Vipassana for Hackers

Paper Two: The Brain

Version 0.2

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Two years ago, I took my first Vipassana course and immediately began researching the effects of meditation on the brain. Written below is a summary of the research available as well as speculations on what goes on in the brain during a 10-day silent Vipassana meditation retreat.

Keywords: neuroscience, vipassana, meditation

TODO LIST

I. INTRODUCTION

I took my first Vipassana course (as taught by S.N. Goenka) in 2017. Vipassana meditation was so unlike anything I had ever experienced before, after the course I was left extremely curious about what exactly had happened to me during those ten days. For months afterward, I spent my mornings and evenings wading through the research in the field of meditation. I was specifically focused on white papers dealing with the effects of a 10-day Vipassana course on the brains of participants. The research in this area is limited. The quality research which does exist usually uses a sample of highly experienced meditators [1] rather than beginners and/or self-reports rather than objective measures.

Over the past year, I have tried to write down what I experienced during that first 10-day course and the 10-day courses I have taken since, corroborating my experience with research that does exist regarding meditation and the brain.

Proviso: S.N. Goenka, the principal teacher of Vipassana meditation, actively dissuades students from precisely the sort of brain-centred biological inquiry presented in this paper.

> **The brain itself is just a physical organ. As you deal with other parts of the body, you deal with the brain in the same way, that's all. Nothing special to do with the brain. But the mind is totally different. In the West, all importance is given to the brain as if the mind is located here. Nothing doing, it is everywhere. The mind is in the whole body. So give attention to the whole body.** — S.N. Goenka [2]

This paper does not contradict Mr. Goenka's sentiment, but instead acts as a starting point for readers who view the function of the brain as central to the activity of the mind.

Disclaimer: Although my primary field of research is within the field of biology, my work is far removed from neuroscience. I have tried to simplify the research available so as to better understand it. If there are any corrections to make or editing in terms of the content, please feel free to get in touch with me.

II. BRAIN FUNCTION AND ANATOMY

Before dissecting the experience of meditation as it pertains to the brain, this section describes the different parts of the brain that have shown up in scientific literature as correlated to meditative practices. Recent neuroscience divides the brain into the reified geography of the brain, its anatomy, and the abstract concepts governed by brain activity, its function. Between concrete physiology and abstract functional outcomes exist networks of cooperative structures which correspond to general high-level activities of the brain.

The Default Mode Network (DMN) is the constellation of regions which fire when the brain is not engaged in any external or goal-oriented tasks. As the name suggests, the brain is in its "default mode". [3] The DMN is anticorrelated to the Central Executive Network (CEN), which is active during externally-directed, high-level cognitive functions. [5] This anticorrelation between the DMN and the CEN is governed by the Salience Network (SN), the collection of regions in the brain which help decide which stimuli deserve our attention. The SN acts as a switch between the internally-directed DMN and the externally-directed CEN. [5]

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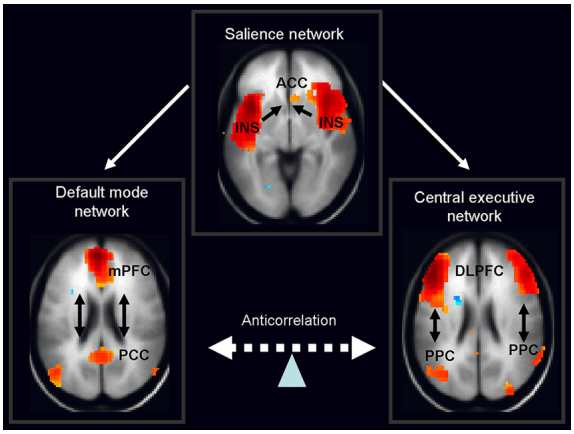

Figure 1: The Salience Network consists of the Anterior Cingulate Cortex and the Anterior Insular Cortex. It helps switch between the Default Mode Network and the Central Executive Network.

A. Default Mode Network

The DMN is comprised of specific anatomy including portions of the mid-line of the brain, an evolutionarily primitive area related to memory and emotion, and structures in the cortex, an evolutionarily recent part of the brain containing the executive and higher order functions. [4]

These functionally connected regions are involved in the neurological basis of the self, considering the mental states of others, remembering the past, and imagining the future.

This network is mostly observed through changes in blood flow to different parts of the brain measured using fMRI (functional Magnetic Resonance Imaging) or PET (Positron Emission Tomography)defaultnetworkadaptive

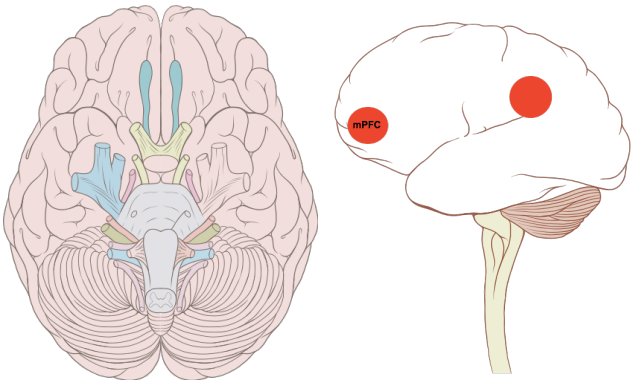

Figure 2: Highlighted: areas of the brain firing when the Default Mode Network is active.

1. *The neurological basis of the self*

The regions involved in an individual's conceptual‘ ‘self" are the Posterior Cingulate Cortex (PCC), Ventromedial Prefrontal Cortex (vmPFC), and the Inferior Parietal Lobule (IPL).That is to say, these regions are preferentially activated when volunteers were asked to reflect on personal preferences, beliefs, abilities, anything relevant to the self. [3]

Cerebral blood flow and metabolic rate is 40% higher than average in the PCC, making it one of the most active regions of the brain. [6]

The PCC has been thought to mediate interactions between emotion and memory. Under an fMRI, it consistently lights up when a person recollects something from their life. The strength of this activity varies depending on the emotional importance of the memory recalled. It is also activated by emotional stimuli, both positive and negative, and acts as an interface between the external world and the individual by gauging the importance of different stimuli. [7]

The vmPFC is involved in creating a conceptual self by self-related processing and the assignment of personal significance to self-related information. [8] The vmPFC is paired with the Dorsomedial Prefrontal Cortex (dmPFC), which assists in the creation of the conceptual self through an individual's consideration of "others".

The Inferior Parietal lobe (IPL) is situated in the back of the brain and it is involved in the perception of facial stimuli. [9]

It is hypothesized that the activation of these three regions of the brain (PCC, vmPFC, and IPL) are responsible for providing a sense of self — a subjective agent in space and time. It functions as a network in which phenomena such as self representations are accessible via the PCC [10] and are gated into conscious awareness by activity in the mPFC, as influenced by changing internal and external demands. The PCC acts as a brain-wide connectivity hub, through which a unitary notion of self is created by a large scale integration of DMN activity. [10]

2. *Thinking about others*

The *Theory of Mind* is a body of work in philosophy and psychology which describes an individual's ability to consider the mental states of others, such as appreciating another individual's false beliefs (knowledge based on incorrect or outdated information). The Theory of Mind captures not only one's ability to attribute beliefs, desires, and emotions to others but also to oneself — and to differentiate the two. [11]

There is a rich body of work pointing to this network (especially the dmPFC subsystem) being engaged when individuals reflect upon, evaluate, appraise their own thoughts, feelings and desires as well as those of others. [12]

In addition to this, the dmPFC is involved in empathy, moral reasoning, and altruistic behavior. [3, 14, 15]

3. *Autobiographical memory and future simulations*

The Medial Temporal Subsytem is primarily activated during these processes This subsystem consists of the Medial Temporal Lobe and parts of the limbic system especially the Hippocampus.

The limbic system is a complex set of structures that lies on both sides of the Thalamus, just under the Cerebrum. It includes the Hypothalamus, the Hippocampus, the Amygdala, and several other nearby areas. It appears to be primarily responsible for our emotional life, and has a lot to do with the formation of memories. [13]

The critical role of the Medial Temporal Lobe (MTL) which is a part of the DMN in long term memory is well documented. [16] This network has also been activated during autobiographical memory retrieval, contextual association, and semantic knowledge. [3]

It has been hypothesized that the adaptive role of memory retrieval is to facilitate construction of episodes to prepare for immediate and distant future scenarios. [3] The DMN is therefore involved in remembering the past, imagining the future, and story comprehension. [3]

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Therefore the DMN that plays a role in constructing a sense of self, in memory, in thinking about other also lends itself to excessive rumination and anxiety. [17] When I sit down to meditate and my thoughts wander away (and how they wander!), it is the DMN that is being activated.

B. Central Executive Network

The CEN is activated when high-level cognitive tasks or external goal-oriented tasks are being performed. These tasks or executive functions are cognitive processes involved in cognitive control of behavior. This depends on three types of brain functions : working memory, mental flexibility and self-control. The regions of the brain involved in these executive functions are Dorsolateral Prefrontal Cortex (DL-PFC), Orbito Frontal Cortex (OFC), and the Posterior Parietal Cortex (PPC).

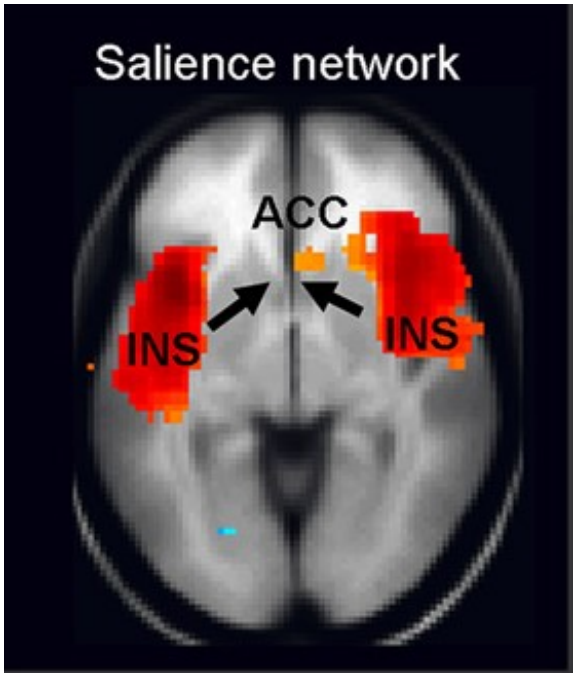

Figure 3: The Salience Network consists of the Anterior Cingulate Cortex and the Anterior Insular Cortex. It helps switch between the Default Mode Network and the Central Executive Network.

1. *Dorsolateral Prefrontal Cortex*

The DL-PFC is a part of the Prefrontal Cortex found in primates, including humans. The DL-PFC is involved in higher cognitive processes including working memory (holding different pieces of information, manipulating them, and using them for tasks), selective attention, cognitive flexibility (switching between tasks) and planning. It also seems to be involved in social cognition and lying. The DL-PFC has also been seen to increase dopamine levels in the brain. [27–29]

2. *Orbito Frontal Cortex*

The OFC is an area found in front of both hemispheres of the brain, just above the eyes. It is again a part of the Prefrontal Cortex and is thought to be involved in decision making through emotion and reward. It also receives input from multiple sensory modalities and in turn activates the Amygdala and the Hypothalamus. [30–32]

3. *Posterior Parietal Cortex*

The PPC is a region of the parietal cortex that is posterior to the primary somatosensory cortex. The posterior parietal cortex receives input from auditory, visual, and somatosensory systems as well as a variety of other brain

regions, and it integrates this input to facilitate the execution of functions that require diverse information (also known as higher-order functions). It in turn activates the DL-PFC and motor cortex and is involved in the performance of attention related tasks as well as higher-order motor tasks such as grasping and catching. [35, 36]

C. Sidenote: Somatosensory Cortex

The primary somatosensory cortex is located in a ridge of cortex found within the parietal lobe. It is responsible for processing somatic sensations. These sensations arise from receptors positioned throughout the body. They are responsible for detecting touch, for proprioception (i.e. the position of the body in space), nociception (i.e. pain), and temperature. [33] When such receptors detect one of these sensations, the information is sent to the thalamus and then to the primary somatosensory cortex. The sensory homunculus which is a part of the somatosensory cortex is a cortical representation of the body based on the degree of sensory innervation. [34]

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So, the Central Executive Network is involved in goal-directed behavior and processes related to attention. These goals are usually external and attention is also directed externally(whether voluntary or not). When you meditate, you direct your attention voluntarily inside, to the same sensory cues that are directing the PPC.

D. Salience Network

Salience: The perceptual quality by which an observable thing stands out relative to its environment.

The SN is an intrinsically connected large-scale network anchored in the Anterior Insular Cortex (AIC) and Dorsal Anterior Cingulate Cortex (ACC). Both regions have reached a high degree of specialization in the great apes. It is the collection of the regions in the brain that help decide which stimuli deserves our attention. It acts as a switch between the internally-directed DMN and the externally-directed Central Executive Network. [5]

1. Anterior Cingulate Cortex

The ACC is the front end of the Cingulate Cortex and collars around the Corpus Callosum, the band connecting the two hemispheres of the brain. It is the connector between the emotional (Limbic System) and the cognitive (Prefrontal Cortex) part of the brain. It is involved in functions such as attention allocation, reward anticipation, decision making, morality, impulse control, emotional awareness and registering pain. [18–22] It also appears to play a role in the regulation of Autonomic functions such as blood pressure and heart rate. [23]

2. Anterior Insular Cortex

The Insula is a part of the Cerebral Cortex located deep within the Sulcus, the fissure separating the four lobes of the brain. The AIC physically projects itself into the Amygdala. It is involved in multimodal sensory processing such as audio-visual integration tasks, interoceptive awareness (so its activity is directly related to an individual's sense of internal body states), empathy and conscious awareness. [24]

It also plays a role in the regulation of autonomic functions such as bodily sensations (including judgement of the severity of pain), taste, and control of the immune system. [25]

The AIC and ACC together give rise to our interoceptive and conscious self-awareness. [26]

The salience network is directly involved in switching between the DMN and CN. When you meditate, you cultivate the cognitive processes related to attention. When your mind wanders, you notice it and bring it back. The salience network should be directly involved in this process of assigning attention. Meditation should strengthen the salience network and its ability to switch from the default.

III. THE COURSE

I applied for my first 10-day Vipassana course after I quit my job. From the time I was accepted into the course until the first day of the course I was very nervous about what it might entail. I had never done anything like this (meditation) before and I was quite happy with the idea that meditation, with its spiritual connotations and religious mumbo-jumbo, was a waste of my time. In my mind, a silent meditation retreat was for people who had time to waste — and I was not one of them. Yet friends had convinced me that I should give Vipassana a try and in the interval between workplaces I had time to experiment with a course.

The following are my observations and speculations about what could be happening in the brain during a 10 course.

I went for my first course in Chennai, my home town. When I arrived, I had to fill all the application forms all over again (despite applying online), keep all my luggage in a locker, and go to my room. I had to share the room with one other person. I felt quite out of my element and I was certain everyone could see in me that I was the odd one out, the one that was not supposed to be there. Because I felt so out of place, I was too scared to actually make conversation with anyone before silence was enforced.

A. Anapana Meditation

And so it was. With my brain filled with thoughts about myself, about the people around me, I started this meditation business. For the first 3.5 days you are asked to focus your attention on the area below your nostrils and above your upper lip. That's all, these were really simple instructions, but so hard to keep up with. Within the first two days, I had made up elaborate stories about my fellow meditators, all of them superheroes, tirelessly working to save humanity together. My default mode network was in overdrive.

Focusing our attention below the nostrils starts with observing your breath coming in and going out. As the teacher mentions in the late evening discourses, the reason for starting with your breath is because this the only activity of the body which is both conscious and unconscious — it acts as a bridge to the unconscious mind and the involuntary processes of the body.

During the meditation hours I was trying hard. If I was to examine this practice empirically, I had to give it an honest shot. I focused on the small patch beneath my nostrils above my upper lip. To begin with, while trying to observe your breath and your mind wanders, that is the default mode network working. As you realize your mind has wandered and bring your attention back to your breath, your salience network is activated. This happens slowly at first, with your mind wandering for many, many minutes before you realize you are not with your breath. But within the 3.5 days, the SN learns quite quickly to bring attention back to the breath. After a few days, this refocusing almost happens by habit, almost automatically.

As I gave in to this activity, tried to focus more intently, tried to sit still for longer, there were longer periods of awareness on that patch of skin and, with them, stranger sensations arising and passing within that physical area. By the third day, it felt like entire ecosystems were writhing and flopping and crashing, all of them very alive in the area below my nostrils above my upper lip.

There have been studies that have shown that once you bring your attention back to breath, the neural structures involved in the control of the Autonomic Nervous System and attention start firing more actively (in this case, the DL-PFC — a part of the CEN and the Hippocampus a part of the DMN and ACC — a part of the SN). There are also global dampening changes seen in the brain, particularly within the DMN and the Amygdala, which is involved in the flight-or-fight (stress) response. These changes have been termed the "relaxation response", as they are antagonistic to the stress response. This relaxation response can be thought of as a gateway to altered states of mind. [37]

There has also been research in mice, showing a cluster of nerves called the pre-Bötzinger Complex (preBötC), found in the brain stem of most mammals, which fires with every breath taken. This breathing pacemaker seems to work not only for regular conscious and unconscious breathing but for all kinds of breathing — such as yawns, sighs and gasps. The preBötc also appears to play a role in calming and arousal. [38] It would be interesting to see the activation in these neuron clusters during the first three days of a Vipassana course, even among novice meditators.

B. Vipassana Meditation

After lunch on the fourth day the instructions for Vipassana are given. During Vipassana, you transfer your attention from the patch below your nostril to the top of your head. From there, for two hours, the instructions are given to slowly move your attention throughout the entire body: "from the top of the head to the tips of the toes", then repeat. The two criteria for observation of bodily sensations are focused attention (making use of the narrow focus practiced during the Anapana period) and open monitoring (observing the sensations objectively).

The Salience Network (ACC and AIC) and the Central Executive Network (DL-PFC, OFC, and PPC) which are involved in the control of attention start firing rapidly. Usually when a person is engaged in an external task, the OFC and PPC are receiving signals from all the sensory networks (Visual, Audio, Somatosensory, etc.) and, in response, continuously send signals to the different motor cortices, Amygdala, and Hypothalamus to respond by performing a task, feeling an emotion, etc.

But Vipassana is an internal task. The Salience Network is activated by focused attention, which in turn activates the Central Executive Network. Rather than an external task, as the CEN is accustomed to, the conscious instruction is to observe bodily sensation — and do nothing. So as you sit in silence with your eyes closed, not moving and scanning your body with your attention, you are doing what the CEN has always done except attempting not to react.

This is hard at first, with the body involuntarily reacting by jerking and writhing in involuntary response to the act of observation. Initially, your awareness is itself jerky and it is hard to observe sensations consciously. There is also the pain. This eclipses all other sensations. In my case, it was difficult to maintain awareness of any other sensation with the pain that was emanating from my legs and back. The OFC is involved in assigning emotion to sensation [39] and the ACC plays a vital role in perception of sensation. These two parts of the brain are usually functionally connected. In the beginning, as I sat trying to observe sensations and was only aware of the pain, the ACC was firing rapidly and the OFC then assigned these signals to the Limbic System which put me in a less than ideal emotional state.

But as your awareness gets smoother and observations get more objective, this functional connectivity between the ACC and the OFC slowly starts changing. As you continue to pay attention to the different sensations and

you attempt to avoid assigning emotions to them. Without assigning an emotional response, you can observe with a non-judgmental attitude, particularly toward unpleasant stimuli. The OFC still fires but the Limbic System is quiesced and, in turn, you react less. It is as if both your conscious and unconscious awarenesses are slowly aligning until you experience some occasions when it feels as if there is nothing but detached awareness moving through your body (or some parts of your body). Senses are not dulled, however. In addition to a feeling of emotional detachment, the Insula and the Somatosensory Cortex, which are involved in sensory awareness, were firing **more** actively, not less.

Perhaps the strangest experience during a Vipassana course is that of shifts in your sense of self. The "self", as a subjective agent in space and time changes, if at first only very slightly. As you close your eyes and meditate, it may feel as though the body has shifted in space or rotated in different directions. During these times, the vmPFC and PCC become less active. As the meditations get deeper the DMN occasionally quiets completely (perhaps only for a short duration) while the Insula fires more rapidly, leading to alternative networks of consciousness arising. It is as if losing the influence of one's own narrative leads to new insights that are usually kept from consciousness. It has been found that experiencing this, even for a few seconds, can lead to lasting changes long after the activity of meditation itself has stopped. [40] In the moment, these experiences can be quite similar to being on certain hallucinogenic drugs or even, in some cases, to ecstatic seizures where the abnormal activity of the Anterior Insular Cortex leads to heightened self-awareness, feelings of bliss, and a lack of ambiguity. [41]

IV. CONCLUSION

I believe attending a 10-day Vipassana course did, in fact, change the habit pattern of my mind — at least for a while.

Vipassana causes global dampening changes in the DMN, causes certain parts of the SN and CEN to fire more rapidly. That is, reacting parts of the network and portions of the network which are aware of bodily sensation, respectively. This changes a person's behavior (in the short term, at least) and these changes can often be seen as soon as someone leaves the course on the tenth day.

But repeated practice is essential for any sustained neuroplasticity since rewriting many years of habit formation requires more than a ten day course. However, the ten day course is well-designed and will give someone experimenting with meditation the minimum observational change necessary to instill an interest, to keep practicing.

There have been studies looking at both the structural changes in the brain and functional changes in brain activity, especially to the DMN and the SN. But such studies are usually only done on meditators who have clocked thousands of hours of practice, which diverges from the purpose of this paper. [1, 42, 43]

How is Vipassana different from simply concentrating on a task, as hard as one can? When concentrating on any task, your DMN is quieted, the SN and CEN are firing, and you enter into a state of flow. But flow or no flow, the reacting part of the brain is also working. And it is working hard. The goal of Vipassana is not simply to concentrate or to enter a state of flow, but to break old reactionary habit patterns altogether.

As I left the Vipassana Center, I was really intrigued as to what exactly had occurred over those ten days. What was it that had changed in my brain? I had to know. I very quickly noticed, however, that as I left the centre (or even earlier, as soon as talking was allowed), those very changes started slipping away. But with each hour-long meditation at home, a tiny bit sticks just a little more. And I get closer to my answer.

V. ACKNOWLEDGEMENTS

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