Neurocircuitry, meditation, and mind-wandering: Distinct fMRI connectivity approaches contribute to biological understandings of conscious thought

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Overview

- **Objective:** to understand how meditative practices facilitate changes in neurocircuitry with implications for ongoing conscious thought.
- **Approach:** compare methods of fMRI connectivity analysis across resting and focused-attention mental states.
  - Study 1: Examined how meditation alters large-scale brain networks *in vivo*
  - Study 2: Explores associations between affect dynamics, attention, and resting state connectivity as a function of MBSR.

What is internally-directed cognition?

- Refers to stimulus-independent thought
- May occur with or without intention
- The nature of internally-directed cognition is directly implicated in psychopathology
- Observing internal thought processes is one of the directives of mindfulness and meditation

Examples of internally-directed cognition

Mind-wandering	Problem-solving	Rumination
Prospection	Mindful Awareness	Dreaming

Measuring the dynamics of internally-directed cognition

- Ecological Momentary Assessment (EMA): a method for measuring the dynamics of ongoing cognition
- How does attention to internal cognition alter the trajectory of moment-to-moment emotions?

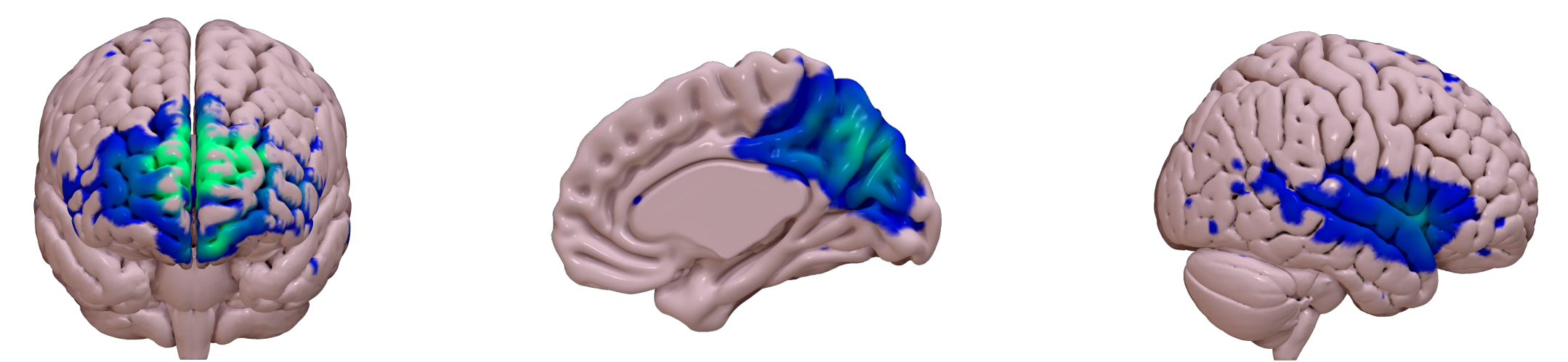| Dynamic Index	Definition
Affective Instability (AI)	A feature of emotional trajectory characterized by the amplitude of moment-to-moment fluctuations in positive/negative affect

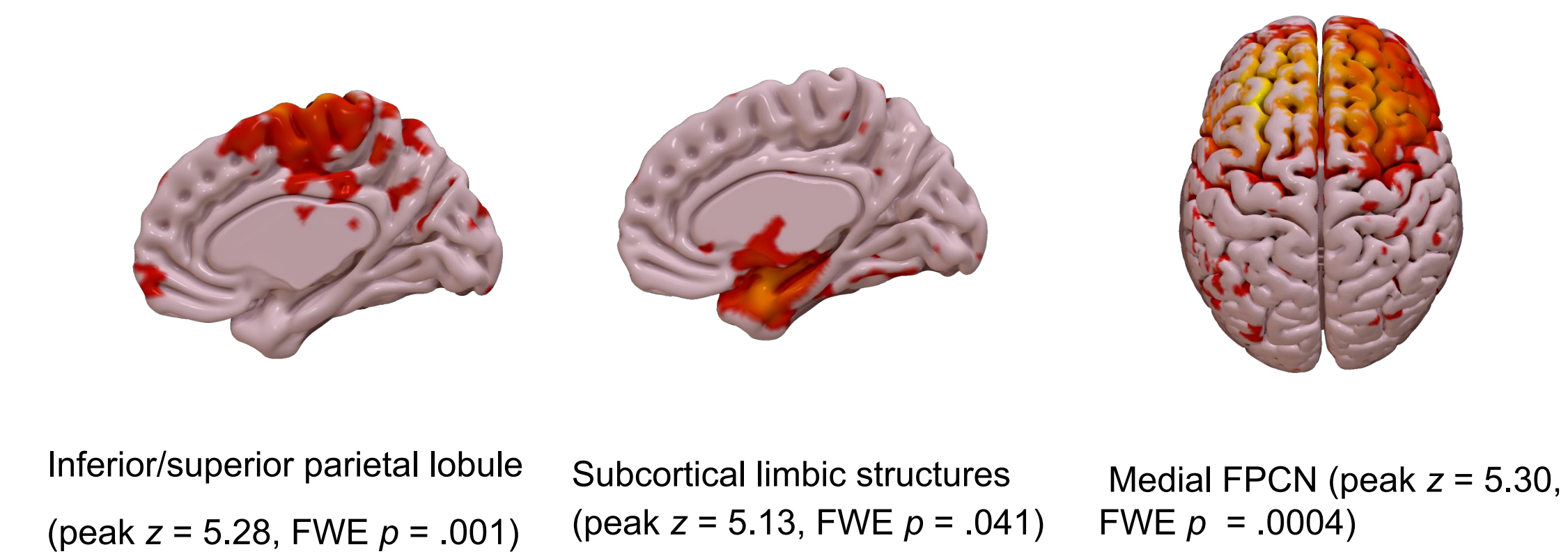| Calculation	Clinical Relevance
Root mean of squared differences in successive momentary affect ratings (RMSSD)	High AI is reliably associated with poor mental health, as well as mood-, personality-, and attention-related disorders
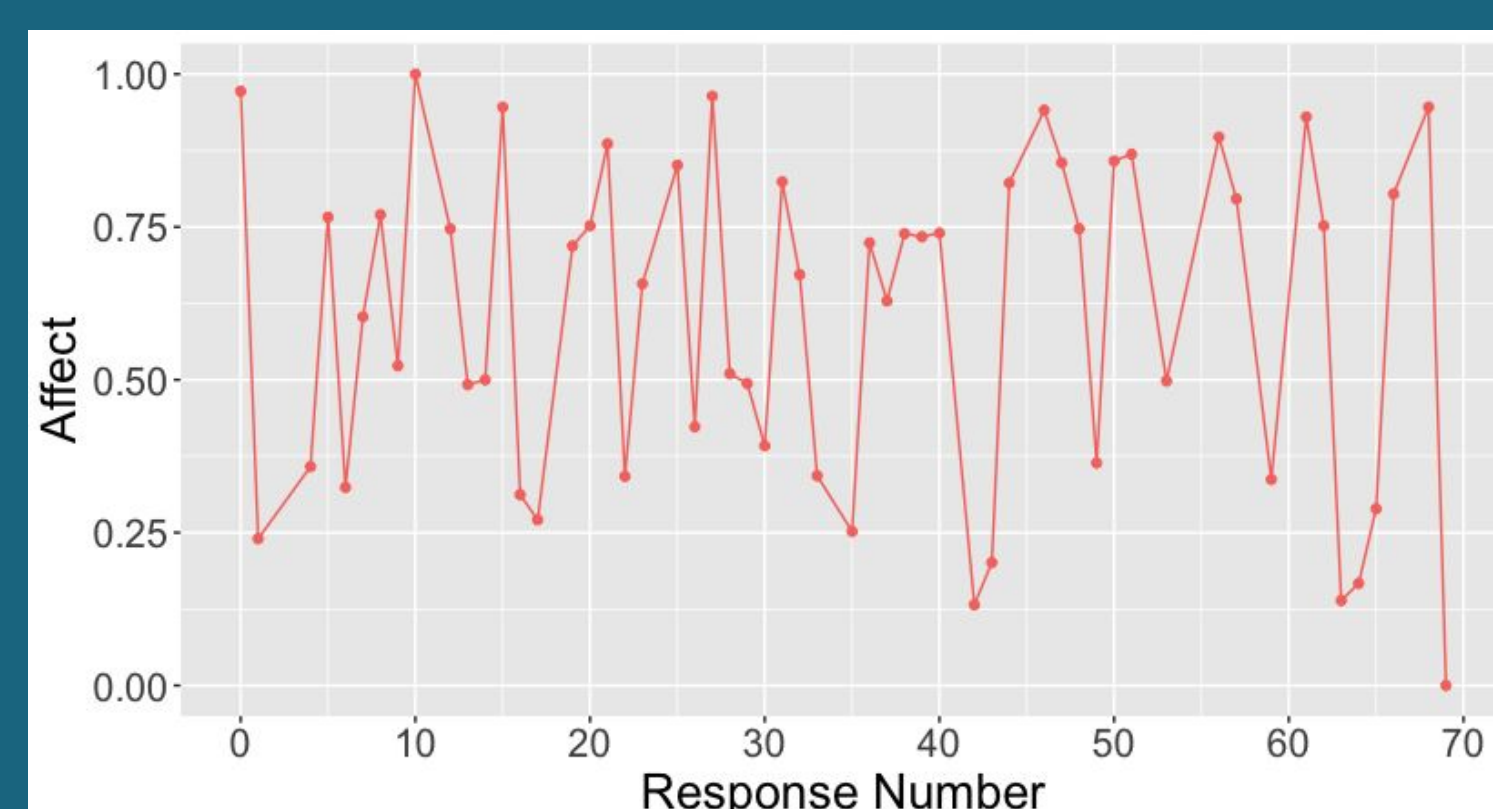
Participant with high emotional instability

Study 1. Measuring mindful brain states: Group independent component analysis

- **Aim:** to explore how first time exposure to mindfulness alters large-scale networks
- **Methods:** fMRI data was collected while engaging in an 8-minute focused attention meditation ($n = 50$) or relaxation instruction ($n = 50$) (control)
- **Results:** Findings suggested that mindfulness elicited changes in large-scale networks associated with internal cognition, executive functioning, and somatosensory awareness

Inferior/superior parietal lobule (peak $z = 5.28$, FWE $p = .001$)

Subcortical limbic structures (peak $z = 5.13$, FWE $p = .041$)

Medial FPCN (peak $z = 5.30$, FWE $p = .0004$)

Anterior medial PFC (peak $z = 5.20$, FWE $p = .015$)

PCC/precuneus (peak $z = 6.96$, FWE $p = .0002$)

Parahippocampal cortex (peak $z = 5.57$, FWE $p = .002$)

Relative to relaxation (control), mindfulness instruction increased intra-network connectivity within components of the Frontoparietal Control Network and Salience Network

Compared to relaxation (control), mindfulness instruction reduced functional coherence within the Default Mode Network
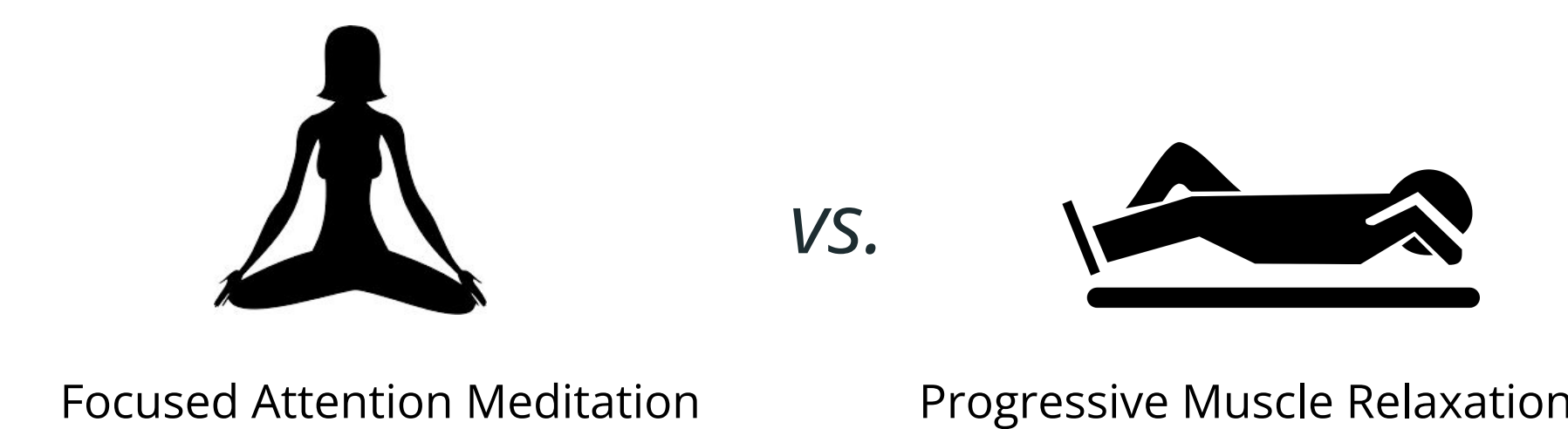
Focused Attention Meditation

vs.

Progressive Muscle Relaxation

Study 2. Relating internally-directed cognition to brain-based mechanisms: A graph theory approach

Research questions:
- Is there an association between emotion and attention dynamics as measured through ecological momentary assessment?
- How does resting state functional connectivity relate to affect instability?
- Can resting state functional connectivity indices determine who responds to mindfulness-based interventions?

Correlation between Attention and Emotion Instability

While there was no relationship between emotion instability and attention instability at baseline, a significant, positive relationship emerged following MBSR training, $F = .16$, $p = .007$.

What is graph theory?
- Graph theory is a mathematical approach to characterizing the properties of brain networks
- In graph theory, networks are defined by nodes (i.e., parcellated regions) and edges (i.e., functional connections between nodes).
- Some graph theory indices include: participant coefficient (PC), degree, within-modulate degree (WMD), and **modularity**
- **Modularity** is the extent to which brain sub-networks are segregated (vs. integrated) from other sub-networks
- Brain network modularity has been linked to **intervention-related gains.**.
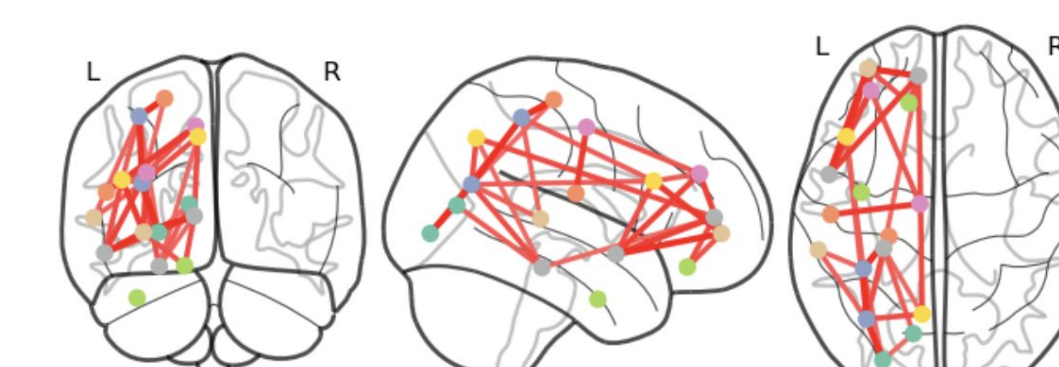
Representation of nodes and edges in a resting state time series

Emotion Instability Post-Intervention
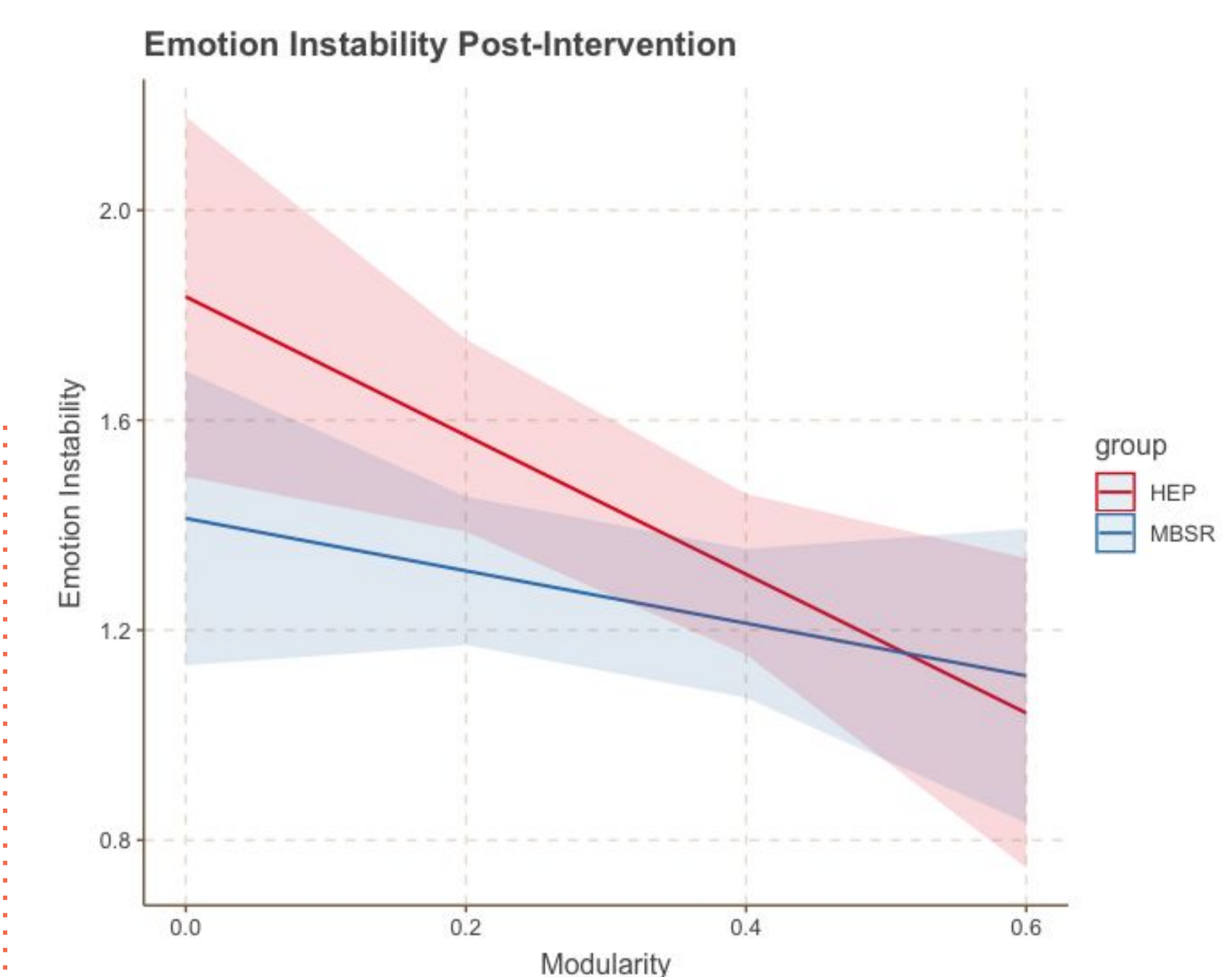
- At post-intervention, emotion instability was highest in those with low modularity, $F = -1.32$, p = .008
- The effect of modularity on emotion instability was less pronounced in the MBSR group compared to the active control intervention (HEP), $F = -.422$, $p = .042$.
- Accordingly, those with lower baseline modularity showed greater benefit from the MBSR intervention compared to the active control intervention (HEP), $F = -1.322$, $p = .025$.

Comparison to other network-based indices (Rahrig et al., 2022)

- A recent meta-analysis examined **seed-based resting-state functional connectivity** changes resulting from standard mindfulness training

Posterior cingulate cortex–seeded connectivity localized to the dorsal anterior cingulate
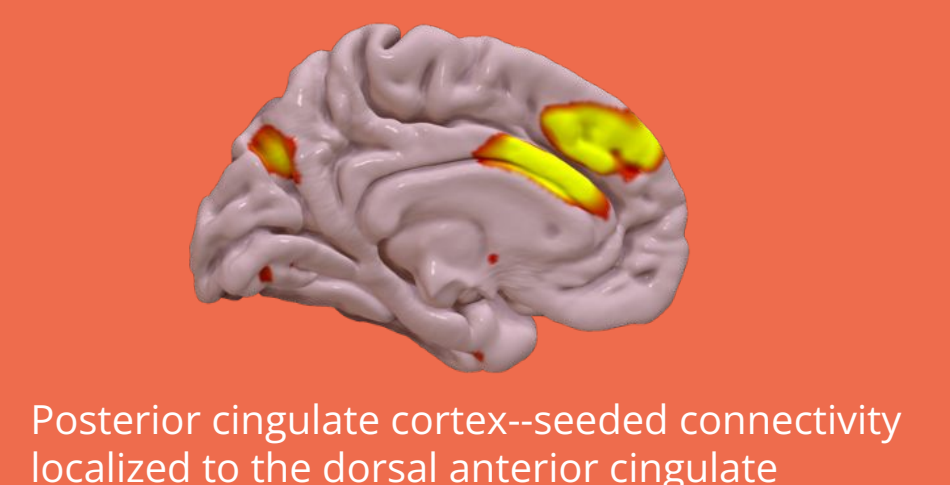
- Results suggested that mindfulness-based interventions increased cross-network connectivity between the Salience Network (SN) and Default Mode Network (DMN).

Outstanding Questions

Neuroimaging
- How can dynamic resting state functional connectivity approaches contribute to our understanding of ongoing conscious thought?
- Can neural signatures of first-time exposure to meditation be used to predict outcomes of long-term meditation training?

Phenomenology
- What is the optimal sampling resolution for measuring dynamic internally-directed cognitions? What is the minimally sufficient sampling rate?
- What approaches can we use to capture context as it occurs in daily life?

Collective well-being
- Are the network-based indices described here invariant across different populations?
- How can we begin to relate brain networks to environmental systems (i.e., social networks)?
- How can we leverage knowledge of internally directed cognition to promote prosocial behavior?

Acknowledgements

View **Appendix** for further information on Study 1 and 2 methods and results