Neuroscientific Perspectives

Mindfulness Meditation & the Default Mode Network (DMN)

In an important study, Malia Mason of Columbia University wrote,[1]

> What does the mind do in the absence of external demands for thought? Is it essentially blank, springing into action only when some task requires attention? Everyday experience challenges this account of mental life. In the absence of a task that requires deliberative processing, the mind generally tends to wander, flitting from one thought to the next with fluidity and ease. Given the ubiquitous nature of this phenomenon, it has been suggested that mind-wandering constitutes a psychological baseline from which people depart when attention is required elsewhere and to which they return when tasks no longer require conscious supervision.

She and her colleagues proceeded to demonstrate that mind wandering is associated with increased activation in the 'default mode network' – brain regions including the posterior cingulate and the medial prefrontal cortex. The researchers were able to correlate increased activity in these brain regions with individuals' reports regarding their own mind wandering.

The DMN is a clear target for meditative practice. Mindfulness is often considered an attentional training. Preliminary but intriguing data suggest that mindfulness practice may target the DMN and change its functioning. Judson Brewer and his colleagues did research in 2011 on this subject. They wrote:[2]

> Mind-wandering is not only a common activity present in roughly 50% of our awake life, but is also associated with lower levels of happiness. Moreover, mind-wandering is known to correlate with neural activity in a network of brain areas that support self-referential processing, known as the default mode network (DMN). This network has been associated with processes ranging from attentional lapses to anxiety to clinical disorders, such as attention-deficit hyperactivity disorder (ADHD) and Alzheimer's Disease. Given the interrelationship between the DMN, mind-wandering, and unhappiness, a question arises: Is it possible to change this default mode into one that is more present-centered, and possibly happier? One potential way to reduce DMN activity is through the practice of mindfulness meditation.

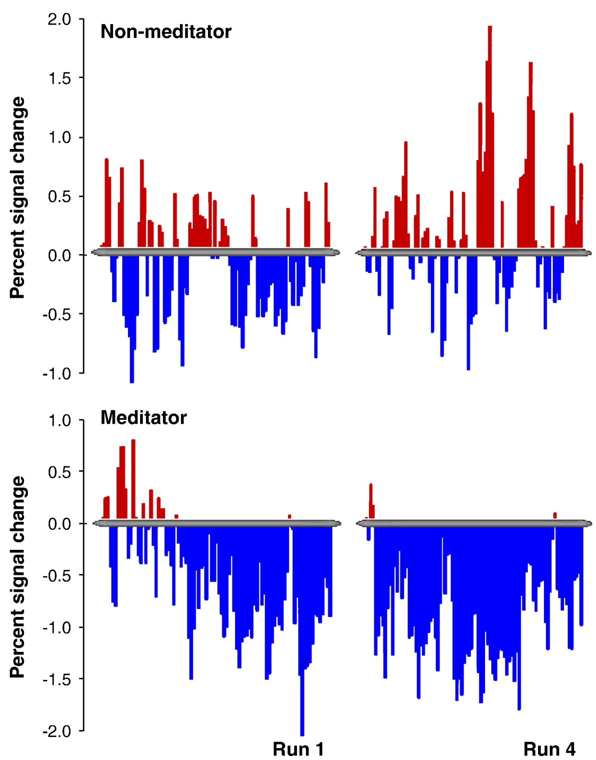
The study found that:

1. Experienced meditators had less activity in the DMN regions during meditation compared with meditation-naïve participants.
2. Meditators had different functional connectivity between the DMN and other regions of the brain.
3. Those differences were evident both when they were meditating and when they we not meditating.

The authors conclude that “The consistency of connectivity across both meditation and baseline periods suggests that meditation practice may transform the resting-state experience into one that resembles a meditative state, and as such, is a more present-centered default mode.”

The same research group has also explored using functional magnetic resonance imaging to provide real-time feedback to practitioners to see if they are able to deliberately regulate the activity in the posterior cingulate[3]. Their study was preliminary, but had intriguing results. The graph below shows activation in the posterior cingulate – a region associated with mind wandering and self-referential thinking. Red means there was an increase in activation, blue means a decrease. As you can see below, the meditator was better at reducing activation in the posterior cingulate, compared with the non-meditator.

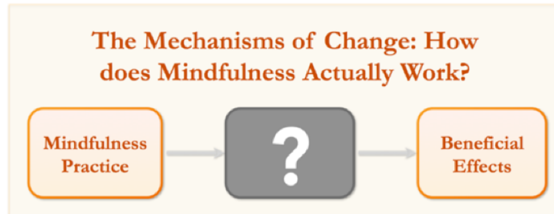
One participant said, “I noticed... that the more I relaxed and tried to stop doing anything, the bluer it went.”



Real-time feedback from the posterior cingulate cortex during focused attention meditation. Mean percent signal change from the PCC during focused attention with real-time feedback is shown from an example non-meditator (top) and meditator (bottom) for run 1 and run 4.

Does Meditation Change the Structure of the Brain?

Numerous clinical benefits have been documented for mindfulness and meditation practices. When there's evidence for the effectiveness of a practice, the next question is, "Ok, but how does it work?" Understanding the "mechanism of change" – how it works – is an important scientific question. When we can understand how something works, it gives more control to distill the "active ingredients" from what's not beneficial or even harmful, like the side effects of a medication. It may even help to make the intervention – in this case, mindfulness – more powerful.



The dominant view within neuroscience is that changes in behavior, cognition or emotion always involve associated neurobiological changes. One implication of this framework is that the benefits of mindfulness practice must somehow be related to changes in the function and/or structure of the brain.

An important study[4] was recently published by Christoff and her colleagues. In that article, she asked the question, *Is meditation associated with altered brain structure?* This research is significant because it mathematically synthesized the findings from numerous prior studies. This kind of synthesis is known as a meta-analysis. The findings from a single study are always shaped by the particular subjects included in that study and other features of the research design, but aggregating many studies in a meta-analysis has the advantage of examining a specific question across different study samples and research designs.

The studies cited above examined the functioning of the brain – increased or decreased activity. Christoff's study examined brain *morphology*, which is the study of structure, shape and composition of the brain. Scientists are interested in morphology because there is a link between morphology and the capacities of the brain. This is important –if brain changes weren't related to behavior and subjective well-being, then we wouldn't care so much about the brain!

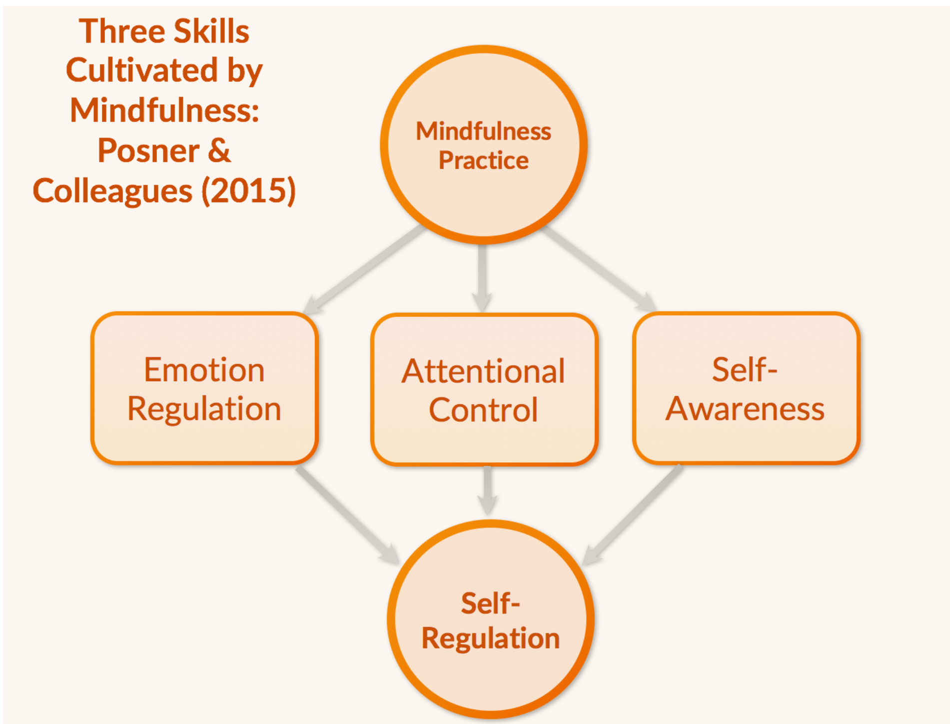
The authors approached the subject cautiously and were 'conservative' in their work: they wanted to be careful not to *overestimate* the effects of meditation on the brain. Despite this cautious approach, the researchers identified several brain regions that evidenced structural changes resulting from meditation practice. These areas include rostrolateral prefrontal cortex, sensory cortices and insular cortex, hippocampus, anterior and mid-cingulate, orbitofrontal cortex, superior longitudinal fasciculus and the corpus callosum.

Surveying these brain regions, Christoff notes that meditation appears to engage high order brain regions. The authors speculate how changes in the insula might be related to superior bodily and emotional awareness, and changes in the orbitofrontal cortex could plausibly provide meditators more freedom to evaluate the present situation rather than relying exclusively on prior learned associations. Hippocampal degeneration has been found in a number of psychiatric and neurologic diseases. The association between meditation and hippocampal volume could represent a mechanism whereby meditation alleviates symptoms of depression and anxiety and helps manage stress.

Now, there's an important caveat here. As we say, *correlation is not causation*. That means that while two things can be associated (meditation & brain changes) it does not necessarily mean that meditation *causes* brain changes. Here is what the authors write: "Evidence for meditation practice as the causative factor in structural brain change remains tenuous, and much further work is needed before such a relationship is either established or disconfirmed…Any firm claims about whether meditation truly causes differences in brain structure are still premature. That said, we do find that meditation is consistently associated with changes in brain morphology." Clearly, there is more work to be done and so much more to be learned.

Attentional Control, Emotion Regulation, Self-Awareness & the Brain: A Model of Change from Tang, Holzel & Posner

In a prominent brain science journal, *Nature Reviews Neuroscience*, Posner[5] and colleagues described three mechanisms by which mindfulness meditation might support self-regulation: Attentional control, emotion regulation and self-awareness. For each of these mechanisms, they discuss the evidence suggesting that particular brain changes underlie the benefits of mindfulness. Below, the model is depicted:



Regarding *attention control*, the authors highlight ways in which mindfulness may be linked to attention-related brain changes:

- The brain region to which the effects of mindfulness training on attention is most consistently linked is the anterior cingulate cortex (ACC).
- The ACC enables executive attention by detecting the presence of conflicts emerging from incompatible streams of information
- Cross-sectional studies have reported enhanced activation of regions of the ACC in experienced meditators.
- Greater activation of the ventral and/or rostral ACC during the resting state following 5 days of [mindfulness training] was also found in an actively controlled, randomized, longitudinal study.

- Structural MRI data suggest that mindfulness meditation might be associated with greater cortical thickness and might lead to enhanced white-matter integrity in the ACC.

Brain changes linking *emotion regulation* and mindfulness have also been detected. The authors highlight these points:

- The hypothesis that drives many studies is that mindful emotion regulation works by strengthening prefrontal cognitive control mechanisms and thus downregulates activity in regions relevant to affect processing, such as the amygdala.
- Present-moment awareness and non-judgmental acceptance through mindfulness meditation are thought to be crucial in promoting cognitive control because they increase sensitivity to emotional cues that help to signal the need for control.
- A frequently reported finding is that mindfulness practice leads to (or is associated with) a diminished activation of the amygdala in response to emotional stimuli during mindful states as well as in a resting state, suggesting a decrease in emotional arousal.
- Some studies suggest differences in how the brains of new versus experienced meditators. Neuroimaging studies of improved pain processing through mindfulness meditation have also pointed to expertise-related differences in the extent of cognitive control over sensory experience.
    - Meditation beginners showed increased activity in areas involved in the cognitive regulation of nociceptive processing (the ACC and anterior insula) and areas involved in reframing the evaluation of stimuli (the orbitofrontal cortex), along with reduced activation in the primary somatosensory cortex.
    - Whereas meditation experts were characterized by decreased activation in dorsolateral and ventrolateral PFC regions and enhancements in primary pain processing regions (the insula, somatosensory cortex and thalamus) compared with controls in two cross-sectional studies.
- Brain regions involved in motivation and reward processing also show functional alterations that are related to mindfulness training, such as stronger activity of the putamen and caudate during a resting state following mindfulness training and lower activation in the caudate nucleus during reward anticipation in experienced meditators.

Lastly, Posner and colleagues have underscored changes in the neural correlates of *self-awareness*:

- fMRI studies have investigated activity in the DMN in association with mindfulness practice. Regions of the DMN (the medial prefrontal cortex and posterior cingulate cortex) showed relatively little activity in meditators compared to controls across different types of meditation, which has been interpreted as indicating diminished self-referential processing.

- Functional connectivity analysis revealed stronger coupling in experienced meditators between the posterior cingulate, dorsal anterior cingulate and dorsolateral prefrontal cortex, both at baseline and during meditation, which was interpreted as indicating increased cognitive control over the function of the DMN.
- Increased functional connectivity was also found between DMN regions and the ventromedial prefrontal cortex in participants with more compared to less meditation experience.
- Multiple studies have shown the insula to be implicated in mindfulness meditation: it shows stronger activation during compassion meditation and following mindfulness training, and has greater cortical thickness in experienced meditators.
- Given its known role in awareness, it is conceivable that enhanced insula activity in meditators might represent the amplified awareness of present-moment experience.

The authors conclude by reflecting on the early state of the data, the limits of what are known and the considerable promise of mindfulness. They write "Knowledge of the mechanisms that underlie the effects of meditation is therefore still in its infancy. However, there is emerging evidence that mindfulness meditation might cause neuroplastic changes in the structure and function of brain regions involved in regulation of attention, emotion and self-awareness… If supported by rigorous research studies, the practice of mindfulness meditation might be promising for the treatment of clinical disorders and might facilitate the cultivation of a healthy mind and increased well-being."

Affect Labeling, Mindfulness & Neuroimaging

One way to manage intense emotion is to put word to our feelings. Sometimes, just naming what is happening in the moment, has a soothing effect. Perhaps this partially explains why talking to a friend about a struggle can be so useful. What about naming our emotions to ourselves? In the scientific literature, this is called 'affect labeling.'

Affect labeling is a vital part of mindfulness practice. Initially, we might attend primarily to the breath, but we often expand the focus of mindfulness to include emotional states. We can learn to mentally label the particular emotion as it is arising. There is evidence that this practice supports healthy emotion regulation.

Neuroimaging studies have shown that labeling affective or emotional stimuli activates a region of the prefrontal cortex (specifically, the right ventrolateral prefrontal cortex) while diminishing amygdala activity.[6]

A study by Creswell[7] provided the "first neural evidence for associations among mindfulness, affect labeling, and improved neural affect regulation." Their study found that:

- Trait mindfulness was associated with greater widespread prefrontal (PFC) activation and attenuated amygdala responses during affect labeling.
- Participants high in mindfulness had strong inverse relationships between activity in these PFC regions and the right amygdala, whereas participants low in mindfulness did not show these effects.
- Mindfulness may be associated with enhancements in these neural affect regulation pathways.
- The most robust finding indicated a strong positive association between dispositional mindfulness and activation of the MPFC, a neural area that has been found to be activated during self-relevant tasks, such as monitoring one's own emotional state.
- These findings make an important contribution to the existing mindfulness literature by suggesting one neurocognitive pathway that may link mindfulness meditation practices with reductions in negative affect, mood disturbance, and physical symptoms across a number of patient populations.

Daniel Siegel's Model

Daniel Siegel has highlighted nine aspects of well-being that may be impacted by mindfulness practice. He writes[8,9]

> Mindful awareness has been demonstrated to alter brain function, mental activity, and interpersonal relationships toward well-being. This article hypothesizes that mindful awareness promotes these positive changes through a proposed ''internal attunement'' that catalyzes the fundamental process of integration. Integration—the linkage of differentiated elements of a system—leads to the flexible, adaptive, and coherent flow of energy and information in the brain, the mind, and relationships. This coherent flow enables the individual to attain an intentionally established state of mindfulness with practice in the moment and creates the experiential substrate for developing mindful traits in daily life. By freeing the individual from the top–down associations of memory, mindfulness also promotes an emergent sense of a vital and resilient self.

Here are the nine functions critically involving the prefrontal cortex that may be impacted by mindfulness practice. This work is theoretical and awaits more data, but it has provided a basis for thinking and talking about mindfulness and the brain.

1. Bodily regulation – a state of coordination and balance between the brakes and accelerator of the nervous system. Too much "braking" leads to under-arousal, sleepiness, rigidity; too much "acceleration" results in chaotic energy. When our bodies are regulated, our level of alertness and energy is appropriate to the setting.
2. Insight – "self-knowing awareness." Our sense of ourselves, creating a coherent life story by connecting present awareness, our life story, and images of the future. This is key to building positive social connections.
3. Attuned communication with others – "resonance." This involves the coordination of input from another's mind with the activity of our own: receiving signals from another and allowing our state to be influenced by theirs. This leads to the other person's experience of "feeling felt," of being understood. When we become more "tuned in" to ourselves, the ability to tune in to others is enhanced.
4. Empathy – builds upon our insight into ourselves, and upon attuned communication with others. Empathy enables us to "see from the stance of another person's mind," imagining others' reality and perspective. Our brains are designed to enable us to imagine what might be going on inside someone else, and this ability can be cultivated.
5. Emotional balance or regulation – emotional experience that is appropriately activated, so life has vitality and meaning. When emotions are overactive, we become overwhelmed and emotionally chaotic; when emotions are not active, we may experience stagnation or a sense that our life is not meaningful.
6. Fear modulation – our ability to calm and soothe, and even unlearn, our own fears.

7. Response flexibility – the capacity to pause before taking action; being able to consider a variety of possible options, and to choose among them; the flexibility to move beyond habitual response, with a sense of spaciousness of mind and possibility.
8. Intuition – access to awareness of the wisdom of the body, particularly the complex neuronal webs around the viscera, the hollow organs including the heart and intestines. These areas constitute a separate "brain" that processes information and experience, learns, and makes decisions. This intuitive intelligence can inform, and influence, our reasoning.
9. Morality – taking into consideration the larger picture, imagining and acting on what is best for the larger group rather than just for ourselves.

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