

Vipassana for Hackers

Paper Two: The Brain

Version 0.3

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Two years ago, immediately following my first Vipassana course, I began researching the effects of meditation on the brain. This paper is a summary of the research available on the topic and speculations, based on my experience, as to what is happening in the brain during a 10-day silent Vipassana meditation retreat.

Keywords: neuroscience, vipassana, meditation

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 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 curious

readers who, whether they have taken a Vipassana course or not, 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 contact 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 (anatomy) and the abstract concepts governed by brain activity (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” of operation. [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. In this way, the SN acts as a switch between the internally-directed DMN and the externally-directed CEN. [5]

Where possible in the following sections these networks are described in terms of function. The description of the DMN is also organized by function but the subsystems of the CEN and SN offer too many potential functional categorizations and are instead organized by anatomy.

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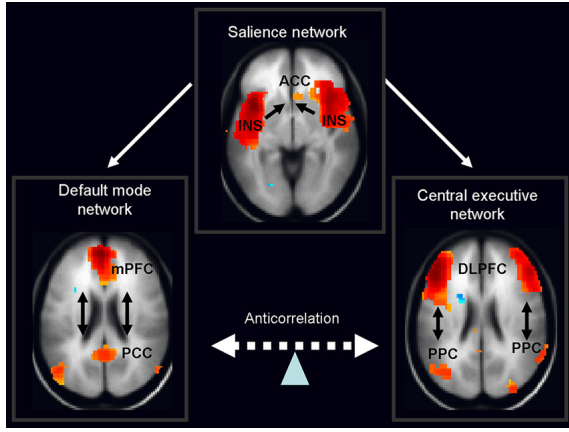


Figure 1: The Salience Network consists of the Anterior Cingulate Cortex and the Anterior Insular Cortex. It helps switch between the Default Mode Network and the Central Executive Network.

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). [3]

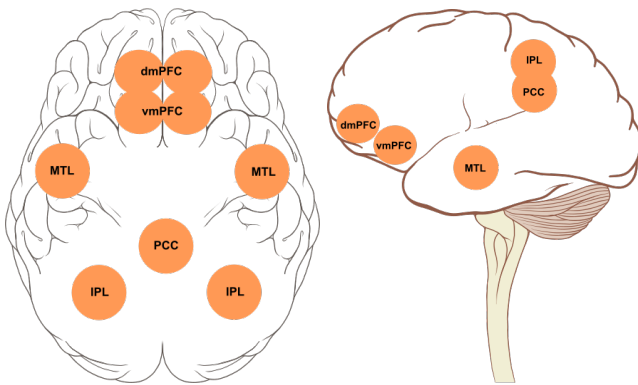


Figure 2: Highlighted: approximate locations of brain regions firing when the Default Mode Network is active.

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). Observationally, these regions are preferentially activated when subjects were asked to reflect on personal preferences, beliefs, abilities, or any other qualities relevant to the self. [3] Cerebral blood flow and metabolic rate are 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 an event 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 a navigational interface, between the individual and the external world, 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". Together, the vmPFC and dmPFC form the Medial Prefrontal Cortex (mPFC).

The Inferior Parietal lobe (IPL) is situated in the back of the brain and it is involved in the perception of facial stimuli. [9] The IPL has been hypothesized as being involved in distinguishing self from others, in a study where subjects were asked to retrieve previous judgments about oneself, their friend and the Dutch queen, the activation of the IPL was seen to decrease with decreasing self-reference. [10] Another study also used Transcranial Magnetic Stimulation (TMS) to create a sort of "virtual lesion" (transiently disturb the neural circuitry in that area) of the right-IPL and showed that this disrupts self-other discrimination. [11]

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 [12] 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. [12]

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. [13]

The DMN (especially the dmPFC subsystem) is engaged when individuals reflect upon, evaluate, or appraise their own mental states or the mental states of others. "Mental states" include thoughts, feelings, and desires. [14] In addition to consideration of these states, the dmPFC is involved in empathy, moral reasoning, and altruistic behavior. [3, 16, 17]

Default Mode Network

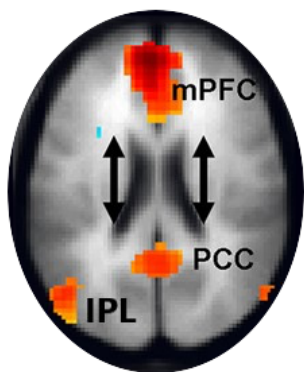


Figure 3: fMRI scan of the Default Mode Network.

3. Autobiographical memory and future simulations

The term "autobiographical memory" refers to our memory for specific episodes, and to our conceptual, generic, and schematic knowledge of our lives.

The Medial Temporal Lobe (MTL) which is found on the medial surface of the temporal lobe. The critical role of the MTL in long term memory is well documented. [18]

The MTL consists of the hippocampal formation on top and the parahippocampal gyrus below it as well as the entorhinal and perirhinal cortices. The MTL, amygdala, the olfactory cortex, hypothalamus and several other anatomically connected areas forms the limbic system. It appears to be primarily responsible for our emotional life and has a specific involvement in the formation of memories. [15]

The MTL along with mPFC, IPL and PCC forms the Medial Temporal Subsystem (a part of the DMN). This subsystem is triggered 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]

4. Summary

The DMN plays a role in constructing a sense of self, in memory, and in thinking about others. Because of this, it is also a key component in excessive rumination and anxiety. [19]

When a meditator sits down to meditate and thoughts wander away to past experiences or anxieties about the future, classic meditation texts and instructions refer to this behaviour as "Monkey Mind". It is the DMN playing the most active role in this distraction.

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 the Dorsolateral Prefrontal Cortex (DL-PFC), Orbito Frontal Cortex (OFC), and the Posterior Parietal Cortex (PPC).

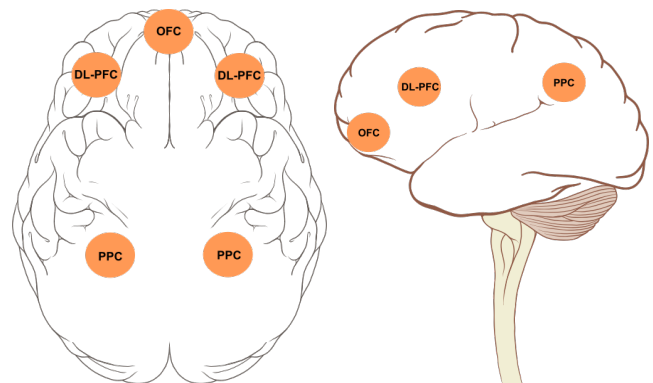


Figure 4: Highlighted: approximate locations of brain regions firing when the Central Executive Network is active.

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. [29–31]

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. [32–34]

3. Posterior Parietal Cortex

The PPC is a region of the Parietal Cortex, physically located behind the primary Somatosensory Cortex. The PPC is responsible for facilitating higher-order functions. Higher-order functions are defined as those requiring diverse information for the purposes of higher evolutionary behaviour: intelligence, memory, planning, speech, orientation, decision-making, etc.

To do this, the PPC receives input from auditory, visual, and somatosensory systems, integrates this input, and uses the aggregate to activate 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. [37]

4. Sidenote: Somatosensory Cortex

The Primary Somatosensory Cortex is located in a ridge of cortex found within the Parietal Cortex. It is responsible for processing somatic sensations. These sensations arise from receptors positioned throughout the body. They are responsible for detecting touch, for proprioception (the position of the body in space), nociception (pain), and temperature. [35] When such receptors detect one of these sensations, the information is sent first 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. [36]

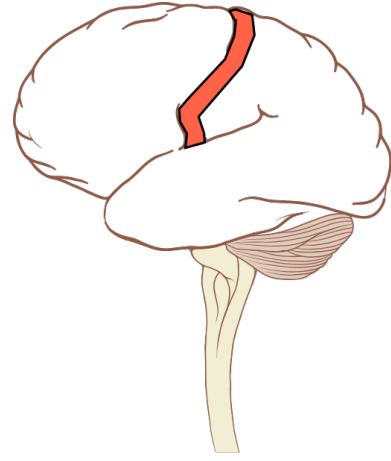


Figure 5: Location of the Somatosensory Cortex.

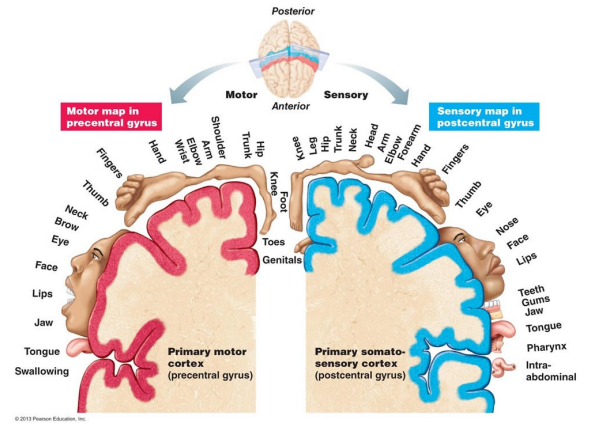


Figure 6: The Sensory Homunculus mapped across the Somatosensory Cortex.

Central Executive Network

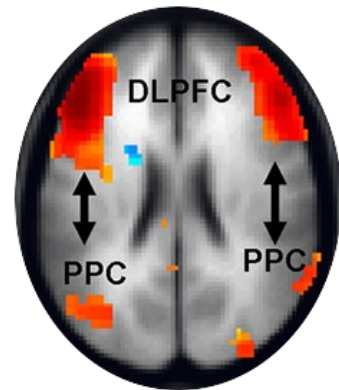


Figure 7: fMRI scan of the Central Executive Network.

5. Summary

The CEN is involved in goal-directed behavior and processes related to attention. These goals are usually external and attention is also directed externally (regardless of whether attention is voluntary or not). When you meditate, attention is directed both internally and voluntarily, to the same sensory cues that are normally directing the PPC.

C. 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 CEN. [5]

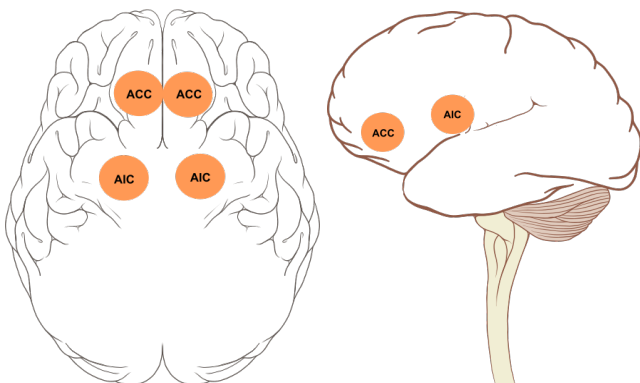


Figure 8: Highlighted: approximate locations of brain regions firing when the Salience Network is active.

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. [20–24] It also appears to play a role in the regulation of Autonomic functions such as blood pressure and heart rate. [25]

2. Anterior Insular Cortex

The AIC 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. [26]

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. [27]

The AIC and ACC together give rise to our interoceptive and conscious self-awareness. [28]

Salience Network

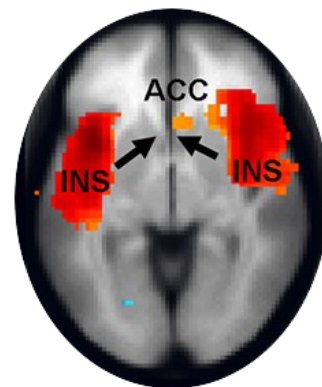


Figure 9: fMRI scan of the Salience Network.

3. Summary

The SN is directly involved in switching between the DMN and CEN. When you meditate, you cultivate the cognitive processes related to attention. When the meditator's mind wanders, she notices it and brings it back. The SN is directly involved in this process of assigning attention, since it is responsible for the prominence of any object of attention. Meditation, or the act of returning to an object of meditation, can therefore be thought of as an exercise in strengthening the SN and its ability to perform this switch, over time.

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 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-day course.

I went for my first course in Chennai, my home town. When I arrived, I had to fill 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 student. I felt quite out of my element and I was certain everyone else could see that I was the odd one out. In my head, I 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 I was instructed to focus my attention on the area below my nostrils and above my upper lip. That’s all. These are undoubtedly very simple instructions but in practice I found them very difficult. Maintaining my focus was much harder than I had anticipated. Within the first two days, I had made up elaborate stories about my fellow meditation students. In these fantasies all of the other students were superheroes, tirelessly working to save humanity together. My Default Mode Network was in overdrive.

Focusing our attention below the nostrils starts with observing 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.

There has 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. [39] 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.

During the meditation hours I was trying hard. I had decided that 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. Initially, while trying to observe one’s breathing, the mind will

wander — not just to fantasies of superheroes but to almost any object or daydream imaginable — as the mind wanders the Default Mode Network is working. With the realization that the mind has wandered, and the consequent return of attention back to the breath, the Salience Network is activated. This happens slowly at first. One’s mind wanders away for many, many minutes before realizing that the object of attention, the breath, has been lost. But at some point within the 3.5 days, the SN learns 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, and tried to sit still for longer continuous stretches of time, there were longer periods of awareness on that patch of skin. With these longer periods of awareness came 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. Since Anapana meditation is very simple and these strange sensations appeared within a few days of my practice as an absolute beginner, it would be very interesting (and relatively easy) to study the neurological and physiological basis for such sensations.

There have been studies that have shown that once subjects bring their 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, the Hippocampus — a part of the DMN, and the ACC — a part of the SN). During Anapana 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. [38]

B. Vipassana Meditation

After lunch on the fourth day the instructions for Vipassana are given. During Vipassana, students transfer their attention from the patch below their nostrils to the top of the head. From there, for two hours, instructions are given to slowly move one’s attention throughout the entire body: “from the top of the head to the tips of the toes.” This movement of attention throughout the body is then repeated, over and over. The two objectives while observing bodily sensations are focused attention (making use of the narrow focus practiced during the Anapana period) and open monitoring (observing the sensations objectively).

As this process progresses, the Salience Network (ACC and AIC) and some parts of the Central Executive Network (DL-PFC, OFC, and PPC), which are involved in the control of attention, fire more actively. The anti-

correlation between the DMN and CEN reduces. Usually when a person is engaged in an external task, the OFC and PPC receive 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 your body physically but instead moving throughout your body with your attention, the CEN is doing what it has always done. However, the outcomes of activity in the CEN are different during Vipassana. Instead of focusing on external sensory input the sensory input is internal (bodily sensations) and instead of reacting to input by performing tasks or feeling emotions the goal is to not react, to simply observe as objectively as possible.

This is hard at first, with the body involuntarily reacting by jerking and writhing in involuntary response to the very act of observation. Initially, even awareness itself has a jerky quality 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 and the shaping of pain by expectations [40, 41] 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.

Over the final seven days of the course, as awareness gets smoother and observations get more objective, this functional connectivity between the ACC and the OFC slowly starts changing. While continuing to pay attention to constantly changing bodily sensations the goal remains: avoid assigning evaluations (and therefore, emotions) to them. Without assigning an emotional response, one learns to observe with a non-judgmental attitude, particularly toward unpleasant stimuli. The ACC is still up-regulated but the OFC and the Limbic System may acquiesce and, in turn, reactions become smaller and less frequent. This snowball effect almost mirrors the spiral of brain behaviours exhibited early in the course. Early in the course, the CEN's normal mode of operation is in play, which is to experience unpleasant stimuli and react (desiring to rid the body of them), which in turn causes the unpleasant stimuli to appear all the more unpleasant. Once a measure of objectivity is reached, however, the brain's function snowballs in the other direction. It is as if both conscious and unconscious awarenesses

are slowly aligning until there are occasions of experience when it feels as if there is nothing but detached awareness moving through the body (or some parts of the body). This is not at all akin to the detachment of sleep or intoxication, however, and the senses are not dulled. In addition to a feeling of emotional detachment, the ACC, AIC and the Somatosensory Cortex, which are involved in sensory awareness, were **more** active, not less. As the OFC, and Limbic System are calmed and attention is narrowed further, the sensations become progressively more intense.

Perhaps the strangest experience during a Vipassana course is that of shifts in the sense of self. The “self”, as a subjective agent in space and time, changes. At first, this change is only very slight. As a student closes her eyes and begins to meditate, it may feel as though the body has shifted in space or rotated in different direction, this is due to the temporary down regulation of the pre-frontal cortex. As the meditations get deeper the DMN occasionally quiets completely (perhaps only for a short duration) while the AIC fires more rapidly, leading to alternative networks of consciousness arising.

Consciousness is defined as our subjective awareness of ourselves and our environment. An altered state of consciousness is defined as alternate patterns or configurations of this experience, which differ qualitatively from a baseline state. Altered states of consciousness include a state of dreaming, epileptic seizures, sensory deprivation, hysterical states of dissociation and depersonalization as well as pharmacologically induced altered states.

The notion of altered states of consciousness has been put forth another way by the Entropic Brain Hypothesis, described by Robin Carhart-Harris et al, while studying the brain under the influence of psychedelics. [46, 47] Entropy is a measure of the uncertainty in a system and, in this case, applies to states of consciousness and their associated neurodynamics. The theory makes a distinction between two fundamental modes of consciousness: Primitive Consciousness and the normal Secondary Consciousness of waking states. Primitive consciousness is characterized by higher entropy and it is hypothesized to have preceded the development of modern, adult, human, normal waking consciousness. It is argued that suppression of this entropy facilitates normal waking consciousness and associated metacognitive functions such as reality-testing and self-awareness.

Even one ten-day course will expose a student to these altered states of consciousness and provide access to Primitive Consciousness. However, unlike psychedelics, the Vipassana student is not under the control of an external force. If she opens her eyes and stops meditating, these disorienting altered states of consciousness instantly disintegrate. Lasting changes to consciousness caused by Vipassana take a different shape.

Sometimes it feels like loosening the hold 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. [42] In the moment, these experiences can be quite similar to the influence of 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. [43] Outside the activity of meditation, the lasting effects (“Altered Traits”) of meditation are not so extreme. They tend to include heightened awareness, improved concentration, and increased empathy, among others. [42]

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 activate. 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 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 10-day course is both progressive and systematic. It is designed to give someone experimenting with medi-

tation 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 often only done on meditators who have clocked thousands of hours of practice, which diverges from the purpose of this paper. [1, 44, 45]

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. The mind may learn to focus intensely but the habit patterns of the mind are unlikely to change. 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, 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

Thank you to Steven Deobald for reviews, edits, and corrections. `Brain_human_normal_inferior_view.svg` and `Brain_human_lateral_view.svg` by Patrick J. Lynch, medical illustrator, CC-BY 2.5 [48]

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