How Mindfulness Benefits The Brain

One of the outstanding aspects of the ancient Indian yogic techniques is the applicability of this sort of training with contemporary neuroscientific research. The concepts and disciplines found in Buddhist suttas and commentaries are particularly suitable for this sort of investigation. The intention of these notes and the accompanying discussion is to review some significant discoveries regarding changes in the neuronal structures of the brain that are manifested through mindfulness of breathing meditation that are acknowledged by individual through centuries of Buddhist meditation practices to be of great benefit psychologically, socially and spiritually.

This review cannot completely cover the extensive research that has occurred since the end of WWII and increased significantly since the early 1970’s when, after the social disruption of the Vietnam war was reduced sufficiently in order for Westerners who were spiritually inclined and trained in neuroscience to receive formal mindfulness meditation training in Southeast Asia.

Two of these significant meditators/scientists are Richie Davidson (b. 1951) and Daniel Goleman (b. 1946). Both have known each other since their college days and have over 40 years of meditation training. Davidson does research at the University of Wisconsin in Madison at a facility that is acknowledged as a leader in cutting-edge neuroscientific research. Goleman is a prolific author and educator whose work has had a significant impact in bridging the disciplines of mental health and spirituality. They collaborated in writing “Altered Traits—Science Reveals How Meditation Changes Your Mind, Brain, and Body”, published in 2017, that reviews their significant role in promoting the intersection between Buddhism and modern scientific research.

Davidson’s research initially investigated how the neurological systems in the brain operate when a person shows symptoms of psychiatric disorders such as depression and anxiety. He met the Dalai Lama at an early meeting of the Mind and Life Institute, who asked Davidson a very impactful question: If neuroscience can discover the structures of the brain associated with psychiatric disorders, can the same research investigate what changes in the brain when someone trains the mind through meditation practices? This question inspired a whole new area of neuroscientific research; some of the results of that research will be reviewed in these notes.

First, some basic descriptions of relevant areas of the brain and their functions (note that these areas are bilateral, that is, there is a right and left hemisphere, and each hemisphere has a different functional characteristic):

**Prefrontal (PFC) or preorbital cortex**: This area is in the forehead, and there are several areas that are associated with cognitive functions and affect/emotion regulation. There are extensive connections between the PFC and the areas of the brain associated with emotional and behavioral processes called the limbic system. It functions as an executive “top-down” regulator of other “bottom-up” processes activated in other areas of the brain. .



**Limbic system**: This area is in the mid-sections of the brain, just beneath the cortex and behind the PFC. There are several clusters of neuronal nuclei in this area that are affected by the practice of mindfulness meditation. Relevant areas include the amygdala, the hippocampus, and the nucleus accumbens. The amygdala processes affective responses, that is, emotions and the impulsive reactivity associated with emotions. The hippocampus, located just beside the amygdala, processes the flow that integrates initial sensory input through the limbic system—the amygdala and nucleus accumbens are the most important, related to the benefits of mindfulness meditation training—and through the association cortex where long-term memory processes occur. The nucleus accumbens is located just in front of the amygdala and hippocampus. It functions to orient the body through a reward-seeking process, either to seek pleasure or avoid pain. These three areas are tightly integrated in their functioning, with many neuronal interconnections bridging between them. In the image below, NAc is the nucleus accumbens, AMY is the amygdala and HIPP is the hippocampus. GABA is Gamma aminobutyric acid, a common neurotransmitter, as are Glutamine and Dopamine.



An article entitled “Mechanisms of Mindfulness Meditation” in Wikipedia focuses on how mindfulness affects various functions in the brain and includes references to the executive processes—the “top-down” regulatory function. Here is the URL: <https://en.wikipedia.org/wiki/Mechanisms_of_mindfulness_meditation>. I have copied contributions related to this topic:

**Attention regulation** is the task of focusing attention on an object, acknowledging any distractions, and then returning focus back to the object. Some evidence for mechanisms responsible for attention regulation during mindfulness meditation are shown below.

* Mindfulness meditators showed greater activation of rostral [anterior cingulate cortex](https://en.wikipedia.org/wiki/Anterior_cingulate_cortex) (ACC) and dorsal [medial prefrontal cortex](https://en.wikipedia.org/wiki/Medial_prefrontal_cortex) (MPFC). This suggests that meditators have a stronger processing of conflict/distraction and are more engaged in emotional regulation. However, as the meditators become more efficient at focused attention, regulation becomes unnecessary and consequentially decreases activation of ACC in the long term.
* The cortical thickness in the dorsal ACC was also found to be greater in the [gray matter](https://en.wikipedia.org/wiki/Gray_matter) of experienced meditators.
* There is an increased frontal [midline theta rhythm](https://en.wikipedia.org/w/index.php?title=Midline_theta_rhythm&action=edit&redlink=1), which is related to attention demanding tasks and is believed to be indicative of ACC activation. High midline theta rhythm has been associated with lowest anxiety score in the Manifest Anxiety Scale (MAS), the highest score in the extrovertive scale of the Maudsley Personality Inventory (MPI) and the lowest score in the neurotic scale of MPI.

The ACC detects conflicting information coming from distractions. When a person is presented with a conflicting stimulus, the brain initially processes the stimulus incorrectly. This is known as [error-related negativity](https://en.wikipedia.org/wiki/Error-related_negativity) (ERN). Before the ERN reaches a [threshold](https://en.wikipedia.org/wiki/Sensory_threshold), the correct conflict is detected by the [frontocentral N2](https://en.wikipedia.org/w/index.php?title=Frontocentral_N2&action=edit&redlink=1). After the correction, the rostral ACC is activated and allows for executive attention to the correct stimulus. Therefore, [mindfulness meditation](https://en.wikipedia.org/wiki/Mindfulness_meditation) could potentially be a method for treating [attention](https://en.wikipedia.org/wiki/Attention) related disorders such as [ADHD](https://en.wikipedia.org/wiki/ADHD) and [bipolar disorder](https://en.wikipedia.org/wiki/Bipolar_disorder).

**Body awareness** refers to focusing on an object/task within the body such as breathing. From a qualitative interview with ten mindfulness meditators, some of the following responses were observed: "When I'm walking, I deliberately notice the sensations of my body moving" and "I notice how foods and drinks affect my thoughts, bodily sensations, and emotions”. The two possible mechanisms by which a mindfulness meditator can experience body awareness are discussed below.

* Meditators showed a greater cortical thickness and greater [gray matter](https://en.wikipedia.org/wiki/Gray_matter) concentration in the right anterior [insula](https://en.wikipedia.org/wiki/Insular_cortex).
* On the contrary, subjects who had undergone 8 weeks of mindfulness training showed no significant change in gray matter concentration of the insula, but rather an increase [gray matter](https://en.wikipedia.org/wiki/Gray_matter) concentration of the [temporo-parietal junction](https://en.wikipedia.org/wiki/Temporo-parietal_junction).

The [insula](https://en.wikipedia.org/wiki/Insular_cortex) is responsible for awareness to stimuli and the thickness of its [gray matter](https://en.wikipedia.org/wiki/Gray_matter) correlates to the accuracy and detection of the stimuli by the nervous system. Qualitative evidence suggests that mindfulness meditation impacts body awareness, however this component is not well characterized.

**Emotions** can be regulated cognitively or behaviorally. Cognitive regulation (in terms of mindfulness meditation) means having control over giving attention to a particular stimuli or by changing the response to that stimuli. The cognitive change is achieved through [reappraisal](https://en.wikipedia.org/w/index.php?title=Reappraisal&action=edit&redlink=1) (interpreting the stimulus in a more positive manner) and [extinction](https://en.wikipedia.org/wiki/Extinction_%28psychology%29) (reversing the response to the stimulus). Behavioral regulation refers to inhibiting the expression of certain behaviors in response to a stimulus. Research suggests two main mechanisms for how [mindfulness meditation](https://en.wikipedia.org/wiki/Mindfulness_meditation) influences the emotional response to a stimulus.

* [Mindfulness meditation](https://en.wikipedia.org/wiki/Mindfulness_meditation) regulates emotions via increased activation of the dorso-medial PFC and rostral ACC.
* Increased activation of the ventrolateral PFC can regulate emotion by decreasing the activity of the [amygdala](https://en.wikipedia.org/wiki/Amygdala). This was also predicted by a study that observed the effect of a person's mood/attitude during mindfulness on brain activation.

[Lateral prefrontal cortex](https://en.wikipedia.org/wiki/Lateral_prefrontal_cortex) (lPFC) is important for selective attention while ventral [prefrontal cortex](https://en.wikipedia.org/wiki/Prefrontal_cortex) (vPFC) is involved in inhibiting a response. As noted before, the [anterior cingulate cortex](https://en.wikipedia.org/wiki/Anterior_cingulate_cortex) (ACC) has been noted for maintaining attention to a stimulus. The [amygdala](https://en.wikipedia.org/wiki/Amygdala) is responsible for generating emotions. [Mindfulness meditation](https://en.wikipedia.org/wiki/Mindfulness_meditation) is believed to be able to regulate negative thoughts and decrease emotional reactivity through these regions of the brain. Emotion regulation deficits have been noted in disorders such as [borderline personality disorder](https://en.wikipedia.org/wiki/Borderline_personality_disorder) and [depression](https://en.wikipedia.org/wiki/Depression_%28mood%29). These deficits have been associated with reduced prefrontal activation and increased [amygdala](https://en.wikipedia.org/wiki/Amygdala) activity, which mindfulness meditation might be able to attenuate.

**Pain** is known to activate the following regions of the brain: the [anterior cingulate cortex](https://en.wikipedia.org/wiki/Anterior_cingulate_cortex), anterior/posterior [insula](https://en.wikipedia.org/wiki/Insular_cortex), primary/secondary [somatosensory](https://en.wikipedia.org/wiki/Somatosensory) cortices, and the [thalamus](https://en.wikipedia.org/wiki/Thalamus). Mindfulness meditation may provide several methods by which a person can consciously regulate pain.

* Brown and Jones found that mindfulness meditation decreased pain anticipation in the right parietal cortex and mid-cingulate cortex. Mindfulness meditation also increased the activity of the anterior cingulate cortex (ACC) and ventromedial-prefrontal cortex (vm-PFC). Since the vm-PFC is involved in inhibiting emotional responses to stimuli, anticipation to pain was concluded to be reduced by cognitive and emotional control.
* Another study by Grant revealed that meditators showed greater activation of insula, thalamus, and mid-cingulate cortex while a lower activation of the regions responsible for emotion control (medial-PFC, OFC, and amygdala). Meditators were believed to be in a mental state that allowed them to pay close attention to the sensory input from the stimuli and simultaneously inhibit any appraisal or emotional reactivity.

Brown and Jones found that meditators showed no difference in pain sensitivity but rather the anticipation in pain. However, Grant's research showed that meditators experienced lower sensitivity to pain. These conflicting studies illustrate that the exact mechanism may vary with the expertise level or meditation technique.

**Neuroplasticity** is the dynamic interactive actions that occur in the diverse and complex neural pathways woven into the fabric of the brain. Neurons connect to others “downstream” of neuronal stimulation through dendrites, and the number of dendritic connections increases or decreases depending on how strong and persistent the stimulation of the “upstream” neuron is; the downstream dendrites can connect to ones previously connected, or to other adjacent neurons. These neuronal connections tend to spread out to other associated networks, which might stimulate a part of the brain other than those in the immediate vicinity in broader network arrangement. When these patterned stimulations are repeatedly activated, or the initial stimulus “signal strength” is significantly intense, a phenomenon called:

**Long-Term Potentiation** occurs. In this process the neural pathways become more strongly interconnected, with more dendritic connections between the associated neurons, and it becomes easier to initiate the flow of stimulation through the network. Think of this as how a habit is created, including the ability to recognize a sound, attribute a source, determine whether that source is a threat or not, and create a response, all in a fraction of a second!

**State** is a condition of the mind as the process of identification and action occur. **Trait** is the way a state is embedded into one’s personality so that it becomes a recurring and recognizable pattern. This transition is important in considering how the development of mindfulness from a state to a trait operates—*contemporary research uses these terms regarding a state of mindfulness that is brief and inconsistently manifested, compared to what is called trait mindfulness, which is the learned ability for a person to maintain mindful awareness for extended periods of uninterrupted time and which involves long-term potentiation*.

**Bottom-up Stimulation** refers to the stimulation that emerges from lower-level processes in the brain, such as hearing, seeing, emotions, etc. **Top-down Stimulation** refers to the stimulation that emerges from the PFC down to the limbic system to regulate the levels of activation regarding bottom-up stimulation. The limbic system contains the neuronal nuclei, such as the amygdala, etc, that act as a mediation stage for processing sensory stimuli.

**How Does This Work?**

The following review is superficial and can’t adequately cover the diversity and complexity of how the brain creates a sense of self—what we in the West call the ego. The ego is a sorting system—we are bombarded with a complex input of stimulation through the “sense doors”. The brain must sort through this cascading process and determine which stimuli to pay attention to and which to ignore—this is an ongoing, dynamic process and is inherently irrational because of the emotional elements of the limbic system, which determines the elements of the stimulus flow to focus on and develop, either to simply monitor and regulate or take action about.

An example I frequently use involves the sound that is generated by a barking dog. The following progression is greatly oversimplified, but will serve to provide an opportunity to review how mindfulness operates:

* Sound stimulates the auditory nerve and travels to the limbic system.
* The amygdala assesses for potential threat or reward in the signal, while:
* The hippocampus relates that stimulus flow to previous memories of similar sounds.
* These combined processes stimulate the association cortex, the part of the brain where memories are stored through the operations of long-term potentiation.
* The associated memories of prior experience shuttle back and forth between the limbic system process multiple times a second, “building a case” for a definitive identification of the source of the sound.
* Perhaps a visual process is also activated to bring more information regarding the whereabouts of the dog and what breed the dog is. This too reverberates neurologically through the association cortex and limbic system, coordinated with the auditory meaning-making process.
* If there is a pleasant memory association regarding the sound, sight and concept of “dog”, then the amygdala/hippocampus area stimulates “up” through the nucleus accumbens, which coordinates thoughts, moods and plans regarding the whereabouts of the dog, whether to approach it, and so on.
* Alternatively, if the potentiated memory is unpleasant, a different stimulus travels up through the nucleus accumbens and develops a plan of action to avoid the dog, accompanied by fear.
* There are two processes involved, cognitive and affective. The cognitive process elaborates a narrative that I call the “selfing story”, which is accompanied by the affective process, an impulsive reactivity which has emotional characteristics. These two processes are mutually reinforcing in that the affective initiates the cognitive which, in turn, increases the impulsivity and compelling feeling of urgency that demands attention and action.
* This process develops very quickly, within a second and, if the stimulus strength is potent enough, the system is flooded with hormonal reactions and impulsive behaviors through the pituitary gland, situated very closely to the other areas of the limbic system, either to approach, avoid, or even to freeze (a very strong fear response).

How Mindfulness Operates Neurologically

Mindfulness can operate either as a relatively brief state function, or, more effectively, can provide a trait response to the same stimulus. Again, this review is oversimplified, but does demonstrate how the process operates:

* Sound stimulates the auditory process, which sends the signal through the limbic system.
* The amygdala/hippocampus processes activate a sorting through of the possible meanings of the sound and sends a signal to the association cortex, the “bottom-up” messaging mentioned above.
* Mindfulness, especially when it functions as a trait, monitors the products of the association processes and the emotional signals and, through the actions of the PFC, particularly the Anterior Cingulate Cortex (ACC), sending a “top-down” signal to the amygdala/hippocampus-nucleus accumbens, decreasing the “signal strength” of reactivity and, monitoring the hormonal flow of the pituitary gland, providing relief from impulsively reactive behaviors.
* The cognitive and affective characteristics of neurological processes map onto the Buddhist concept of craving/clinging, with craving matching the affective component and clinging matching the cognitive component. As with traditional Buddhism, the dukkha of distress—either wanting or not wanting exposure to a dog, for instance, the goal is to mediate/regulate the process to liberate the mind from distress and confusion.
* A fundamental function of mindfulness practice is to train attention on the neutral, non-craving affect of breath sensations and disregard any associated narrative processes; when attention is drawn to the affective narrative, it is to be disregarded repeatedly, to return attention to the breath (this is described in the quote above from Wikipedia in the paragraph beginning with “The ACC detects conflicting information…”. Neurologically, the executive function of the PFC coordinates an association of other neurological processes to activate focused attention deliberately on the breath, to initiate long-term potentiation through a top-down signal to the driver of craving/clinging (the interaction between the amygdala/hippocampus/nucleus accumbens and association cortex); this effectively down-regulates the mutually reinforcing cognitive/affective dynamics of the limbic system. Over time and with much practice, this process matures from a state-dominated to a trait-regulated mindfulness and renunciation that liberates the function of attention from craving and clinging.
* Regarding pain, there is the actual neurological signaling caused by injury or illness that is transmitted to the limbic system and then interpreted through the cognitive/affective process. One of the beneficial effects of mindfulness meditation is the effective way that mindfulness and renunciation reduce the aggravation of the initial sensory impulse reporting pain by reattributing the pain so that it remains an affect without being amplified by cognitive exaggeration. This has been demonstrated through many years of the practice of MBSR, Mindfulness Based Stress Reduction, which has been shown to reduce reports of pain and reduction in pain medication dosage reported by patients with chronic pain.