequently severe enough to require hospitalization
- In one study of patients followed after their first hospitalization, only 43% recovered their previous level of occupational and residential function (Tohen 2003).
- Studying bipolar mania is exceedingly difficult

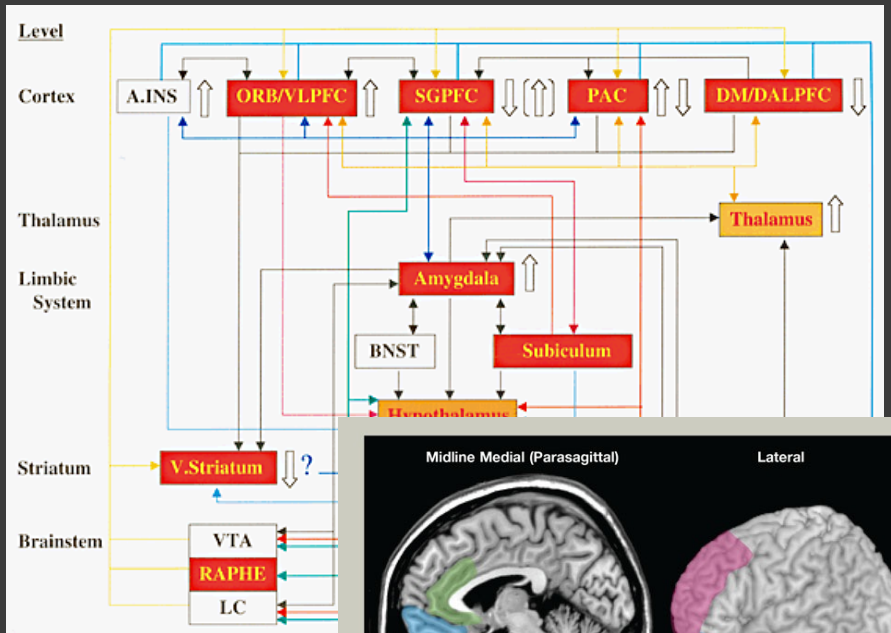
Neurobiology of Depression: Core Brain Regions

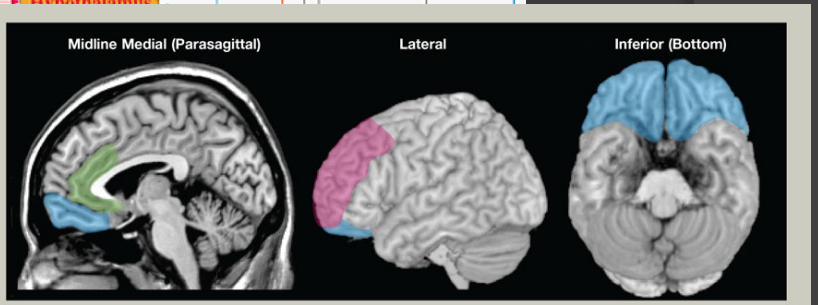


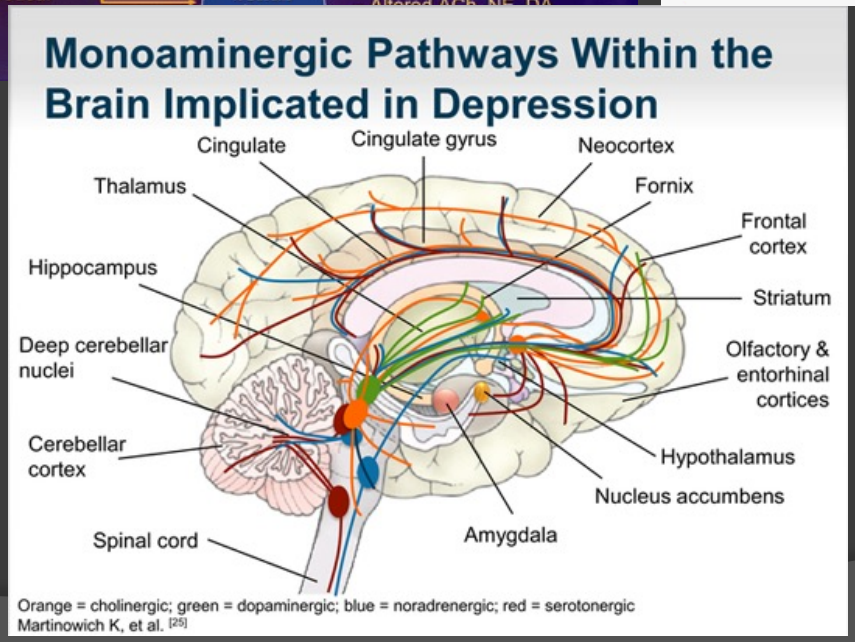
- Subgenual cingulate cortex, BA25
- Amygdala

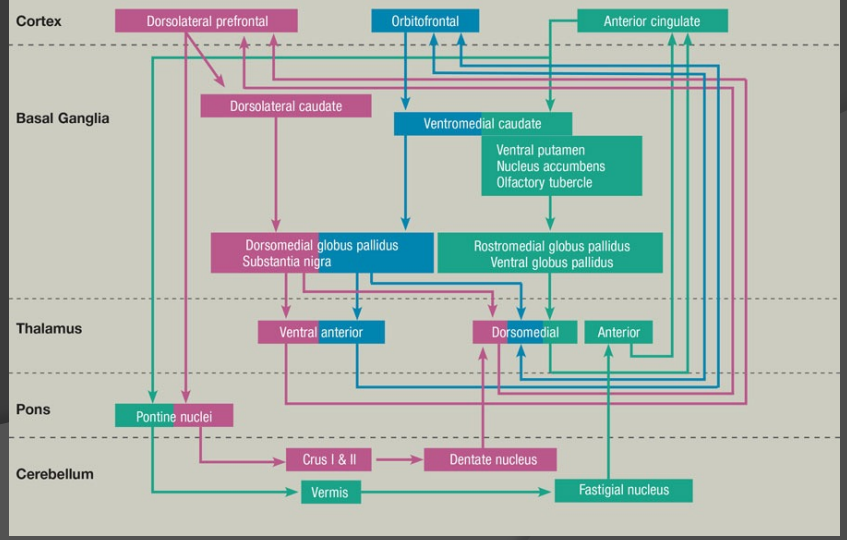
Neurobiology of Depression: Less Simple











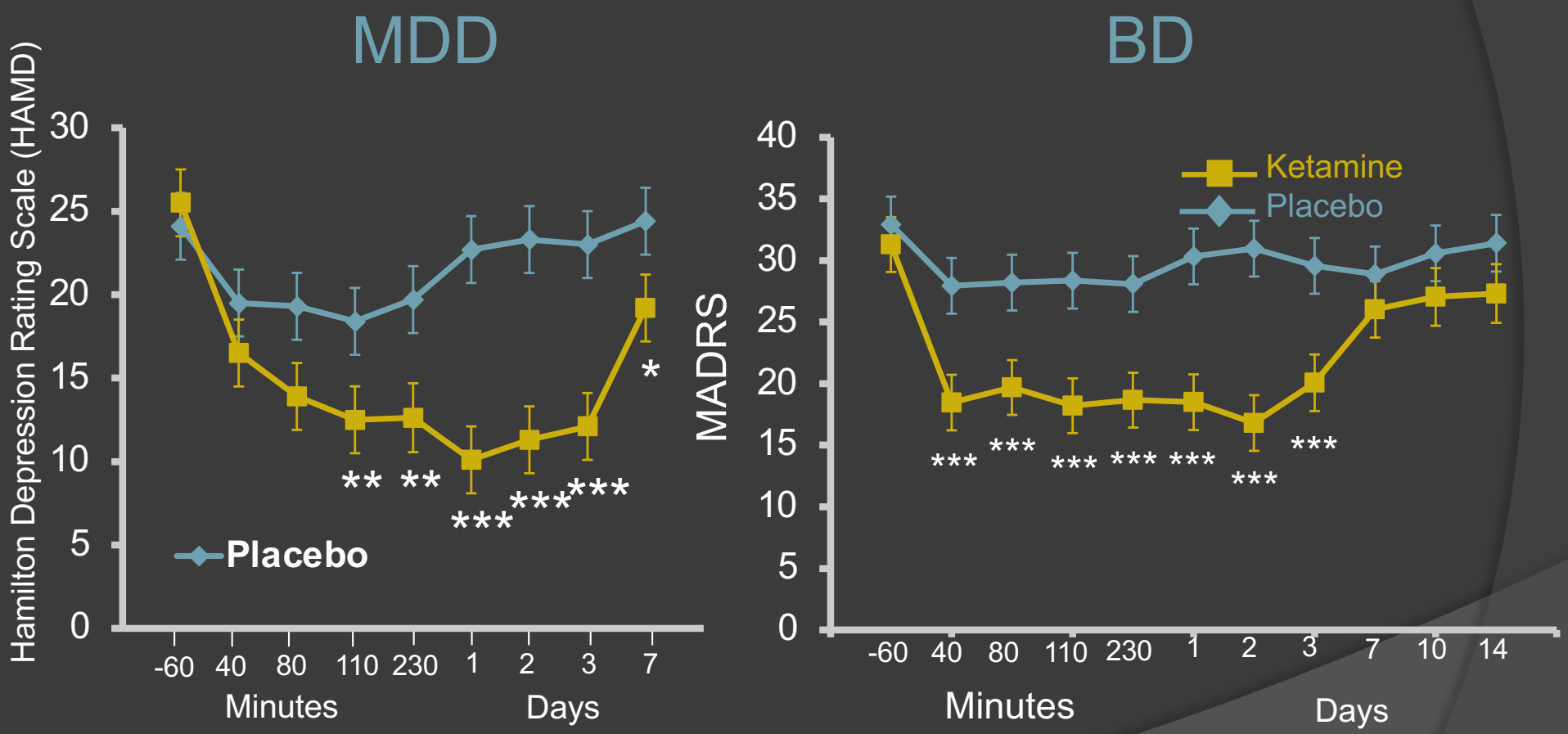
Our Approach

- Alternative Targets
  - Monoaminergic drugs rapidly effect the target neurotransmitter system, but effects are delayed
  - Downstream effects can be targeted more efficiently
- Search for correlates of treatment response to identify potential biomarkers of response

Ketamine

- FDA approved anesthetic and Schedule III controlled substance
- NMDA receptor modulator
- Potent psychotomimetic effects

Ketamine in Severe and Treatment Resistant Depression



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How can we use imaging?

- Find brain “biomarkers” that can subdivide MDD and BD into distinct phenotypes
- Find brain “biomarkers” that can reliably predict who will respond to a given intervention
- To be truly useful, any marker should be agent specific
- Markers may change in response to treatment, and display a dose-response relationship

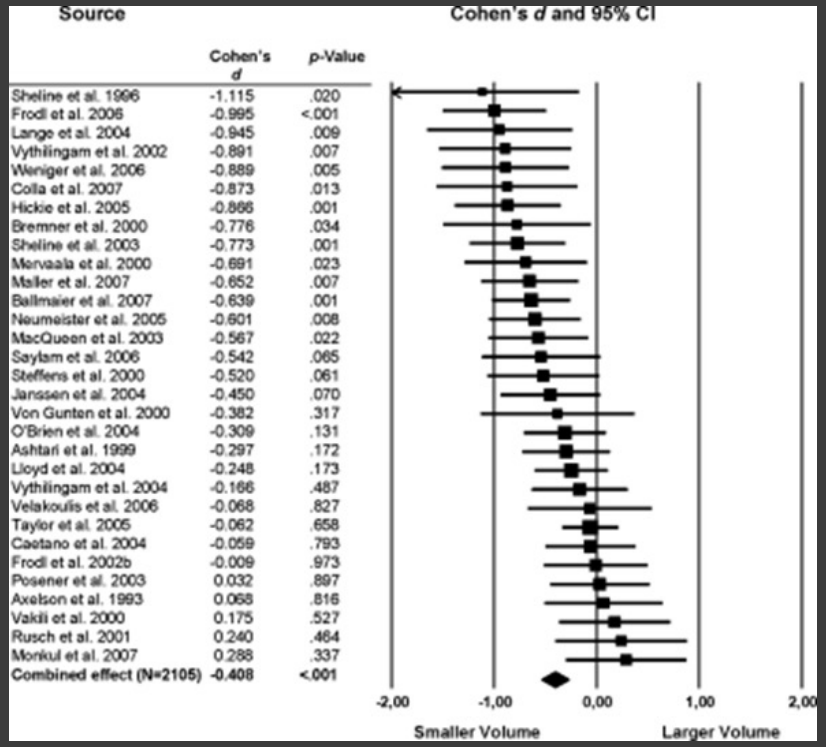
Potential Markers

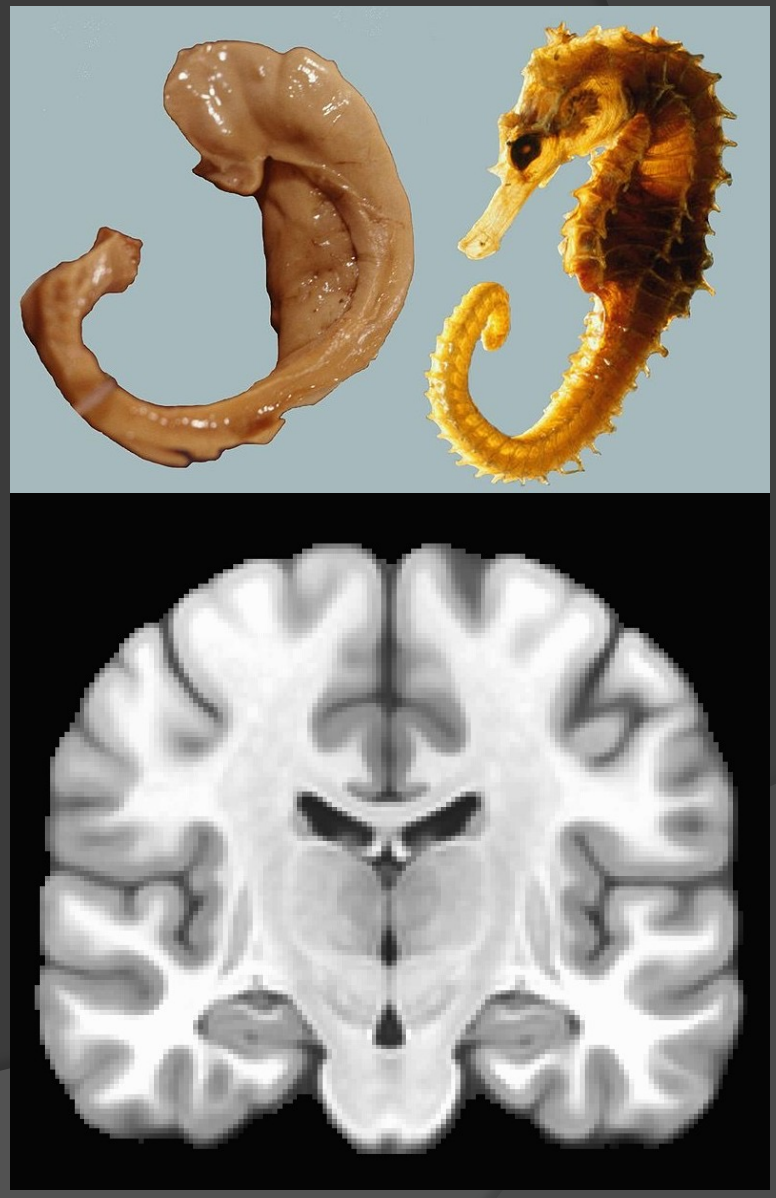
- Structure
  - Volume
  - White Matter
  - Conformation
- Function
  - Cognitive Tasks
  - Resting State

MDD and Brain Structure

- Long history of manual segmentation of structures
- Nearly every structure examined has been shown to be larger, smaller, or no different than in healthy control subjects
- Why? Medication effects, differing segmentation techniques, etc.

MDD and Brain Structure

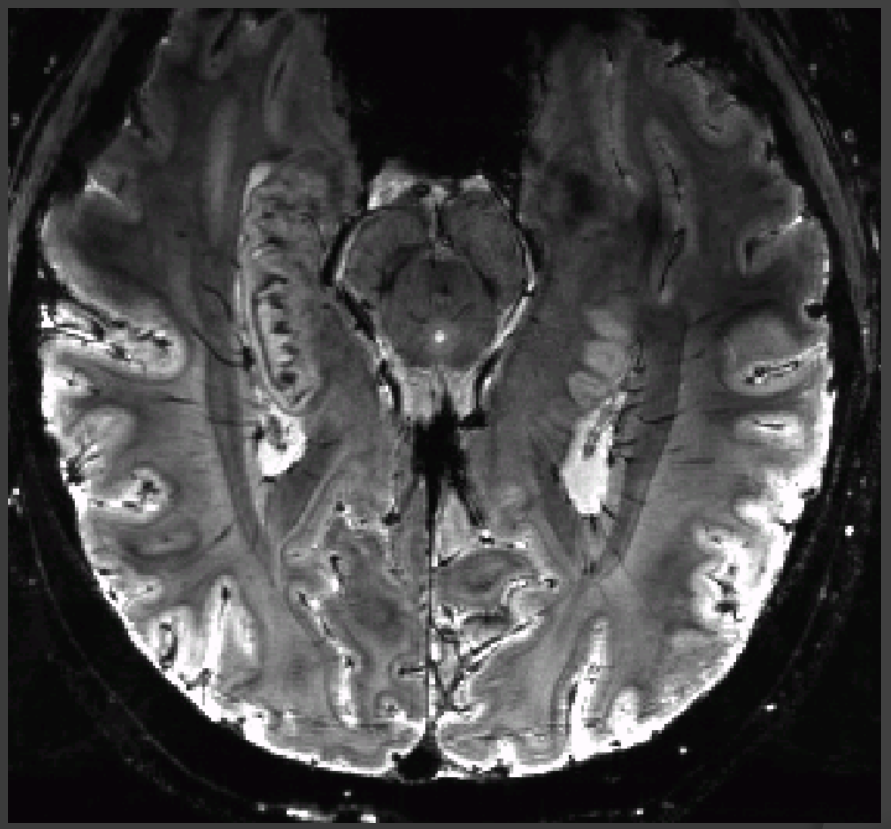




Koolschijn, et al.
Human Brain Mapping (2009) 30(11):3719-3735

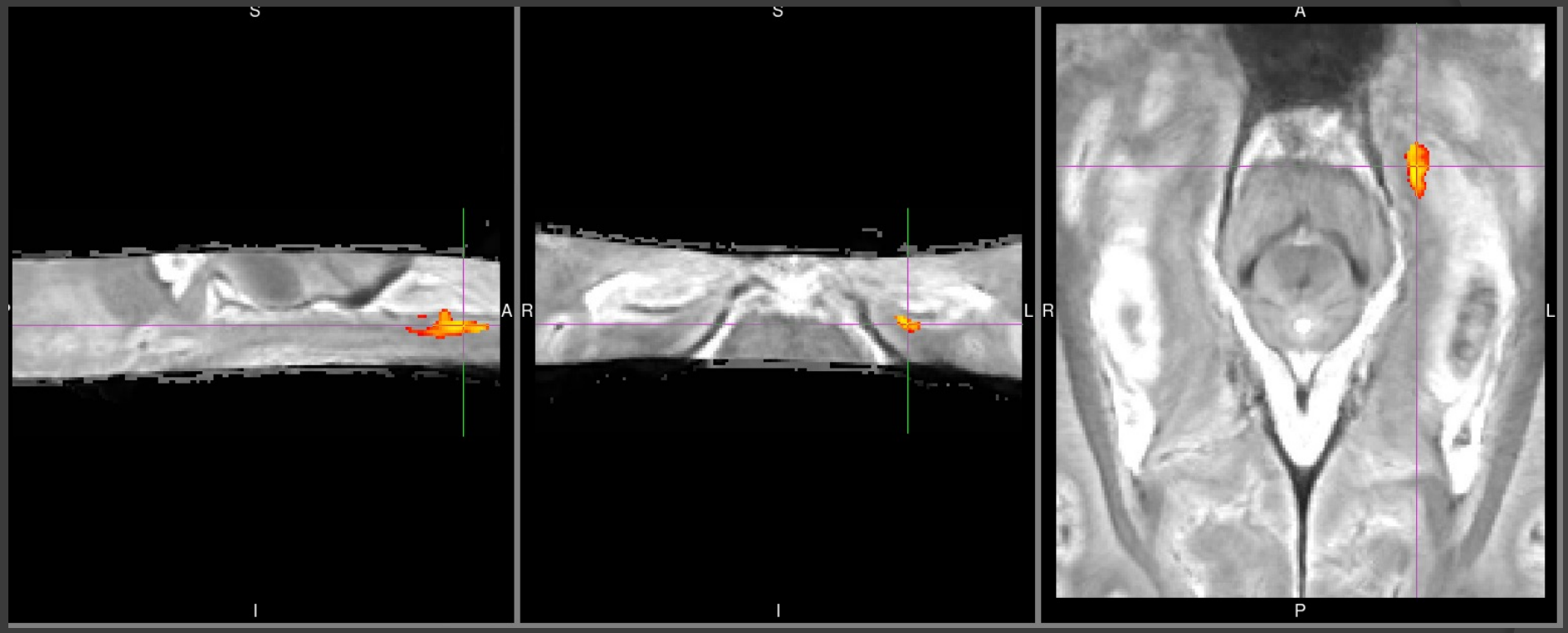
MDD and Brain Structure

- High resolution hippocampal mapping at 7T
- Assessing curvature, surface area, and shape



Adam Thomas and Anna Goodwin

MDD and Brain Structure

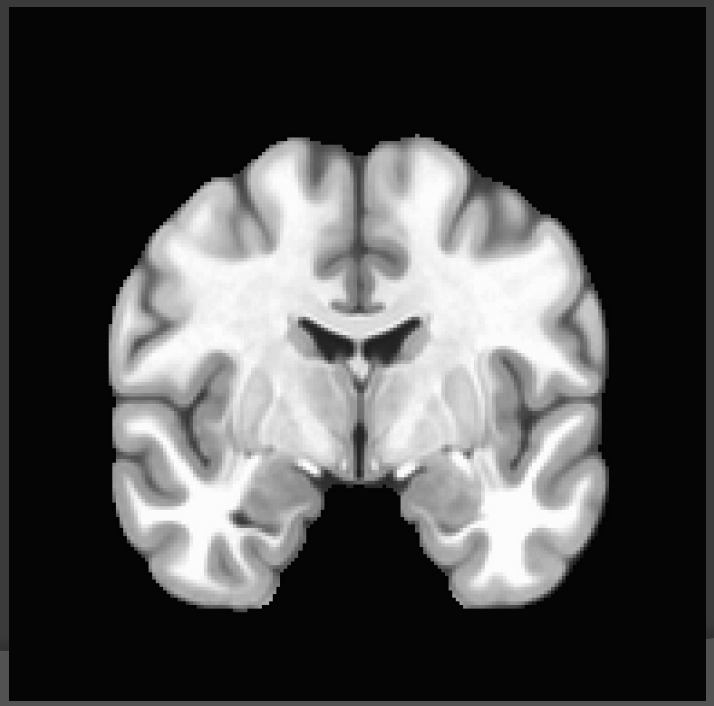


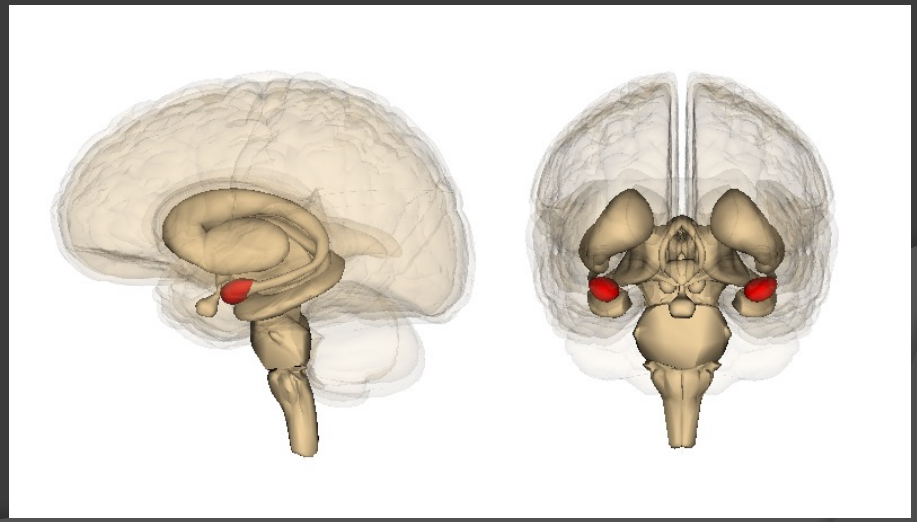
Significant negative association between length of current episode and reduced volume in the subicular subfield of the hippocampus.

Adam Thomas and Anna Goodwin

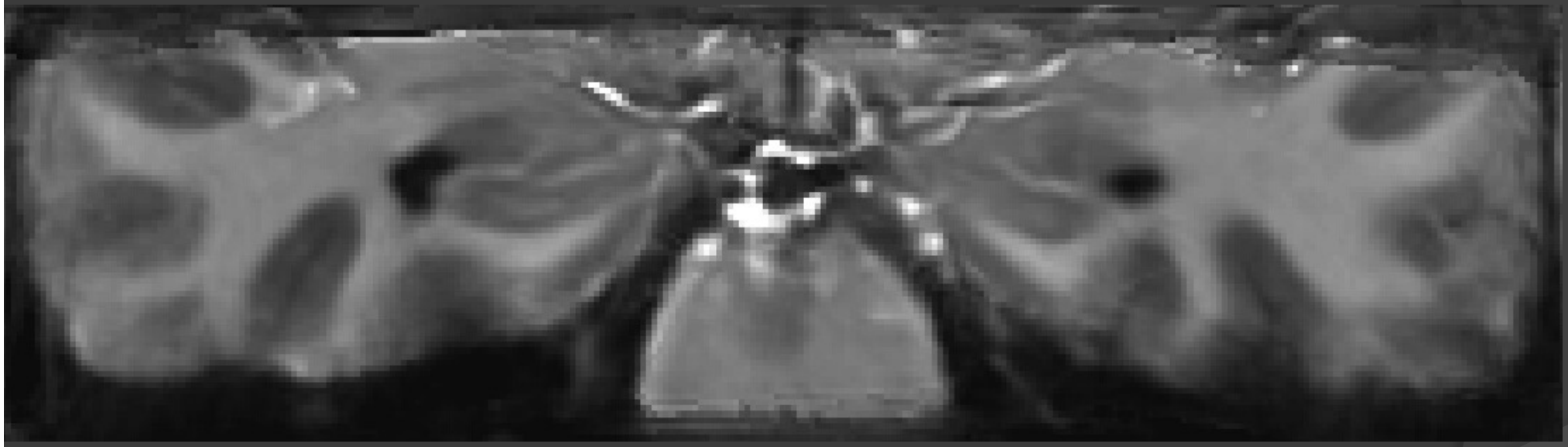
MDD and Brain Structure

- What about the amygdala?
  - Intimately involved in emotional processing and memory
  - Extremely difficult to examine structurally
  - In an area prone to magnetic susceptibility artifacts



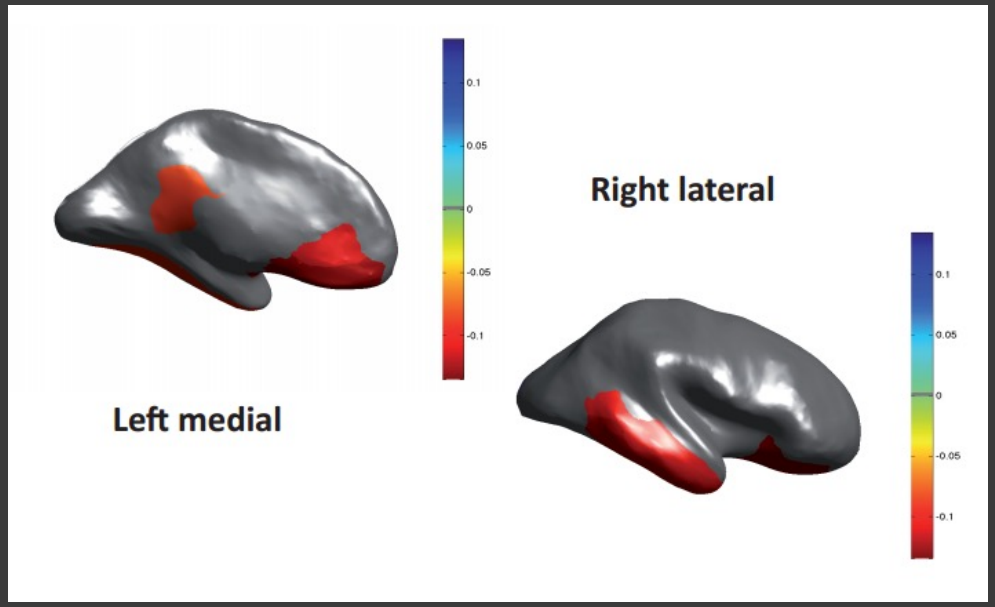


MDD and Brain Structure



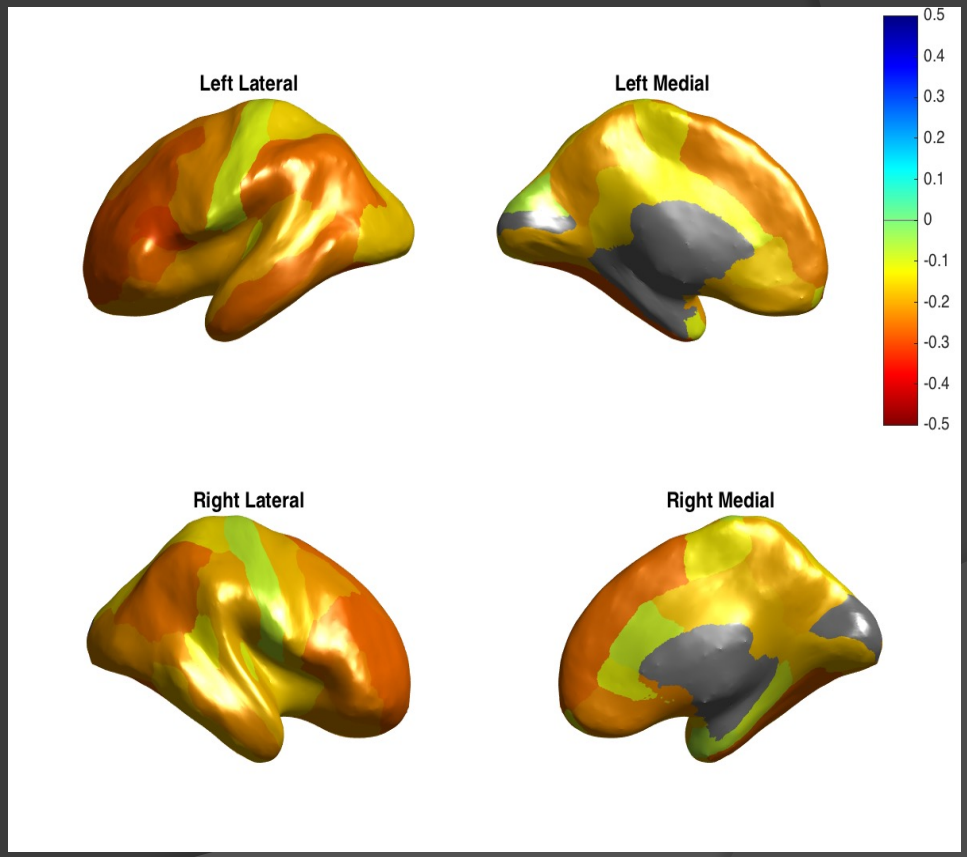
Mood Disorders and Brain Structure: Cortex

ENIGMA MDD Workgroup
N=2104 MDD, N=7971 HC



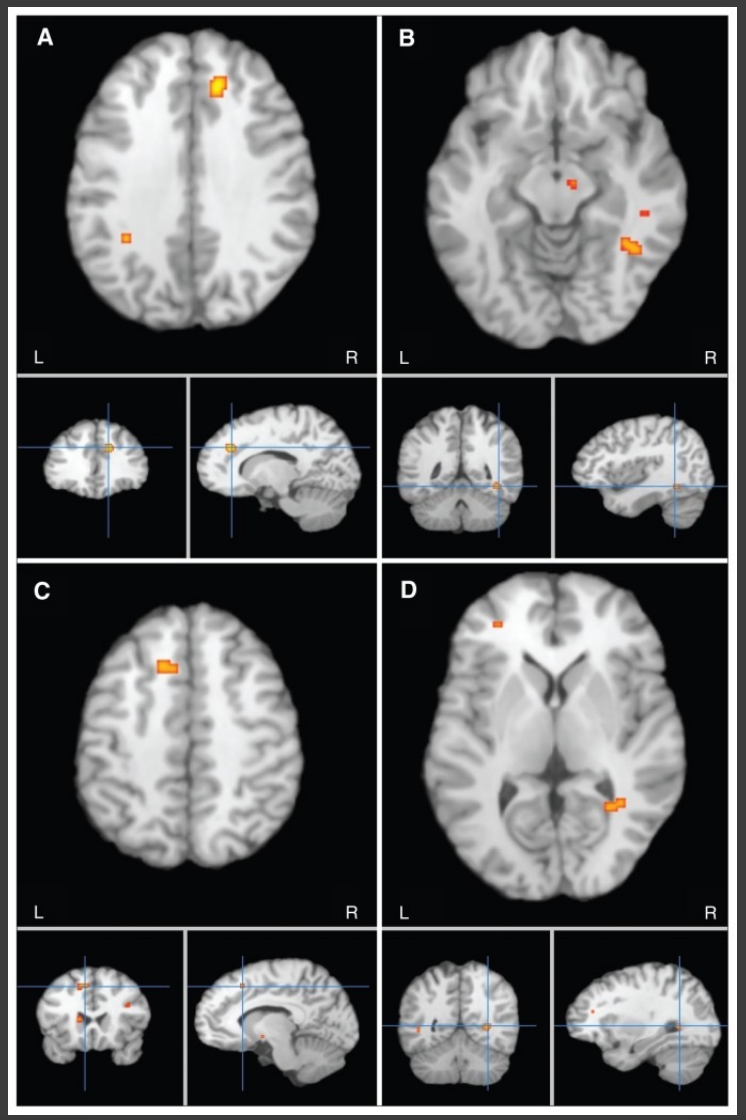
Schmaal, et al., OHBM 2015

ENIGMA BD Workgroup
N=2061 BD, N=3379 HC



Hibar, et al., under review

MDD and Brain Structure: DTI



- Meta-analysis
- 3 TBSS studies, and 8 VBA studies
- Reduced FA in CC, longitudinal fasciculus, fronto-occipital fasciculus, and thalamic radiation

Liao, et al. (2013) J Psychiatry Neurosci 38(1):49-56.

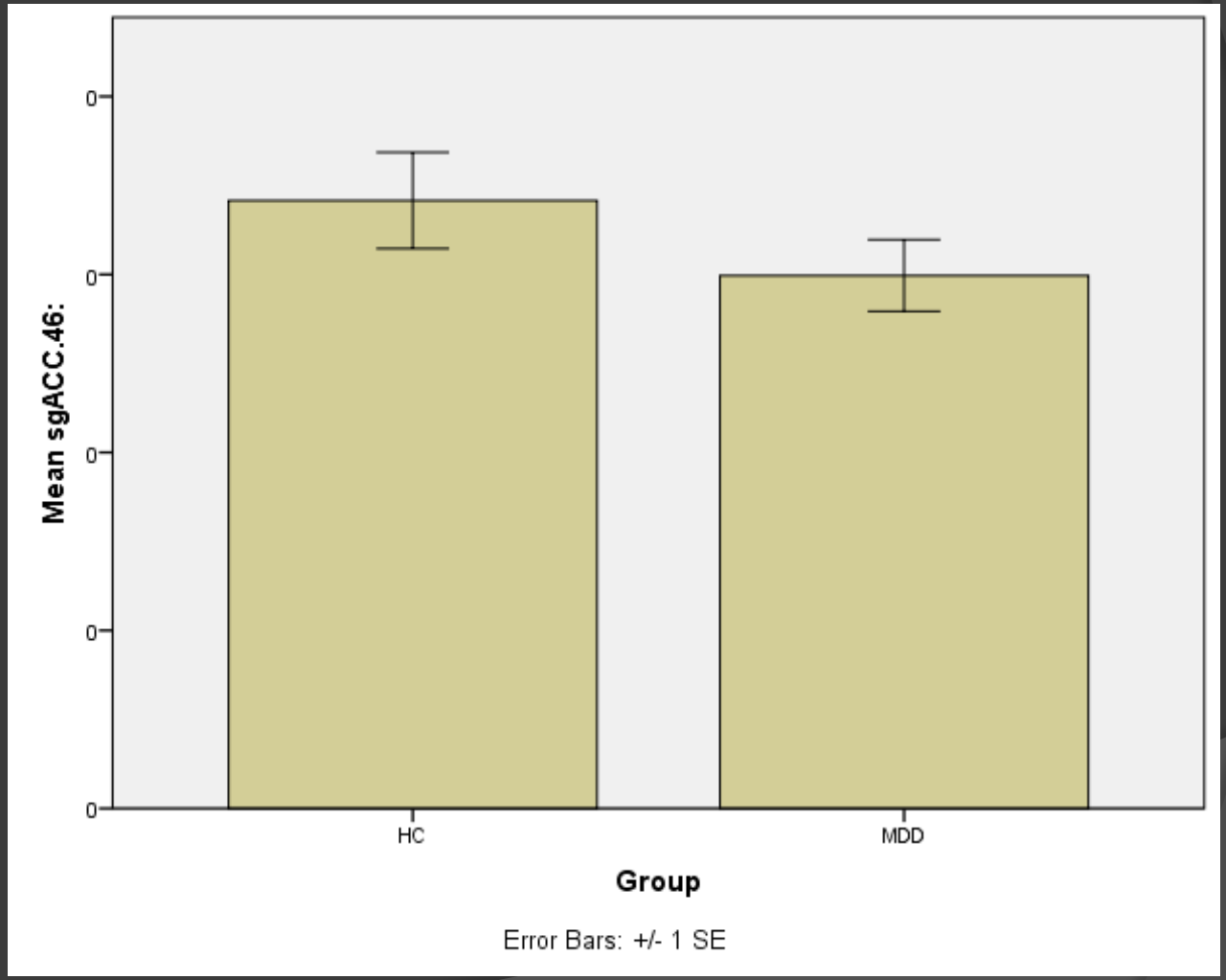
MDD and Brain Structure: DTI

- Choi, et al. Neuropsychopharmacology (2014) 39(6):1332-1339.
- MDD (N=134) and HC (N=54)
- 98 treatment naïve MDD
- All medication free
- No differences found

MDD and Brain Structure: DTI

sgACC to
Right Amygdala

HC: N=15
MDD: N=28



Nugent, Snider, Banerjee et al.

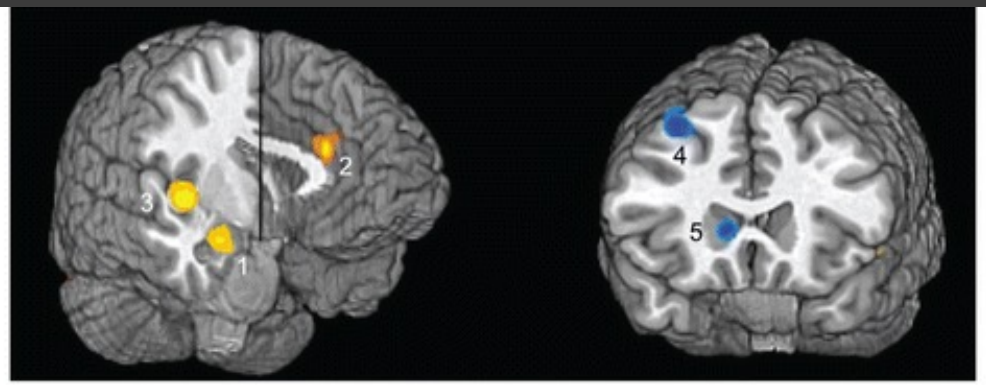
Potential Markers

- Structure
  - Volume
  - White Matter
  - Conformation
- Function
  - Cognitive Tasks
  - Resting State

MDD and cognition

- Affective Processing
  - Bias towards negative stimuli in depression
- Attention
  - Dot probe tasks
- Working memory and executive function
  - N-back task, delayed matching tasks
- Reward processing

Emotion Processing: Depression



Structure	Direction of Effect	Valence Specific Effect?	Talairach Coordinates	Cluster Size (mm^3)	Number
Amygdala	Depressed > Comparison	Yes	24, –4, –13	318	1
Dorsal anterior cingulate cortex	Depressed > Comparison	Yes	–2, 30, 20	196	2
Insula and superior temporal gyrus	Depressed > Comparison	Yes	–38, –6, –8	834	3
Precentral gyrus	Depressed > Comparison	Yes	–30, –15, 44	621	–
Middle temporal gyrus	Depressed > Comparison	Yes	–39, –64, 17	440	–
Dorsolateral prefrontal cortex	Comparison > Depressed	Yes	30, 13, 47	1,380	4
Dorsolateral prefrontal cortex	Comparison > Depressed	No	–22, 27, 42	949	–
Caudate body	Comparison > Depressed	No	10, 20, 6	382	5

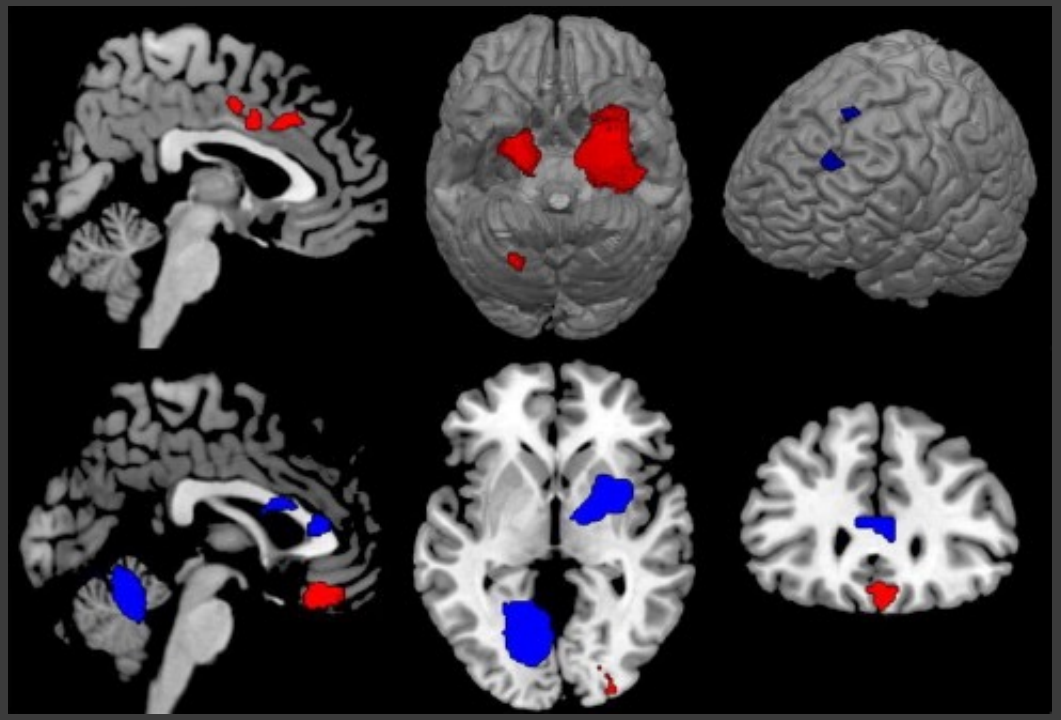
- Meta-analysis
- 14 rCBF and 24 fMRI studies
- Hyper-reactivity in dorsal cingulate and amygdala in response to negative stimulus vs. positive or neutral stimulus
- Hypo-reactivity in DLPFC
- Depressed subjects also showed reduced striatal response to positive stimuli

Hamilton, et al. (2012) Am J Psychiatry 169(7):693-703

Emotion Processing: Depression

Negative Emotions

Positive Emotions

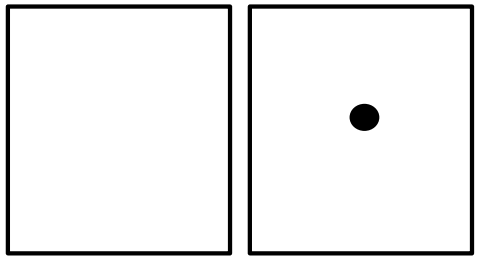


- Meta-analysis
- 44 fMRI studies
- Hyperactivation to negative stimuli and hypoactivation to positive stimuli

Groenewold, et al. (2012) Neurosci and Biobehav Rev 37(2):152-163

Dot Probe Task

Angry Block:

Incongruent Trial

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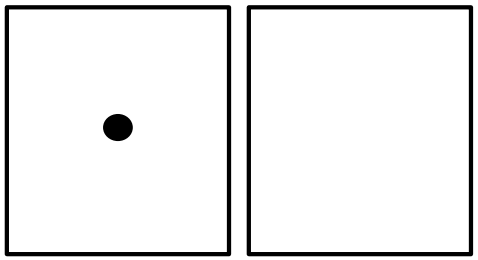
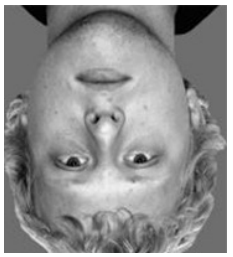
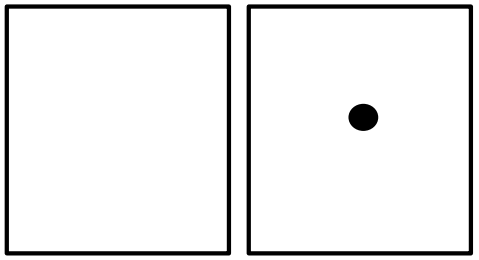


Congruent Trial

Happy Block:



Congruent Trial

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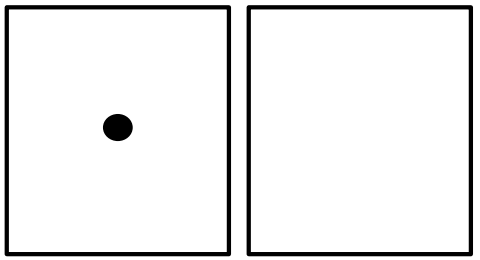
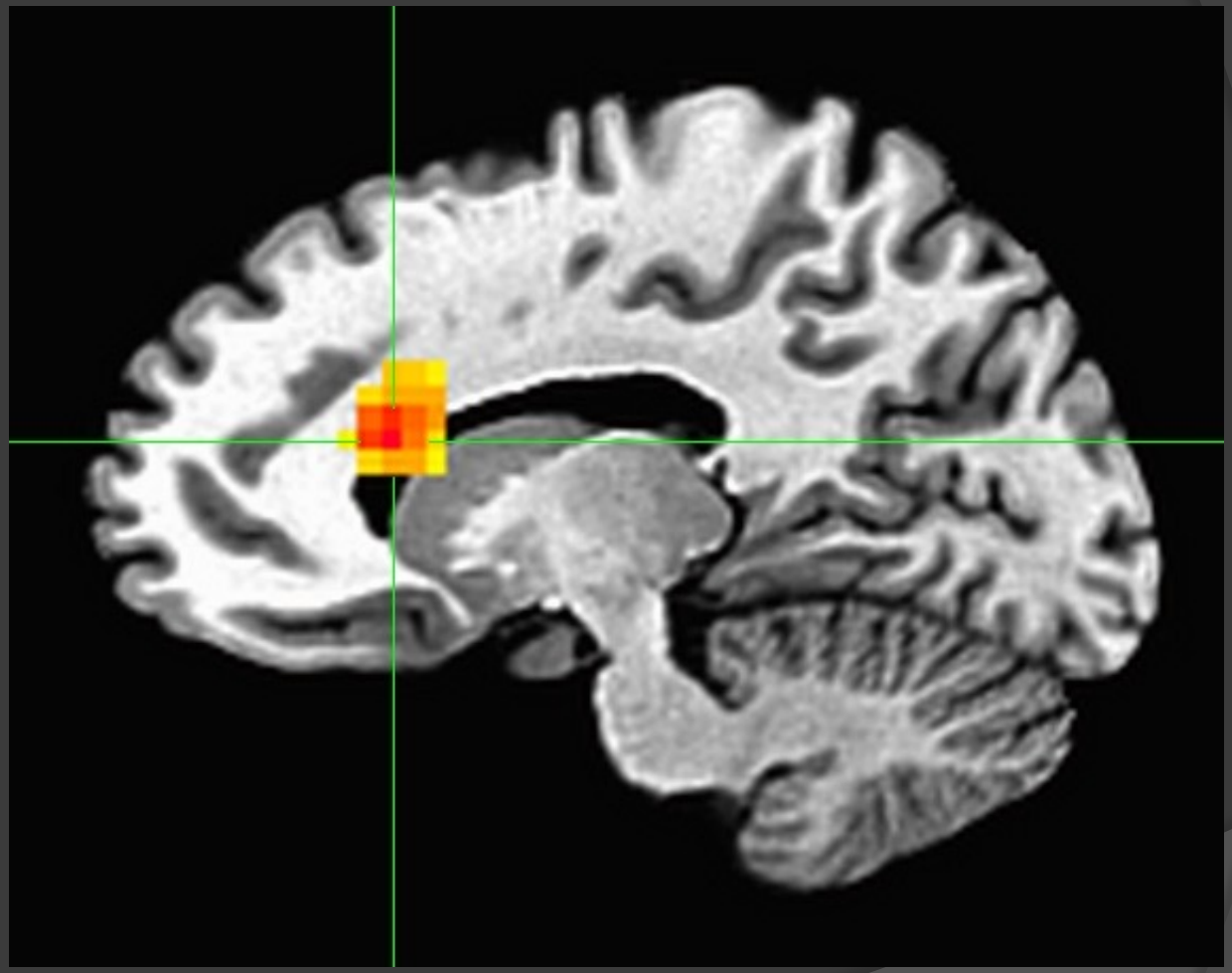
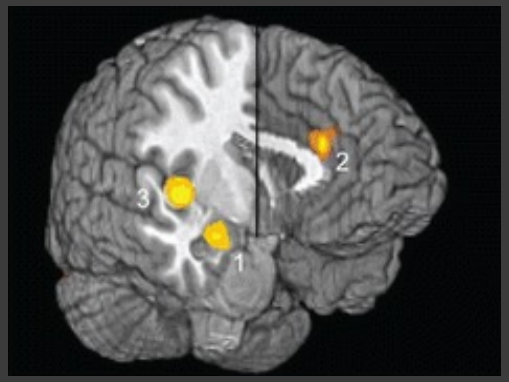


Control Trial

Dot Probe Task:

Group x Emotion Interaction



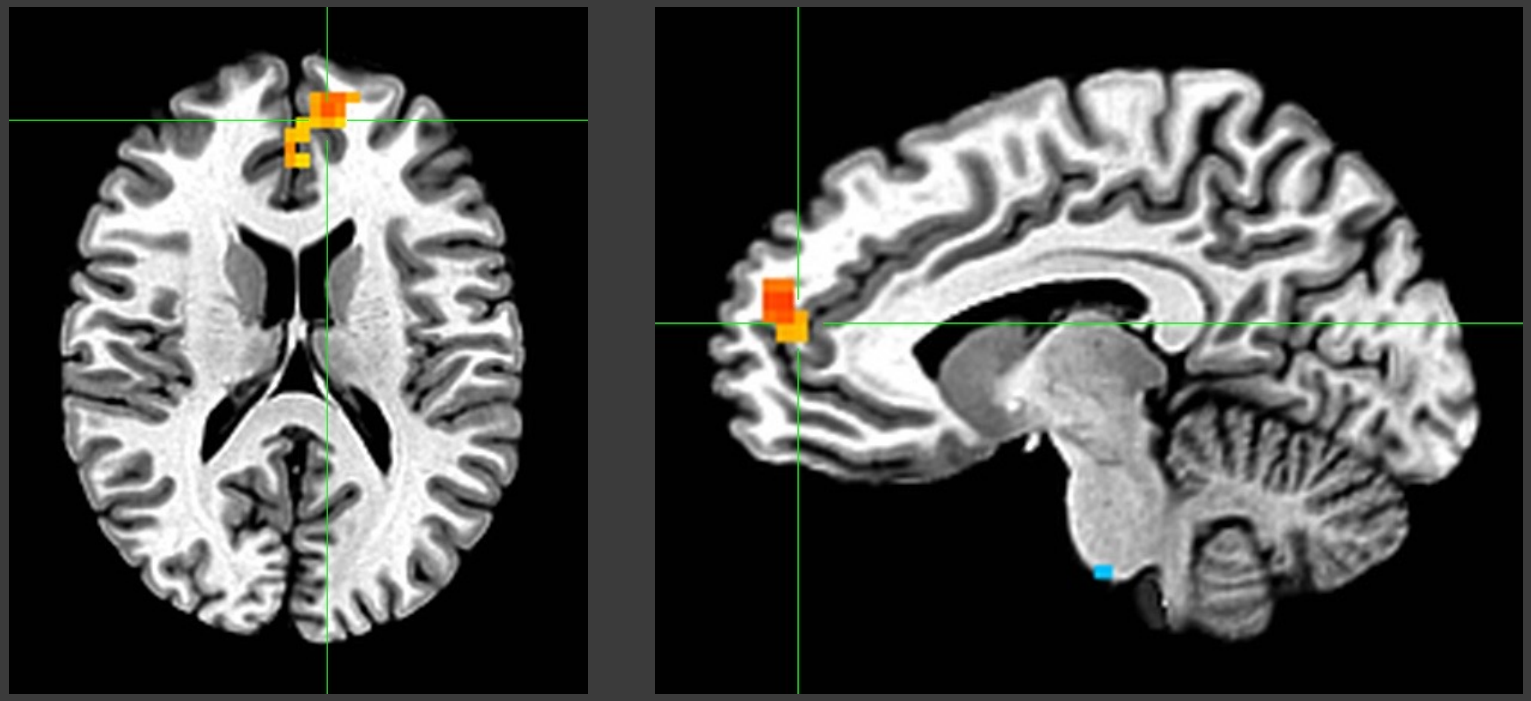


Jessica Ihne Reed, et al.

Dot probe task: Ketamine response

HC: N=17 MDD N=30

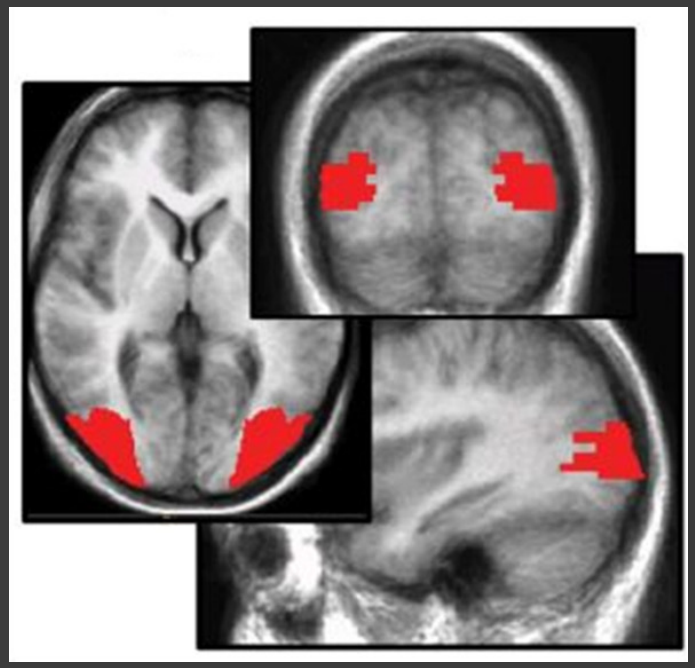
Group x Drug x Emotion Interaction



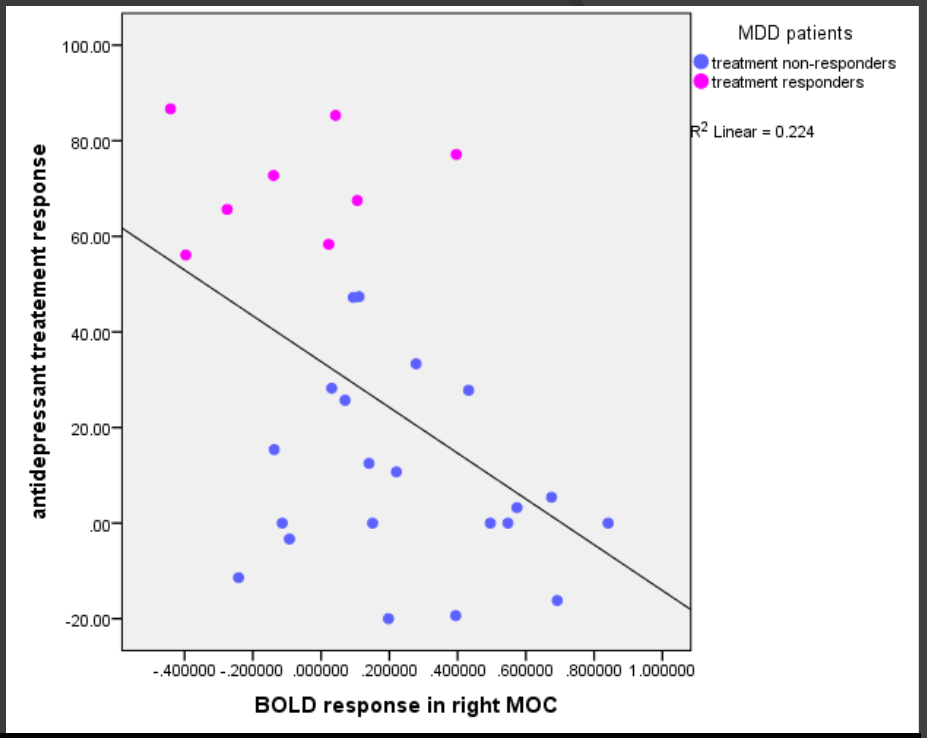
MDD showed greater activation in response to angry faces which decreased following the ketamine infusion

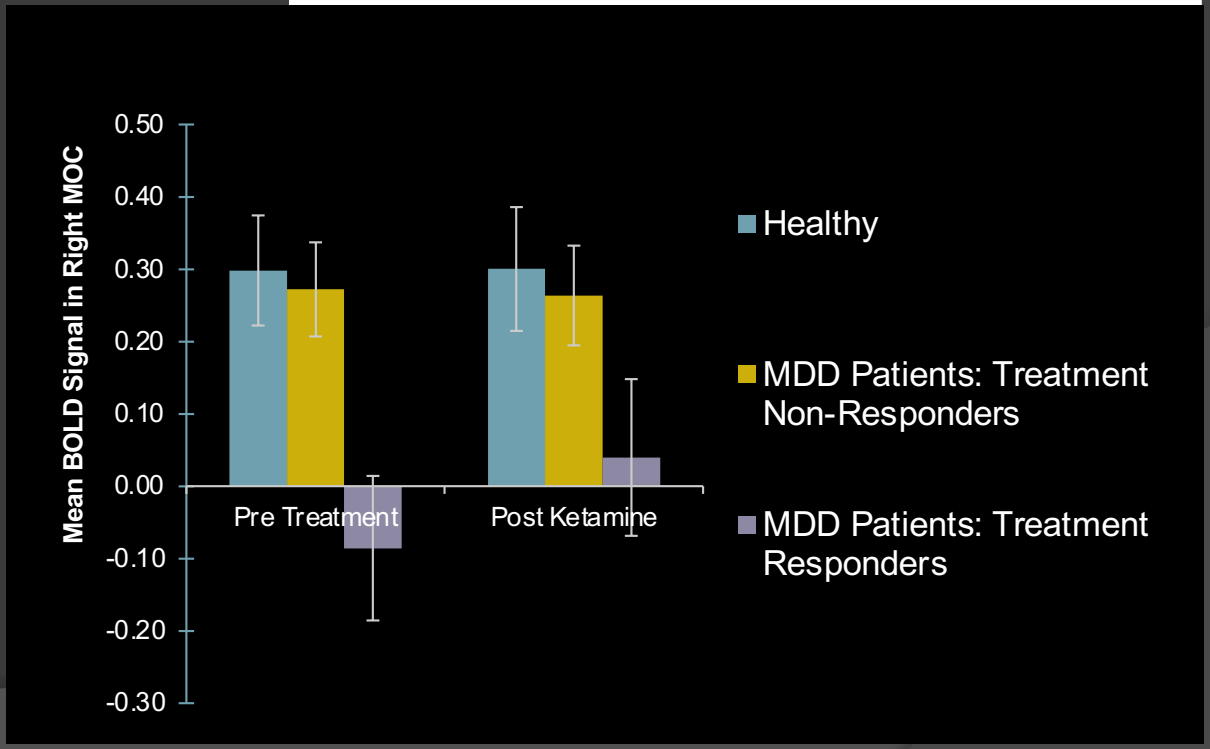
Jessica Ihne Reed, et al.

Dot Probe Task: Response



HC: N=24
MDD: N=30

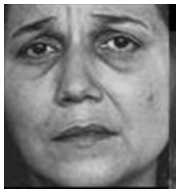




Szczepanik, Reed, Chung et al.

Emotional Evaluation Task: Ketamine

Emotion Block:
Positive or Negative?



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Gender Block:
Male or Female?

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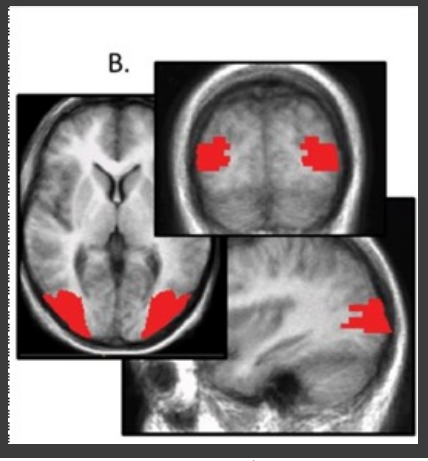
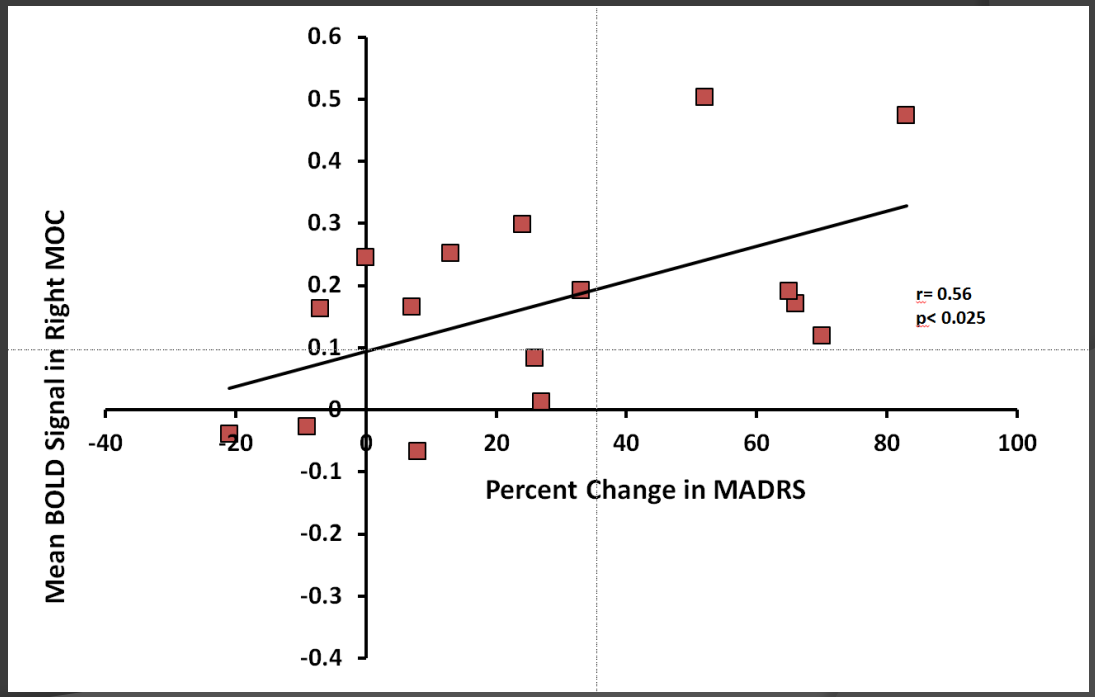


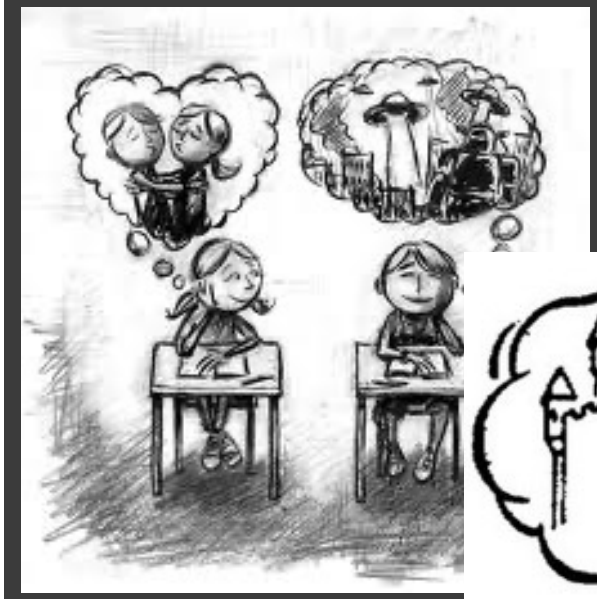


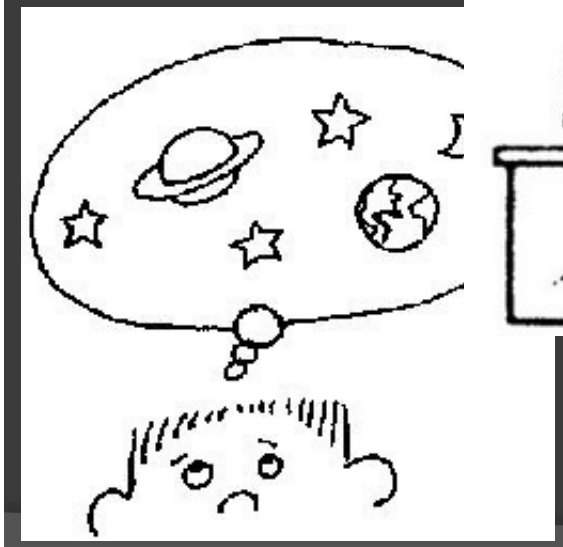
Furey, et al., under review

What do these results tell us?

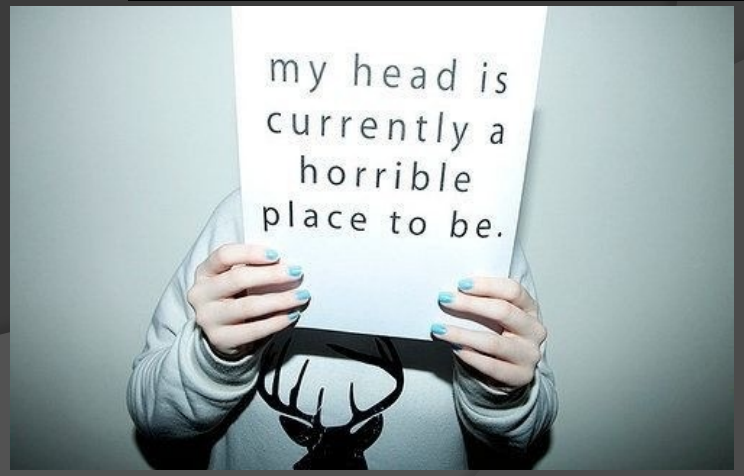
- Hyperactivity to negative stimuli
  - Amygdala
  - Dorsal cingulate/Anterior cingulate
  - Insula
- Hypoactivity to negative stimuli
  - DLPFC
  - Striatum
- Associations with treatment
  - Middle occipital / visual

MDD and the Resting State

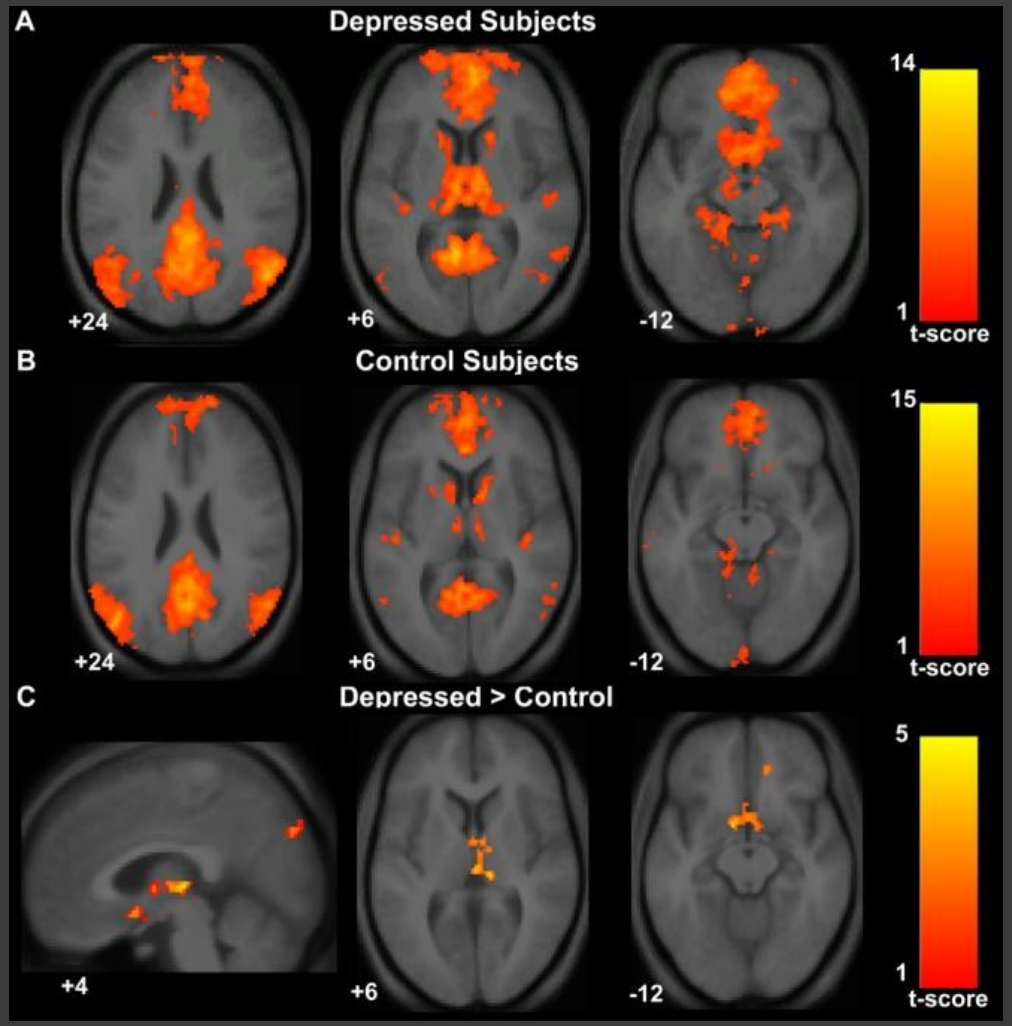




VS.



MDD and the Resting State



- Hyperconnectivity in the sgACC and thalamus compared to healthy subjects
- These are areas of hyperactivity as shown by PET and MRI meta-analyses
- Increased resting state connectivity in sgACC has been replicated in meta-analyses.

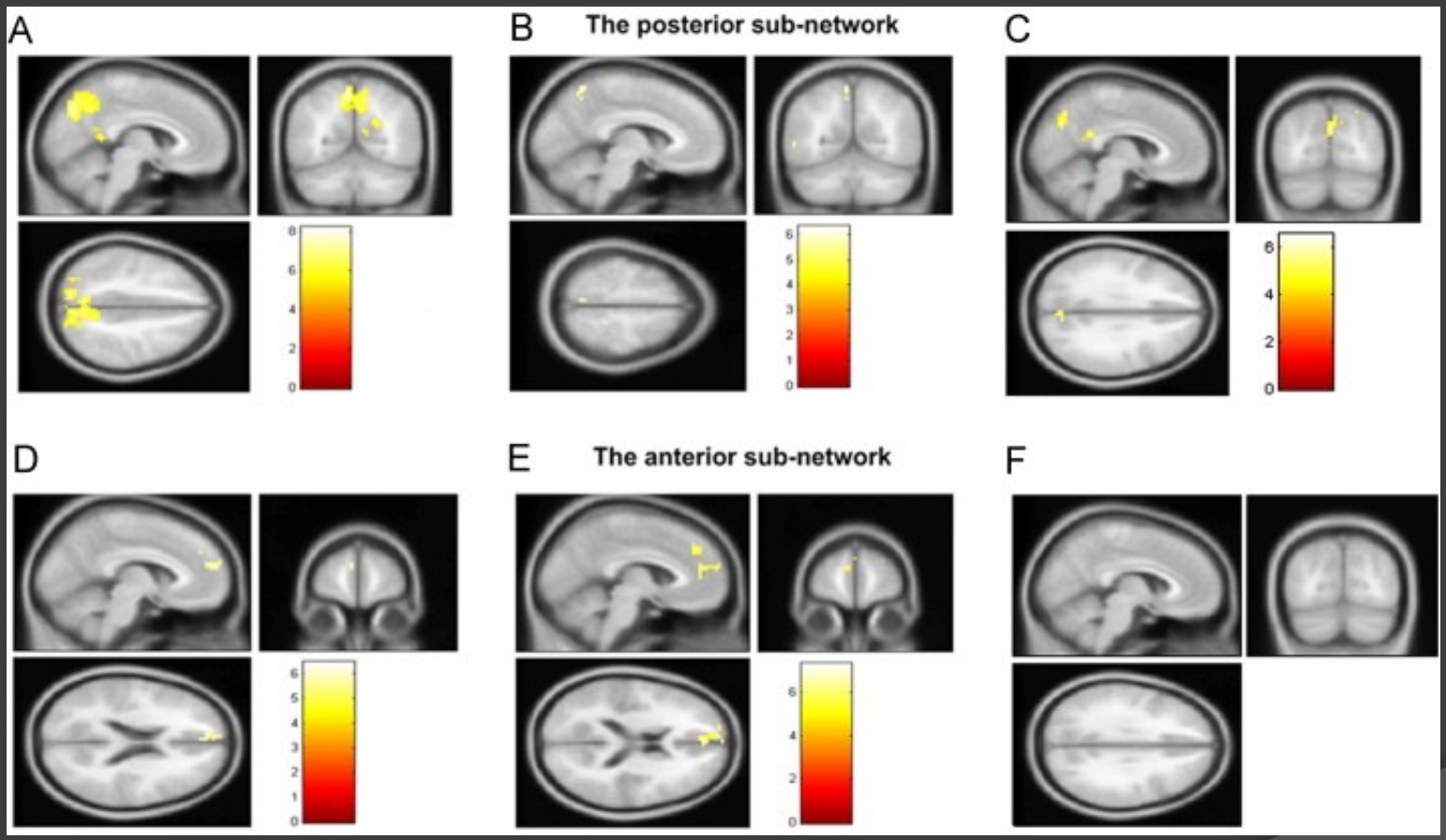
Greicius, et al. (2007) Biological Psychiatry 62(5):429-37

Resting State

Pre-treatment MDD vs. HC

Post-treatment MDD vs. HC

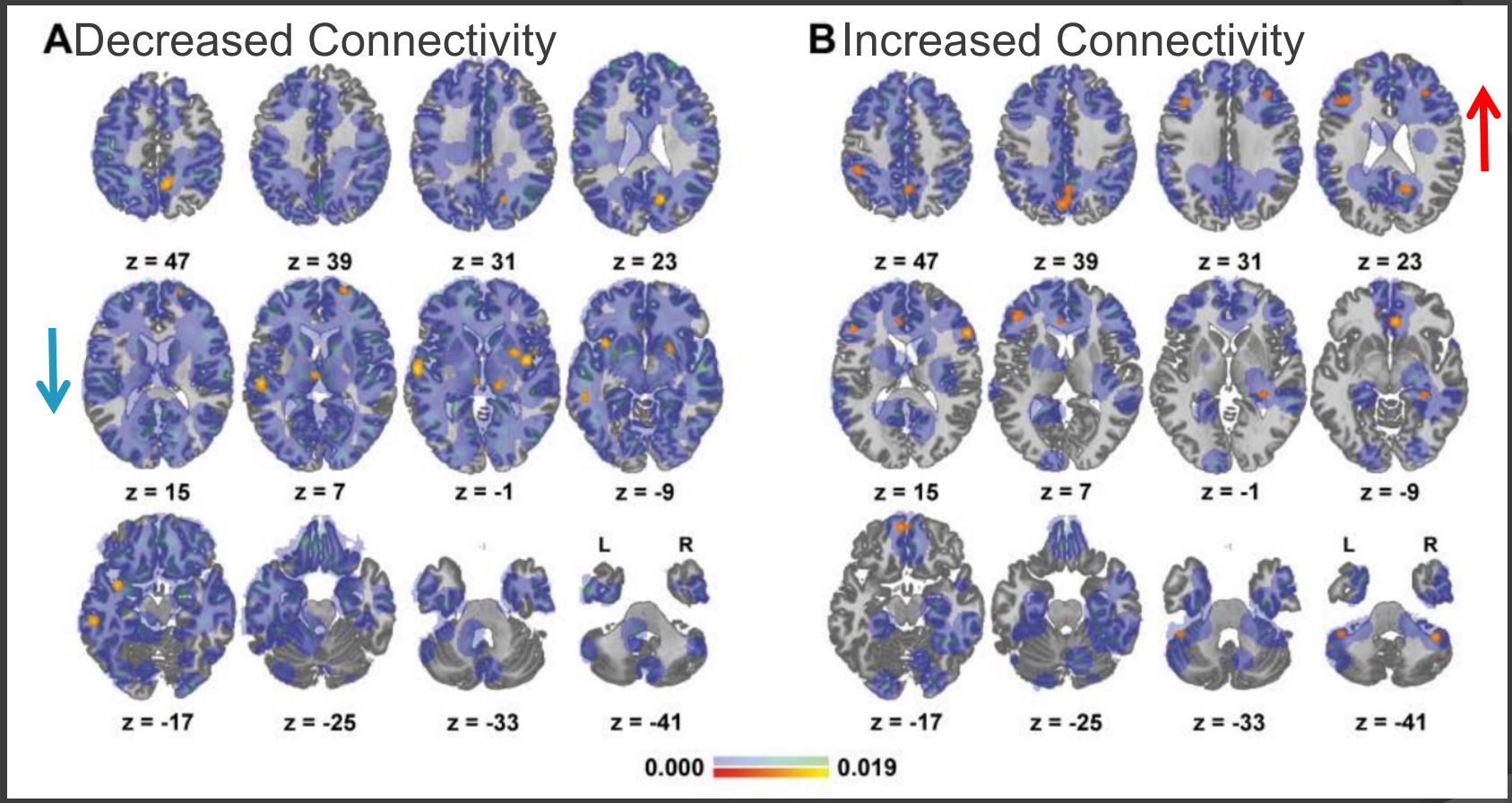
Pre-treatment MDD vs. Post-treatment MDD



While posterior default mode network responds to antidepressant treatment, dysfunction in the anterior default mode network is unchanged

Baojuan, et al. (2012) Biological Psychiatry 74(1):48-54

MDD and the Resting State



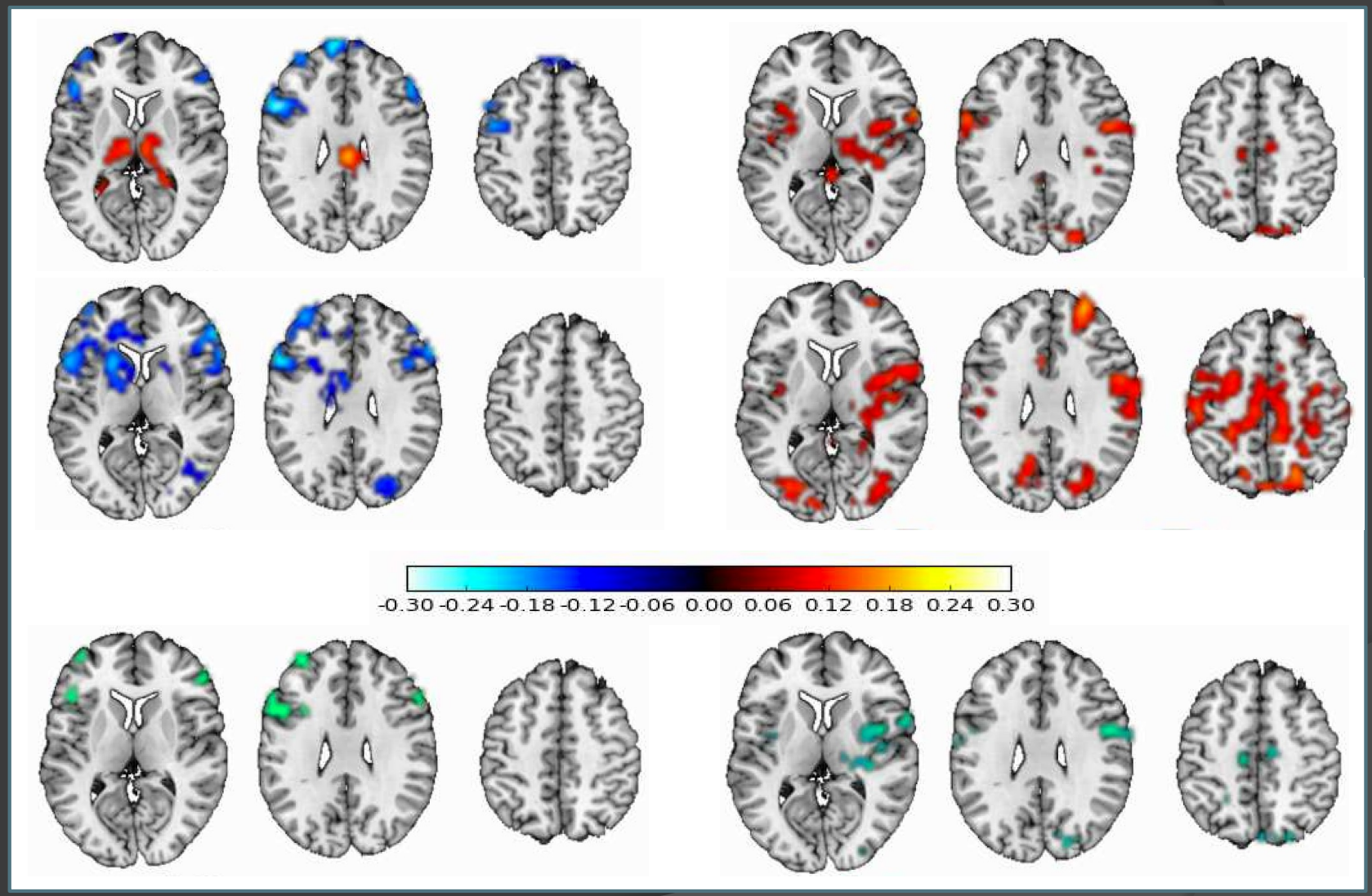
Insula (SN)

DLPFC (CEN)

- Meta-analysis, 32 studies, separate analyses for results showing increased and decreased connectivity

Sundermann, et al. (2014) Front Hum Neurosci

Default Mode Connectivity Associated with Response to Ketamine:



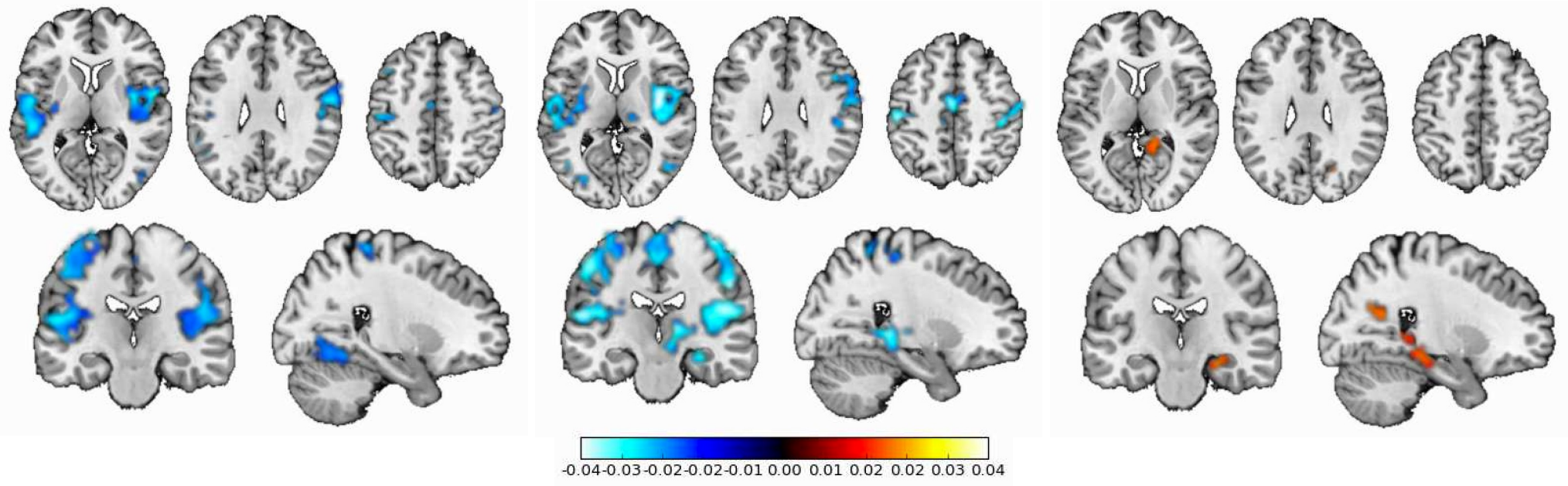
Evans, et al.

Default Mode Network: Mood by Tx interaction

MADRS: drug > baseline

MADRS: placebo > baseline

MADRS: drug > placebo

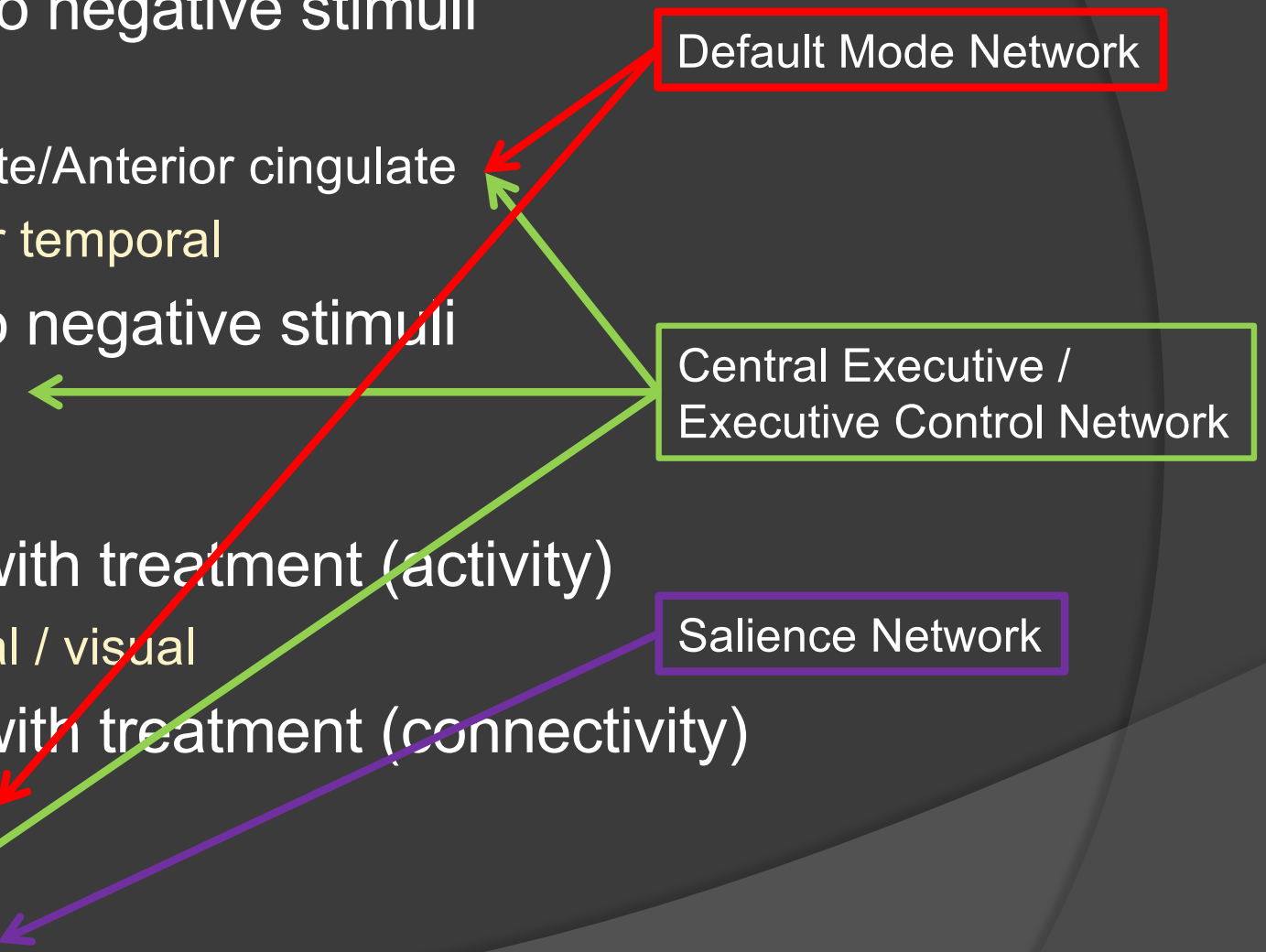


Significant overlap of drug and placebo responses fit within placebo response models

Evans, et al.

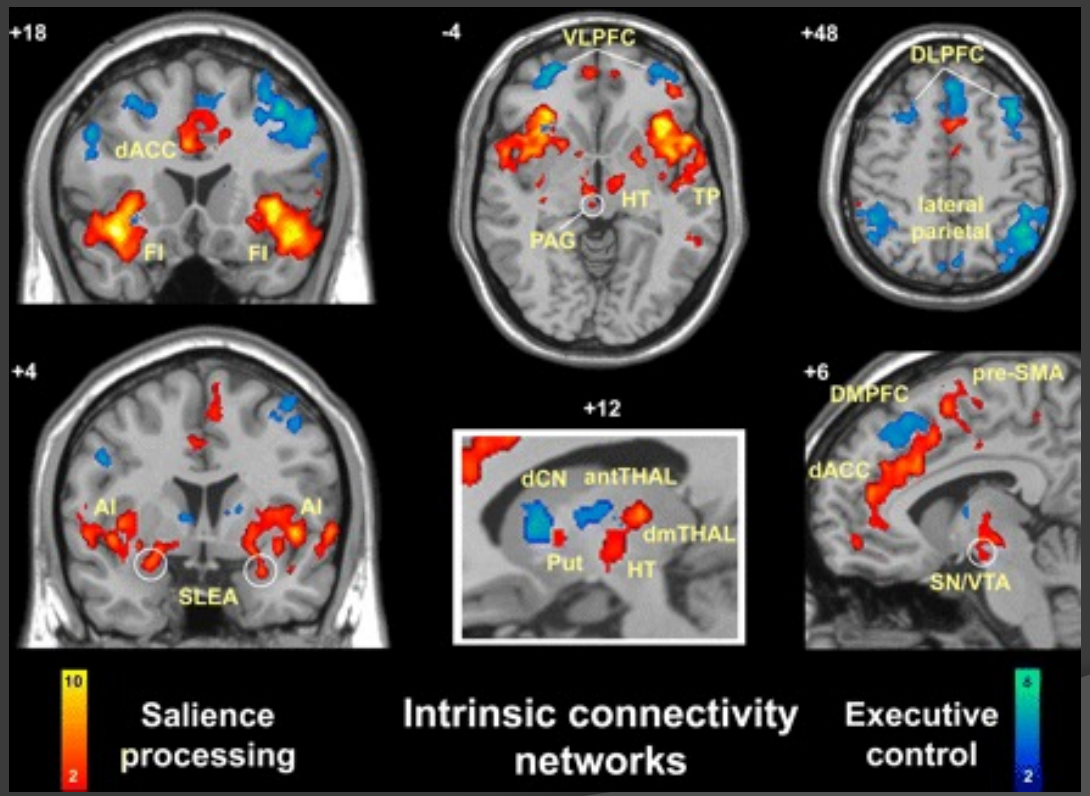
What do these results tell us?

- Hyperactivity to negative stimuli
  - Amygdala
  - Dorsal cingulate/Anterior cingulate
  - Insula/superior temporal
- Hypoactivity to negative stimuli
  - DLPFC
  - Striatum
- Associations with treatment (activity)
  - Middle occipital / visual
- Associations with treatment (connectivity)
  - Hippocampus
  - DLPFC
  - Insula



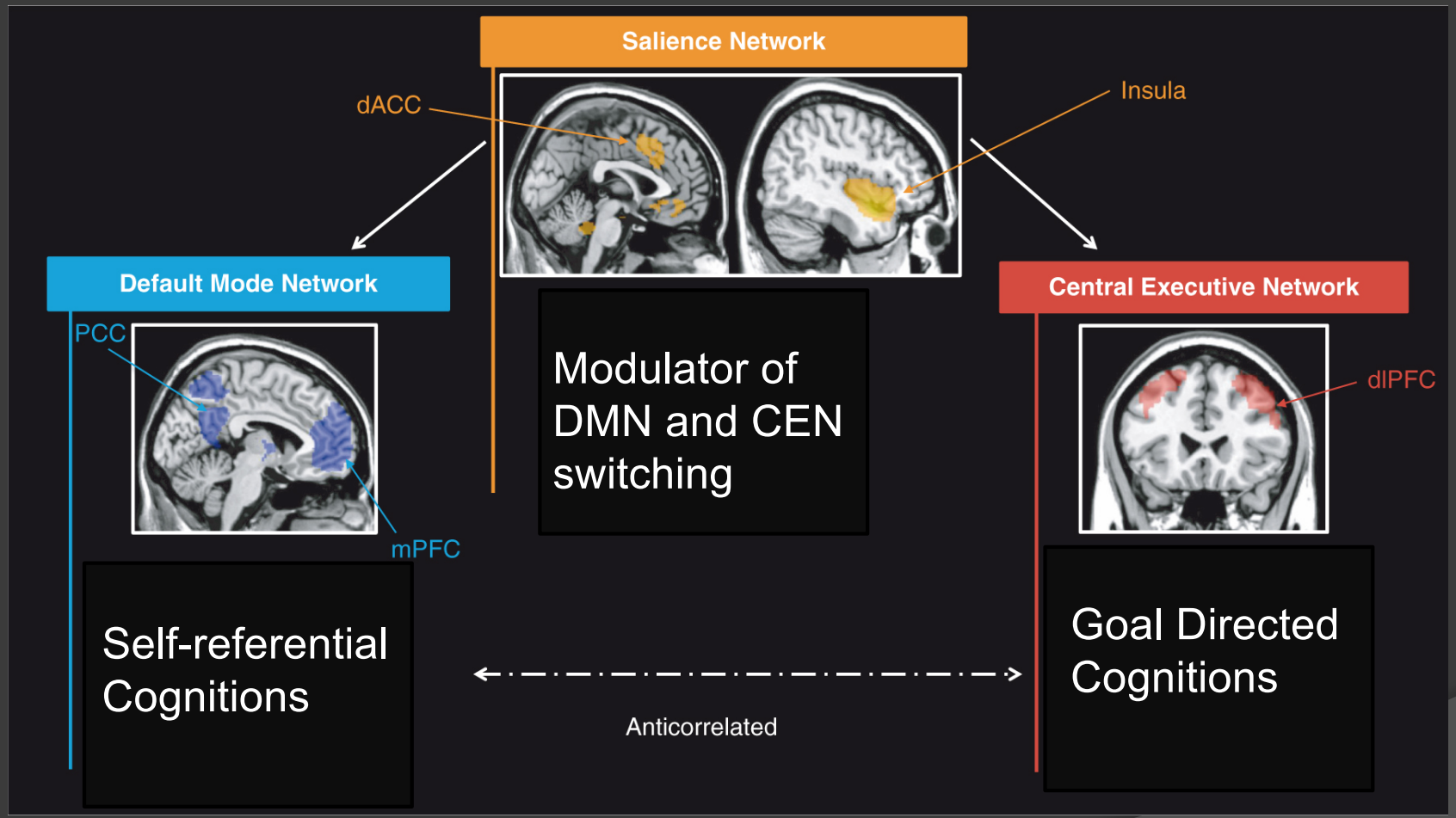
Resting State Networks

- Default Mode Network
- Salience Network
- Executive Control Network



Seeley, et al. (2007) J Neurosci 27(9):2349-2356

Triple Network Model



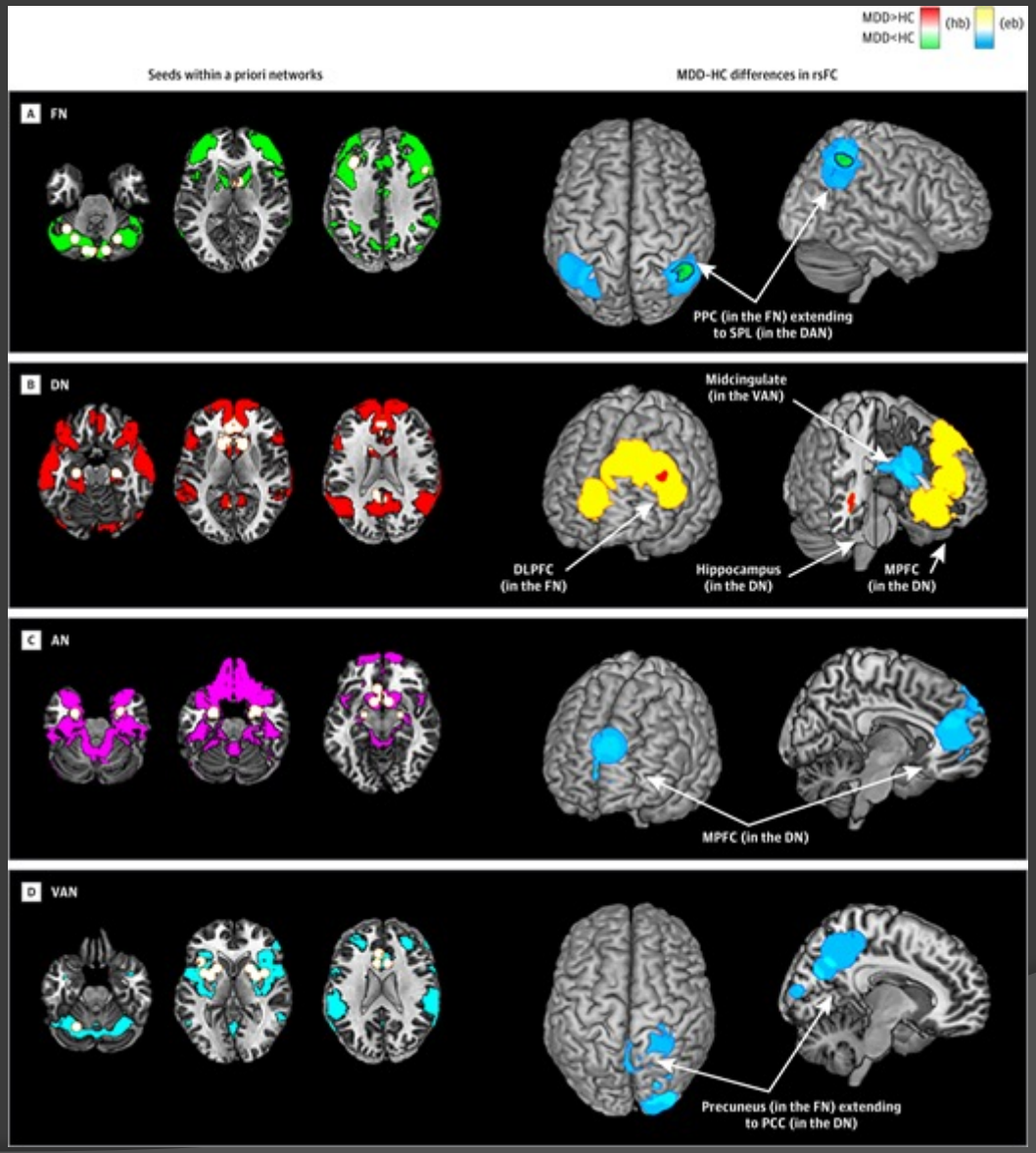
MDD and the Resting State: Meta-analysis, 25 studies

Central Executive

Default Mode

Affective

Salience



↓ Superior Parietal (SN)

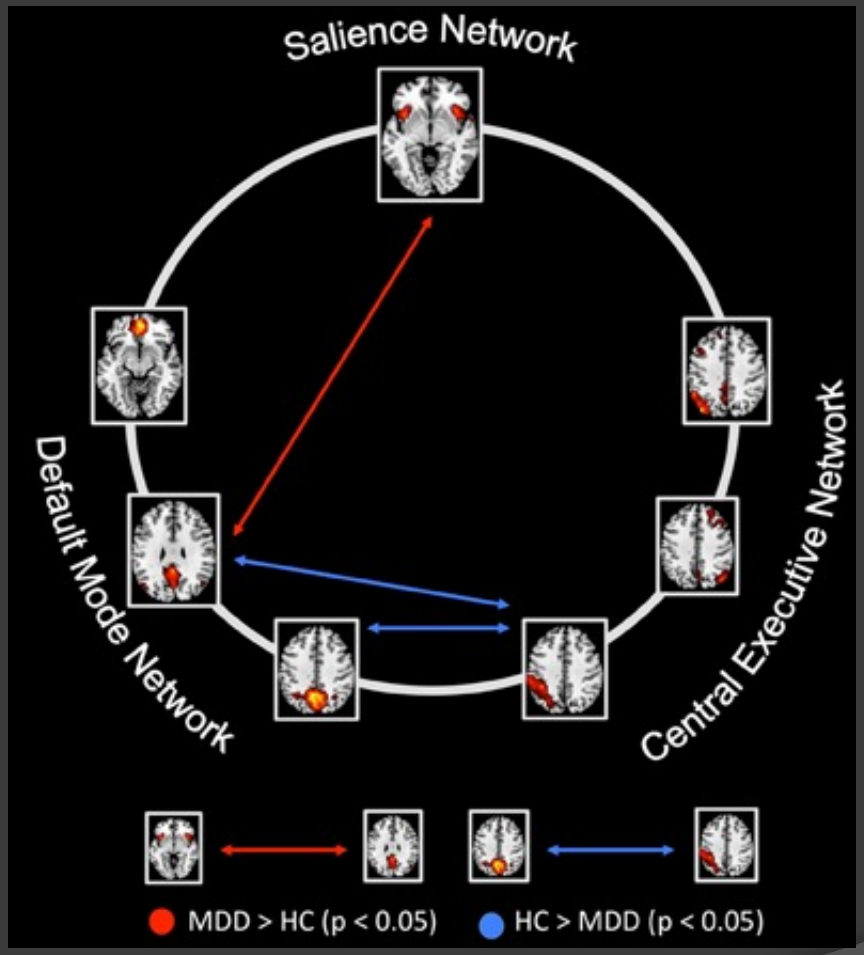
↑ DLPFC (CEN)

↓ dACC (SN)

↓ PCC (DMN)

Kaiser, et al. (2015) JAMA Psychiatry 72(6):603-611

Triple Network Model



Manoliu, et al. (2014) Frontiers in Human Neurosci vol 7

What isn't known

- How does treatment affect the interplay between these networks?
- Are there dynamic changes in the relationship between these networks?
- Are there fundamental differences in network function at a neuronal level?

Conclusions

- Mood disorders are frequently disabling, but poorly understood and ineffectively treated
- New models are emerging, such as the triple network model, which may be significant in understanding brain function in mood disorders
- Translation of these models into new drug targets is not obvious
- Full understanding will likely involve multimodality approaches, integrating structure, function and other diverse modalities

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