Neuroscience of Mindfulness: Default Mode Network, Meditation, & Mindfulness

BY MATTHEW · JULY 8, 2014

"Ipsa scientia potestas est." ~ Sir Francis Bacon

Translated as, "Knowledge itself is power," this quote by Sir Francis Bacon appeared in his 1597 essay, *Meditationes Sacrae* ("Sacred Meditations"). Bacon has been credited as the father of the scientific method, and his work attests to the rigorous approach with which he examined natural phenomena. Bacon's quote and historical contributions make him a fitting character to introduce our proceeding discussion.

I was humbled by the response to my last post entitled, The Neuroscience of Mindfulness and Anxiety. The outpouring of questions and comments reassured me that the science of the Self is of vital importance and is worth exploring further.

As such I want to embark on a journey into the science of mindfulness and meditation in a series of articles to follow that will lead the reader to the cutting edge of science and medicine. I would suggest beginning this journey with my previous article as I will use the information provided therein as a foundation to expand our knowledge base.

So without further digression, I offer the second installment in my Science of Mindfulness series with the conviction that Self-knowledge instills power not *over* but *within* the Self.

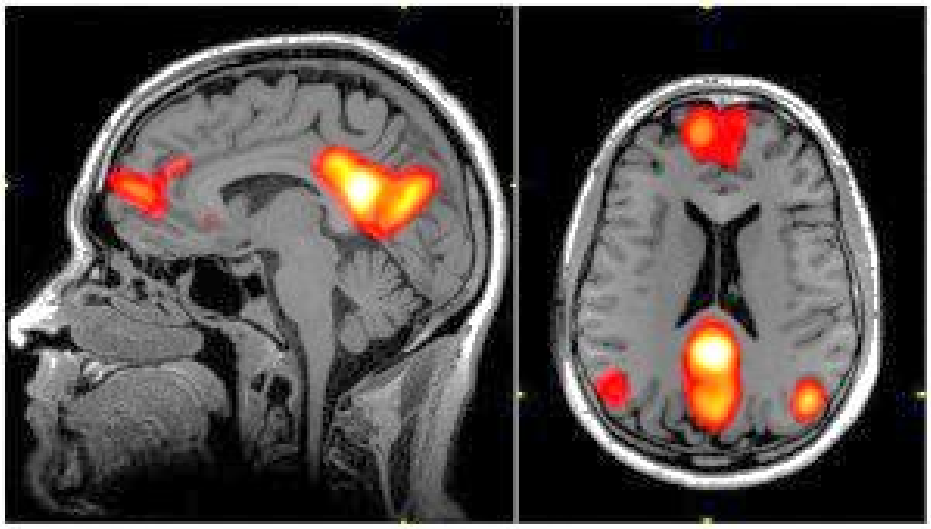
To begin our story we must travel back to 1924 when a German neurologist named Dr. Hans Berger invented the electroencephalograph (better know by its acronym: "EEG"). Some historians suggest that Dr. Berger went on to join the Nazi SS while others claim he was forced into retirement in 1941 because he would not comply with the SS and their medical research techniques. Regardless of which scenario represented the truth, very soon after his retirement he committed suicide at the age of 68 following a lifelong battle with major depression.

The EEG is a device that measures the electrical activity of the brain through external electrodes on the scalp. Because the brain transmits information in the form of electrical impulses, measuring electrical activity can yield information about brain function.

After a few years of working with his invention Dr. Berger made an observation in a 1929 paper that would be the first step on a long road of discovery. Until then, conventional scientific wisdom held that the brain was only electrically active when a person executed an attention-demanding physical or mental task (i.e. reading, classifying pictures, opening and closing their hands). However, Dr. Berger's work with his EEG demonstrated that the human brain remains electrically active even at rest while attention wanders (i.e. daydreaming between activities, remembering past events, ruminating). Despite the evidence, Dr. Berger's colleagues largely ignored his claims and continued to focus on brain function during attention-demanding behavior.

This trend of exclusively studying the brain during attention-demanding behavior continued for decades. However, all of this changed in 2001 when a neurologist by the name of Dr. Marcus Raichle at Washington University revealed a network of brain structures responsible for the inattentive wandering of our minds. Furthermore, Dr. Raichle showed that these same structures were deactivated when we engage in attention-demanding tasks. He coined the term, "default mode network," to describe the group of structures active during our "default," inattentive state (1).

The following decade revealed many more details about the default mode network (DMN) that further validated Dr. Berger's almost century-old claim that the brain was still very much "on" even when we let our attention wander. Now that we have the historical context let's examine the importance of the DMN to mindfulness and mental health.



fMRI of Default Mode Network by John Graner

So what exactly do I mean when I refer to the mental state of inattention that is synonymous with the DMN?

By "inattention" I mean times when you are not attending to physical activity, engaging with the external environment, or carrying on a conversation. Inattention, in the way I am using it, describes states of daydreaming, contemplating the future, reliving the past, or general rumination. The DMN is the set of neurologic structures responsible for this ruminative mental activity.

Hold on! Right away these descriptions bring to mind the most common culprits of mental unrest, namely: anxiety (over potential pasts, presents, or futures), depression (over regretted pasts, presents, or futures), or obsessionality.

Right you are! In fact, multiple studies have demonstrated that increased connection and activity in parts of the DMN are correlated with major depression and other mental illnesses (3).
So if the DMN is a network that is so intimately related to anxiety, depression, and obsessionality why on earth would evolution have selected for it? The answer is that, like most things in life, a well-balanced DMN helps us plan tasks, review past actions to improve future behavior, and remember pertinent life details. But with the expansion of the brain's intellectual capabilities came the unfortunate drawback that some of these functions could go too far and cause mental anguish.

Like most stories, the story of the DMN and the brain has both a protagonist and an antagonist. Perhaps it is slightly punitive to label the DMN as our antagonist, but for the purposes of our discussion the DMN must suffer this injustice.

The protagonist of our story is a series of structures in the brain called the Task-Positive Network (TPN).

The TPN is active during the attention-demanding tasks that we discussed in our introduction. Recall that the TPN was the network of most interest for the better part of the last century.

The TPN is responsible for directing our conscious attention towards the external environment through our five senses, towards our internal bodily states, and to the willful execution of physical and mental action. When we are engaged in conversation, feel the beat of our heart, or experience the breeze on our face we can thank our TPN for the attentional focus that brings these experiences into conscious awareness.

Whoa, whoa! Now *these* descriptions sound a whole lot like mindfulness practices. Indeed, the TPN is responsible for the attention required to observe one's breath during sitting meditation, attend to our environment during walking meditation, and participate in the social world on a daily basis.

Now that we have discussed the major functions of the DMN and TPN we come to a critical point regarding their relationship: they are mutually exclusive. The activation of the DMN inhibits the TPN and vice versa.
In fact, no study has demonstrated the simultaneous activation of the two networks (4). The relationship between the DMN and the TPN is analogous to the relationship between inhalation and exhalation: despite their intimate nature, the two cannot exist simultaneously.

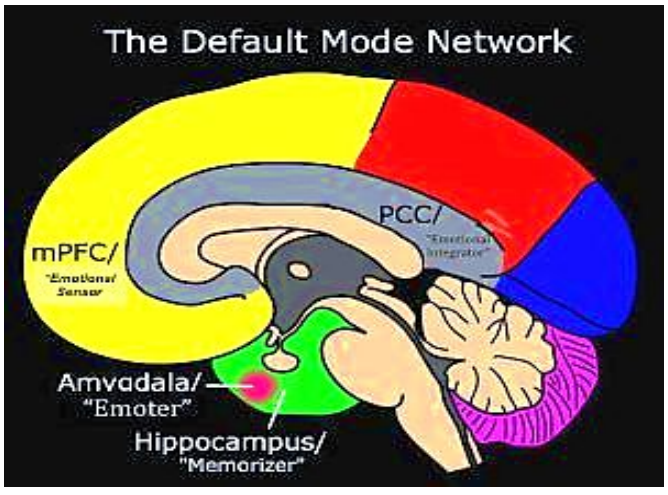
Now that we have the bird's eye view of these two systems let's examine them in more depth. Now would be a good time to go back to my previous article to refresh your knowledge of the various structures in the brain. The DMN can simplistically be thought of as being made up of "medial" (towards the middle) parts of the brain: the medial prefrontal cortex (mPFC), the posterior cingulate cortex (PCC), the hippocampus (located in the medial temporal lobe), and the amygdala (also located in the medial temporal lobe). The inferior parietal lobule is also a component of the DMN but for the purposes of our discussion we can ignore this structure. Also note that all of these structures are "bilateral" (existing on both sides). The brain is essentially a mirror image of itself that is split down the middle into two hemispheres.

As you will hopefully recall from my previous article, the amygdala serves as the raw source of emotional content. When we feel fearful, we can thank our amygdala. For the purposes of our current discussion we will consider the amygdala as the "Emoter."

Not mentioned in my previous article, but equally important, the hippocampus helps generate and modulate our memories. We will refer to the hippocampus as the "Memorizer." The hippocampus/Memorizer and amygdala/Emoter are neighbors and have highly complex interactions beyond the scope of this article.

The PCC is a structure deep in the middle of the brain that serves to integrate self-perception and emotionally relevant memory retrieval. To simplify the PCC's role, we can refer to it as the "Emotional Integrator."

Finally, the mPFC is located in the center of the frontal lobe and processes social and emotional information. Imagine your best friend is frowning at you. Your mPFC is the part of your brain that reacts and tries to make sense of your friend's frown. Did I do something wrong? Am I a bad friend? Is he a bad friend? For the aforementioned reasons we will refer to the mPFC as the "Emotional Sensor."

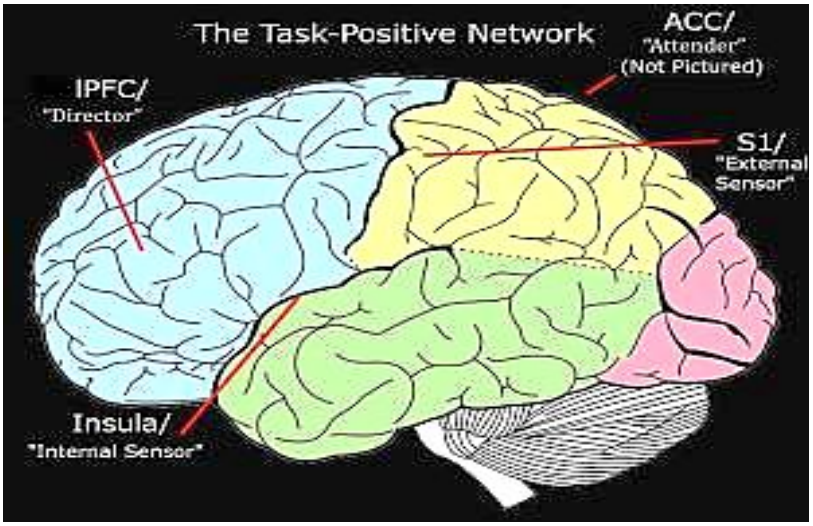


These four structures: mPFC/Emotional Sensor, PCC/Emotional Integrator, hippocampus/Memorizer, and amygdala/Emoter have a complex and interdependent relationship.

Let's use a simplified example to understand their dynamic relationship: Imagine that you are romantically interested in a coworker. Perhaps after a few days or weeks of gathering your courage, you decide to ask her out on a date. Your heart pounds and fear coats your upper lip with sweat as you await her response. But after an agonizing series of seconds that feel like minutes your romantic interest provides a resounding "No."

Later that day, as you sit down for dinner, you begin to process the events of that afternoon. Your mPFC/Emotional Sensor retrieves the memory of your romantic rejection formed by your hippocampus/Memorizer. The memory is laden with fear and embarrassment courtesy of the amygdala/Emoter. The PCC/Emotional Integrator forces you to re-experience the bodily state of fear and embarrassment while the mPFC/Emotional Sensor replays the ordeal over and over again in your mind's eye.

Now that we've examined the DMN in action let's look at the TPN in more detail.



While the DMN is predominantly a medial (towards the middle) series of neurologic structures the TPN can be thought of as composing mostly "lateral" (furthest away from middle) structures. The TPN is made up of the lateral prefrontal cortex (lPFC), the anterior cingulate cortex (ACC), the insula, and the somatosensory cortex (S1).

The lPFC is located in the lateral aspect of the frontal lobe. The lPFC is responsible for attentional-direction, decision-making, working memory (task-specific short-term memory), and cognitive control (regulating our thoughts). For the aforementioned reasons we will refer to the lPFC as the "Director." The lPFC dictates where we direct our attention and what we do with it.

The ACC is an exception to the lateral (away from middle) rule and sits behind and underneath the frontal lobe. The ACC enables us to direct our attentional focus towards emotional and cognitive content. We will refer to the ACC as the "Attender" because of its role in attending to mental and emotional content.

The insula is buried within the lateral sulcus, which separates the frontal and parietal lobes from the temporal lobe. The insula allows us to detect our own internal states such as the beat of our heart, the sensation of our intestines, or the feeling of a full bladder. We will refer to the insula by the very unimaginative title of the "Internal Sensor." And finally, S1 (1st or primary somatosensory cortex) is located in the postcentral gyrus of the parietal lobe. S1 is responsible for our bodily sensation of touch. S1 allows us to feel the sensation of grass beneath our feet, a cool breeze on our face, or the sun on our back. We will refer to S1 as the "External Sensor."

As before, let's use an example to unify these four structures: lPFC/Director, ACC/Attender, insula/Internal Sensor, and S1/External Sensor.

Imagine that you are sitting down to meditate. You rest yourself comfortably on your meditation cushion and straighten your back. Your mind is still operating on the DMN as you relive a conversation from earlier in the day or worry about a project that is due at the end of the week. But then you engage the lPFC/Director and activate the TPN, silencing the DMN (5).

The lPFC/Director directs your attention away from your ruminative thoughts to your internal and external environment. The ACC/Attender facilitates this switch in attentional focus. Perhaps you are practicing *Anapanasati*, (*pana* meaning breath and *sati* meaning mindfulness) a traditional breath-following meditation technique (see Mindful Sitting). Your attentional focus, courtesy of the ACC/Attender and lPFC/Director, is then directed to the insula/Internal Sensor. The insula/Internal Sensor allows you to experience the bodily sensation of the air moving in and out of your lungs, the beat of your heart as it slows in time with your deep breaths, and the feeling of your intestines and stomach as you relax deeper into the natural ebb and flow of your body.

Maybe you feel your attention waver and hear the DMN knocking on your mental door, so you switch to Open Awareness meditation in which you nonjudgmentally attend to all components of your environment. With the focusing beam of attention from your lPFC/Director and ACC/Attender you are able to utilize your S1/External Sensor to attend to your external environment. You feel the cool sensation of air at the tip of your nose during your in-breath and the warmth of your out-breath. You feel the earth pressing up through the cushion on your bottom and legs. You feel the expansion of your rib cage and stomach as they accommodate the flow of breath. Both Anapanasati and Open Awareness meditation utilize the activation of the TPN network to alleviate the mental suffering generated by the DMN.

Because of this article's density, it is worth revisiting a few key points at this time.

- **An overactive DMN is highly correlated with negative mood states and certain mental illnesses.** The DMN can be simplistically conceptualized as a ruminative network. It directs our awareness to the past and future while largely ignoring the present. And while the DMN can be used responsibly to plan and organize, we must always be wary of its runaway force.
- **The TPN is involved in present moment awareness.** The TPN is engaged when we attend to the here and now. It is the action network. The TPN is our direct line to mindfulness and the Present Moment in which worry and sadness cannot survive.
- **The TPN and DMN are mutually exclusive.** By activating the TPN we deactivate the DMN. This may be the most powerful lesson of our entire discussion. The next time you feel helplessly lost in worry or self-recrimination remind yourself of the power of the TPN. Go for a walk, practice yoga, sense your breath, or engage fully in a conversation with a friend. You need not overpower your DMN to escape negative thoughts. You need only to intentionally engage your TPN and allow your natural physiology to disengage your DMN.

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