Meditation and the Brain

Science of Yoga Series, Part 1

1 Topics

Meditation and Brain Waves

Neurology of Hong Sau Meditation

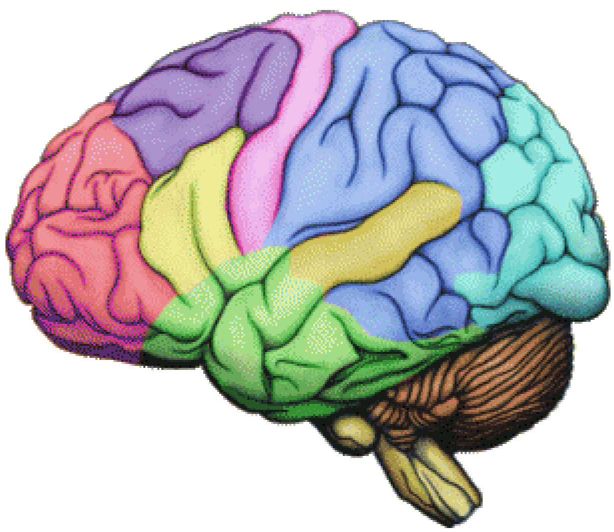
Meditation and Ageing

Science and [the State of] Yoga

2 Tour of the Brain

Some of this material is taken from [VSR] and [HANSON].

2.1 Brain Facts



Brain is about 3 pounds, with the consistency of Tapioca Pudding. It has about 1.1 trillion nerve cells, of which 100 billion are neurons in the grey matter. A neuron is connected to thousands of other neurons. Neurons communicate with each other via electrical signals and via chemicals (called Neurotransmitters).

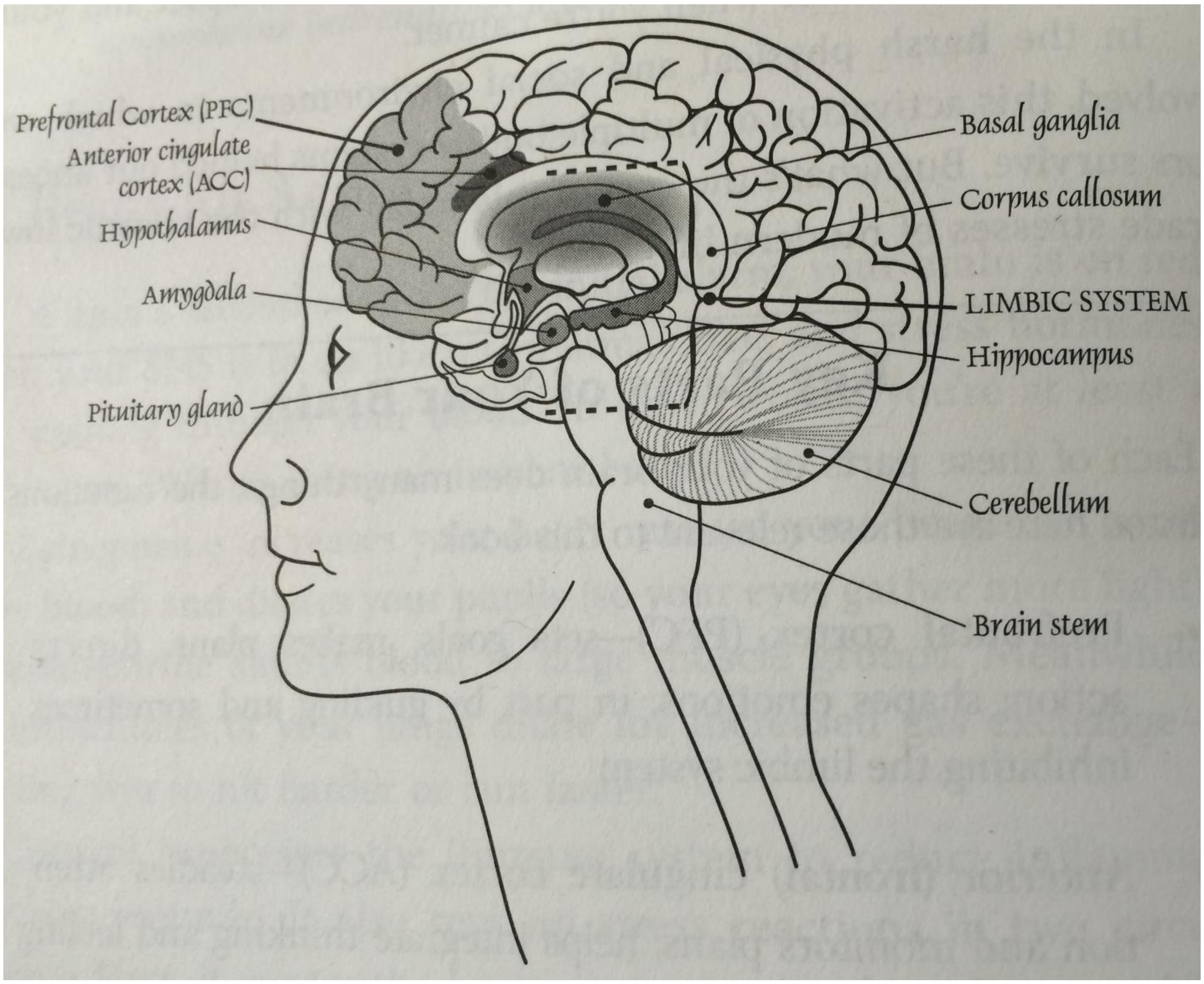
A typical neuron fires 5 – 50 times per second. The brain is always active, regardless of whether one is active, asleep or even in a coma. The amount of activity is staggering – <u>trillions</u> of signals travel in your head every second. This is why the brain consumes an enormous amount of energy: even though it is roughly 2% of your body weight, it consumes 20-25% of its oxygen and glucose.

The totality of the trillions of neuronal firings generate a constant electrical activity in the brain. This electrical activity can be measured by attaching electrodes to the head. They take the form of a jagged waveform, called as an electro-encephalogram (EEG).

The number of possible combinations of 100 billion neurons firing is much, much greater than the number of elementary particles in the Universe. Thus, this little 3-pound gooey organ inside our head is, by a large margin, the most complicated entity in creation.

As Thoreau said: *What lies behind us and what lies ahead of us are tiny matters compared to what lives within us.*

2.2 Main Structures of the Brain



The brain can be thought of as having 3 distinct regions:

- The Reptilian Brain, responsible for unconscious but critical functions such as heart rate, breathing, etc.
- Limbic System, responsible for emotions, long term memories, and social behavior
- Cerebral Cortex, which is governs higher cognitive behavior.

Reptilian Brain begins at the top of the spinal cord.

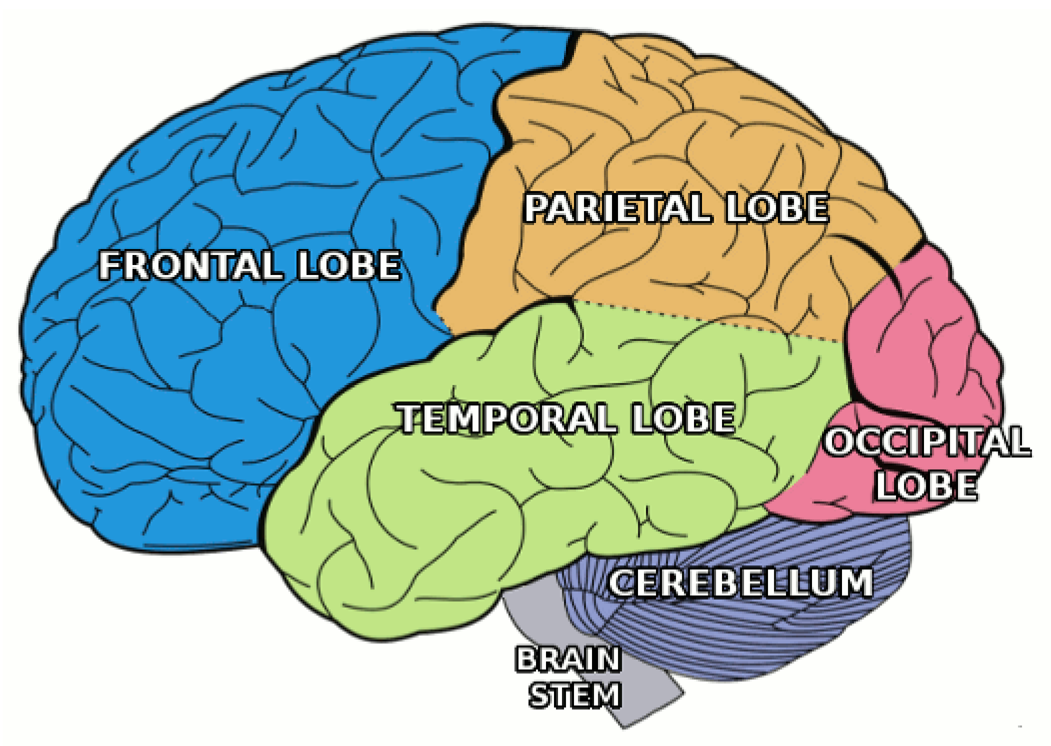
- **Medulla Oblongata** controls critical functions such as blood pressure, digestion, heart rate, and breathing.
- **Pons:** is a bulge on top of the medulla. It is involved, among other things, in producing dreams.
- **Cerebellum:** The pons expands into the cerebellum, whole job is to carry out coordinated movements.

Limbic System: It is at the center of the brain, surrounding the reptilian brain. It is responsible for emotion, esp. those associated with fear or pleasure; long term memory, and sense of smell.

- **Hippocampus** – it is the set of memory. Short term memories are processed into long term memories. Damage here will destroy the ability to form long term memories. You are a prisoner of the present
- **Amygdala** is the center of "raw" processing of emotions, and acts as an alarm bell to the rest of the brain.
- **Thalamus** is the relay station of sensory information. It gathers sensory input from the brain stem and sends it out to the higher centers in the brain
- **Hypothalamus** regulates body temperature, hunger, thirst, and some parts of the reproduction and pleasure sensations. It also controls the pituitary. Generates oxytocin, nor-epinephrine, and dopamine.

Cerebral Cortex governs higher cognitive behavior. It is the largest part of the human brain, about 80% by weight. The cortex resembles a walnut, and is split into two hemispheres. It is convoluted and folded, and has a cauliflower like appearance.

Functionally, the cortex can be split into 4 areas, or lobes:

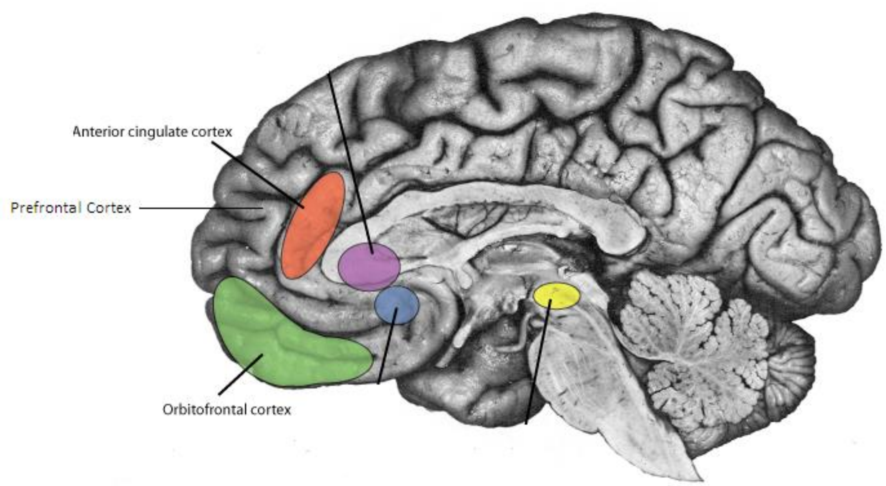


Occipital lobes are concerned with processing visual input.

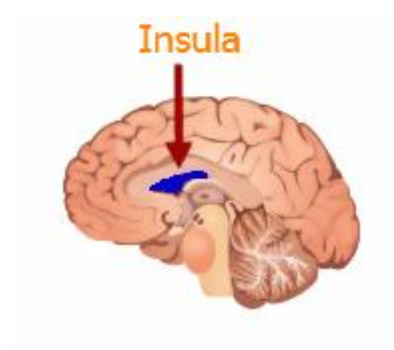
Temporal lobes specialize in higher perceptual functions such as recognizing faces and linking them with emotions. This is done in close cooperation with Hippocampus (memory) and Amygdala (emotions). This is also the center for our linguistic ability.

Parietal lobes process touch, muscle, and joint information from the body, and combines it with vision, hearing, and balance to give you a rich "multi-media" understanding of your body and the world around it.

Frontal lobes perform many distinct and vital functions. Some structures in the Frontal Lobe that are particularly relevant to the study of meditation are:



- **Pre-frontal Cortex**, the front most part of the brain, the area behind the forehead. This is responsible for most traits that we recognize as uniquely human. It sets goals, makes plans, directs action, shapes emotions in part by guiding and sometimes inhibiting the limbic system
- **Orbitofrontal Cortex (OFC)**, the front-most part of pre-frontal cortex, which is involved in nuanced emotional judgments.
- **Anterior Cingulate Cortex**, one of the attention centers in the brain. Roughly, it is located deep behind the eyebrow center, on either side. It also monitors and plans, helps make choices, and is part of the system that integrates thinking and feeling [YAMASAKI 2002]
- **Insular Cortex:** Senses the internal state of your body, and generates a representation of how you feel with respect to the outside world; helps you empathize.



3 Meditation and Brain Waves

3.1 Introduction to Brain Waves

Scientific American has an excellent article on brain waves:
http://www.scientificamerican.com/article/what-is-the-function-of-t-1997-12-22/

Brain waves are produced by the extremely low voltages involved in transmitting messages among neurons. Most conscious activity produces **Beta waves** at 13 to 30 hertz, or cycles per second. They are characteristic of a strongly engaged mind.

Alpha waves are slower, 9 to 14 Hertz. They are produced when we are in a state of relaxed wakefulness. Usually alpha activity requires that the eyes are closed (unless one is an experienced meditator; more on that soon).

Theta waves are even slower, about 5 to 8 Hertz. They are produced when we are "tuned out" but awake. For example, if you are driving on a freeway, and discover that they can't recall the last five miles, then you were probably in a theta state. The ideation that can take place during the theta state is often free flow and occurs without censorship or guilt. It is typically a very positive and creative mental state.

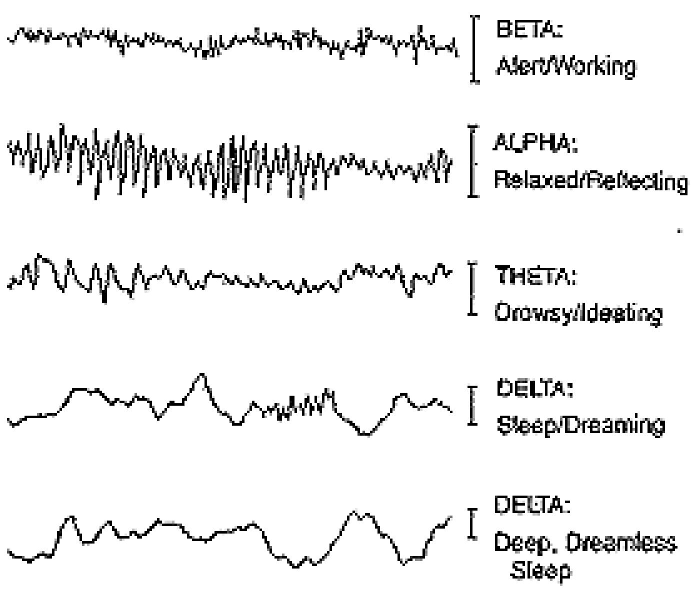


Image: Ned Herrmann, The Creative Brain

Delta waves are the slowest, around 1.5 to 4 Hertz. This is usually the sleep state.

Recently, a new type of EEG wave has been discovered. Called **Gamma Waves,** these are of higher frequency – 40 to 90 Hz – and appear for a brief period when one is integrating visual or other sensory input. Gamma waves indicate a state of intense, focused activity in the brain.

Men, women and children of all ages experience the same characteristic brainwaves. They are consistent across cultural boundaries.

3.2 Increased Alpha and Theta Activity

Yogis have long claimed that in addition to spiritual benefits, meditation is very beneficial to health; and meditation fosters creativity and increases intuition. Several scientific studies are now affirming this claim.

When there is increased alpha wave activity in the brain, it indicates a state of deep relaxation. In this state, the heart rate and blood pressure decrease; the rate of breath slows down and the parasympathetic nervous system gets activated. Most people can access the alpha state only when the eyes are closed.

However, a research published in 1966 [KASAMATSU 1966] concluded that long term Zen meditators get into an alpha state within 50 seconds of sitting in meditation. *This happens even if their eyes are open*. As the meditation progressed, alpha frequency decreased to about 8 cycles per second. It was found that meditators were able to enter this state at will. This deep relaxation and the accompanying parasympathetic response produced by meditation is thought to be responsible for its many stress relieving and healing benefits.

As the meditation progressed even further, rhythmical train of theta waves were detected. According to [ISHII 1999], theta activity in pre-frontal cortex is indicative of a high degree of concentration. Theta stage is also characterized by high levels of creativity and intuition, which affirms yogis' claim that meditation increases these faculties.

3.3 Alpha Blocking and Habituation

Yoga sutras tell us that a meditator has to live in the present moment. They also talk about a state of expanded awareness which accompanies meditation. The phenomenon of Alpha Blocking provide an explanation.

Alpha Blocking was first described in [KASAMATSU 1966].

To understand this phenomenon, let us imagine that a person who is reading quietly is suddenly disturbed by a loud noise. If the same sound is then repeated with a few seconds later his attention will again be diverted, only not as strongly nor for as long a time. If the sound is then repeated at regular intervals, the person will continue reading and become oblivious to the sound.

A normal subject with closed eyes produces alpha waves on an EEG tracing. The loud noise normally obliterates alpha waves for seven seconds or more; this is termed *alpha blocking*. In an experienced meditator, it was found that alpha blocking produced by the first noise lasts only two seconds. If the noise is repeated at 15 second intervals, we find that in the normal subject there is virtually no alpha blocking remaining by the fifth successive noise. This diminution of alpha blocking is termed *habituation* and persists in normal subjects for as long as the noise continues at regular and frequent intervals. In the meditator, however, no habituation is seen. His alpha blocking lasts two seconds with the first sound, two seconds with the fifth sound, and two seconds with the twentieth sound.

This implies that the experienced meditator has a greater awareness of his environment as the paradoxical result of meditative concentration. Thus meditation is both single point of concentration (and absorption) and also a state of expanded awareness.

3.4 Synchronized Gamma Waves

Is Meditation similar to sleep or is it an act of deep concentration? Yogic texts are unanimous on this issue: meditation is an act of deep [calm] concentration. A series of EEG studies of conscious perception provides the underlying neural correlates for this.

When the brain is involved in intense activity, such as visual perception, the EEG shows increased Gamma waves. When we perceive things unconsciously, the gamma waves are *desynchronized* – that is, different areas of the brain are producing gamma waves but these waves are out of step with each other, and are of different frequencies.

When we are involved in conscious perception however, the gamma waves are synchronized, in lock step, across wide areas of the brain. It is as if a large portion of the cortex has to be absorbed in the single task of binding various sensory inputs into one act of perception [MELLONI 2007].

When long time Buddhist meditators – those with over 20,000 hours "on the cushion" – were hooked up to an EEG machine and were asked to go into a deep meditative state, their EEG shifted to high frequency gamma activity [LUTZ 2004]. Not only was the gamma activity sustained, but it was also synchronized. This indicates that the meditative state is an act of deep engagement of the brain, and not of subconscious sleep (a sleep state would produce delta waves).

For meditators, this is reflective of their experience on the cushion: when deep in the absorption state of mediation, the stillness is one of expanded awareness, not one of tuned-out sleep. It turns out that this act of concentration and expanded awareness has wide-ranging benefits in terms of emotional regulation and a feeling of well-being. We will examine this in the next section.

4 Neuroscience of Hong Sau

A lot of scientific studies on meditation mentioned here involve a practice called **Mindfulness**. It has its roots in Buddhist meditative practices, and was popularized by the work of Jon Kabat-Zinn. The Hong-Sau technique taught by Paramhansa Yogananda is very similar to the Mindfulness technique. Thus, most of the research that was done on Mindfulness can be applied to Hong Sau as well.

4.1 Stages of Hong Sau

Like all meditative practices, Hong Sau can be thought of as having 3 phases: *relaxation, concentration,* and *expansion*. (See [JYOTISH]).

When our brain enters the alpha state, we are in the Relaxation phase. In the previous section, we have seen the neuroscience behind, and the benefits of, this phase.

Now let us examine the neuroscience of Concentration.

4.2 Concentration

Where exactly are we concentrating? What happens in the brain when we concentrate?

In [JYOTISH] the act of concentration is described as: *In meditation all of our scattered forces must be brought to a single point of concentration, usually at the spiritual eye, which is located at the point between the eyebrows in the frontal part of the brain.*

The medial frontal cortex (MFC – the area behind our foreheads) and the anterior cingulate cortex (ACC – which is deep within the brain around an inch and half behind the point between the eyebrows on either side), are the "attention centers". In MRI studies, these centers "light up"[1] when we are deeply attentive and focused on something [ISHII 1999].

Thus, when we lift the gaze to focus at the point between the eyebrows, we are helping light up these key attention centers. This is perhaps why most of us feel that this area is a natural center of focus.

When 15 Vipassana meditators were studied in [HOLZEL 2007], it was found that meditators showed strong activation in the MFC and ACC. The degree of activation was greater than control subjects who were focused on other tasks requiring concentration – e.g. performing mental calculations. From this, it is clear that meditators take themselves to a place of deeper concentration than most "normal" activities.

So far so good; the results affirm our natural conclusion that meditation requires deep concentration. But things begin to get interesting as we dig deeper into the nature of ACC.

The ACC is the brain center responsible for making choices. When we are in the watchful state, a lot of inner activity, at least initially, is concerned with *choosing not to get distracted*, rather than actually concentrating on the breath. This is the reason for the strong activation in the ACC. Also, according to [FARB 2007], this act of continually making choices from a watchful state of mind enables the brain to detect harmful habit patterns and inhibit those neural pathways. This leads to an enhanced sense of well-being, which has been observed in long term meditators [SIEGEL 2007].

Thus, the simple act of watchful concentration may be the key to fostering a sense of well-being and in actually re-wiring the brain into a happier modality over the long term.

4.3 Expansion

Meditation is not just concentration, but <u>calm</u> concentration.

Swami Kriyananda says in his book "Affirmations for Self Healing": *Concentration should not involve mental strain. When you really want something, it is difficult not to think about it! Concentrate with interest on whatever you do, and you will find yourself absorbed in it.*

We saw earlier that the area of the forehead – Anterior Cingular Cortex and Medial Frontal Cortex – light up in the MRI's of experienced meditators. An extraordinary study done in 2007 [BREFCZYNSKI 2007], showed that with very experienced and longer term meditators – those with more than 50,000 hours "on the cushion" – the activity in these areas *actually decreases*. This indicates that the act of maintaining concentration has become natural in experienced meditators. They no longer need to put much effort into remaining watchful.

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[1] The phrase "light up" shouldn't be taken literally. It doesn't mean that the meditator sees the inner light of the spiritual eye. Rather, it is referring to fact that an MRI scan detects increased activity in these areas as compared to the surrounding areas.

This seems to echo the words of Swami Kriyananda: *Concentration should not involve mental strain. When you really want something, it is difficult not to think about it! Concentrate with interest on whatever you do, and you will find yourself absorbed in it.*

"There is nothing in all of eternity except Right Here, Right Now!" Yogis say that meditation helps us keep in the present moment.

A study reported in [FARB 2007] showed that experienced meditators showed less activity in the medial pre-frontal cortex (mPFC). mPFC is often called the "narrative center" of the brain. It is the area which takes current sensory and other inputs and combines it with long term memory and emotional associations to create a narrative. This is why we tend to interpret current events within the context of a larger narrative of past experience. The results of this study indicate that experienced meditators are less prone to the influence of past narratives and habit patterns. Instead, they live in the present moment.

5 Meditation and Ageing

Does the brain actually change with meditation?

Recent research indicates that experienced meditators actually increased the grey matter volume in the hippocampus and orbito-frontal regions of the brain. These regions are responsible for emotional regulation and response control – in other words, *the reactive process* is controlled by these regions of the brain. According to [LUDERSA 2009], this could account for the meditator's ability to cultivate positive emotions, retain emotional stability, and engage in mindful behavior.

Meditation also increases the amount of grey matter in the Insular Cortex [HOLZEL 2008], [LAZAR 2005]. Among other things, the Insular Cortex is responsible for empathy.

According to a study reported in [LAZAR 2008], meditation reduces cortical thinning due to age in the pre-frontal regions. This can help slow or avoid the onset of neurological conditions such as dementia.

6 The Science of Yoga – Union

The goal of meditative practices is to achieve the state of Yoga – Union – of the little self with the higher Self. Yogis tell us that in this state, known as Samadhi, the sense of "embodiment" melts away and one perceives the underlying unity of all things. Recently discovered neural structures called Mirror Neurons may provide clues to the neural basis for this state.

In the book Autobiography of a Yogi, Paramhansa Yogananda describes his experience of Samadhi as "*Soul and mind instantly lost their physical bondage…My sense of identity was no longer narrowly confined to a body, but embraced the circumambient atoms.*" [Chapter 14 – An Experience in Cosmic Consciousness]

Scientists have discovered a certain type of neuron the neocortical area of the brain, which responds when <u>others</u> perform an action. For example, pain neurons in the Anterior Cingulate Cortex fire not only when the individual experiences pain, but also when she watches another individual experiencing pain. Similar neurons for touch have been discovered in the Parietal Lobe. These neurons have been labeled Mirror Neurons. Further experiments have suggested that in the absence extra inputs such as touch, the brain literally makes no distinction between you having an experience versus others having the same experience.

This is brought into stark relief in patients with a syndrome called "acquired hyperempathy". In one case, the patient who had had lost his hand watched another person's hand being stroked; the patient could not only see but actually feel the stroking in his own (amputated) hand. The mirror neurons in his brain, in the absence of the touch signal to indicate separateness, literally made no distinction between his experience and another person's experience. Similar results were observed when an intact arm was anesthetized (thus numbing the touch receptors in the skin) – the patient experienced touch sensations in her anesthetized hand by merely watching someone else being touched.

Thus, it seems that at least from a neurological perspective, our skin is the only thing that separates us from each other.

See [VSR] Chapter 4 for a detailed discussion of this phenomenon. For a short, informative, and entertaining talk on this topic, see the video: http://www.ted.com/talks/vs_ramachandran_the_neurons_that_shaped_civilization. It is a little over 7 minutes, and is time well spent.

7 A Caution

Our understanding of the human brain has improved by leaps and bounds since Magnetic Resonance Imaging (MRI) and related tools have come into use. It seems as though every day brings about a fresh insight on how the brain works. While the earlier generation of neuroscientists mostly focused on the relationship of brain to the body, tools such as the MRI are making it possible for them to investigate things like emotion, empathy, happiness, aesthetics and other topics that were hitherto in the realm of psychology. We are in the midst of a revolution in our understanding of the brain.

While these results help us understand the relationship between the brain, mind, and meditation, we should also be careful to not confuse the cause and the effect. Yogic view has always been that the mind (or even more precisely, consciousness) is the causative agent behind brain activity and not the other way 'round.

Most scientists take the opposite view – that the trillions of electrical signals which travel through the mind, in their totality, becomes the mind. It is based on an unstated but generally accepted doctrine in science – that only matter is real; therefore minds are in the brains and mental activity is nothing but brain activity.

Taking about this in his book "Science Set Free", Rupert Sheldrake, an eminent scientist, says: "*…science is being held back by centuries old assumptions that have hardened into dogmas. The sciences would be better off without them: freer, more interesting and more fun*"

Our awareness and experience of the Universe is an aspect of our consciousness, which exists beyond the confines of our brains. As noted in [JYOTISH]: *There are also many* *validated accounts (some in near-death experiences) of people being aware of events taking place far away from their physical presence. If it is the brain that produces consciousness, these examples could not happen, taking place, as they do, far beyond the scope of the physical brain.*

References

8 Books and Websites

[JYOTISH] How to Meditate: A step by step guide to the Art and Science of Meditation, by Jyotish Novak

> This book is a wonderful description of the practice of meditation. It takes you through the various steps of meditation practice, and gives exercises, visualizations, and breathing techniques to help you experience the stillness of the meditative state. The chapter on "Science Studies Meditation" is a great summary of several neurological studies done in this area. If you are new to meditation, definitely read this book. Even if you are an experienced meditator, you will find something new and useful here.

The books below are listed in the order of preference. Thus, if you wanted to read only one book, read Ramachandran's book below; if you want to read two, then add Hanson's book; and so on.

[VSR] Tell-tale Brain, by VS Ramachandran

> This book is a fascinating account of contemporary neuroscience. It talks about how neuroscience is tackling the questions of language, emotions, creativity and consciousness. It is also quite funny.

[HANSON] Buddha's Brain, by Rick Hanson, PhD and Richard Mendius MD

> This book is very well written and simple to read. It discusses how neuroscience can be used to deal with spiritual questions such as suffering, happiness, love, and wisdom. I found it to be very useful in helping to understand various studies on meditation and brain scans. The bulk of the book is devoted to several meditation techniques. I haven't practiced those techniques

[KEAN] The Tale of Dueling Neurosurgeons, by Sam Kean

> A lively, humorous, anecdote filled account of the history of neuroscience. In spite of having a high entertainment value, it is surprisingly informative. Like [VSR], it is filled with fascinating patient histories.

[ROBIN] A Handbook for Yogasana Teachers, by Mel Robin

> The words *encyclopedia* or *compendium* are not enough to describe the scope and depth of this book. It gives an extremely detailed treatment of anatomy, physiology, and neuroscience with a specific emphasis on how it applies to Yoga. The text itself is undoubtedly valuable and informative. The comprehensive set of references at the end are invaluable. *Be warned: you need to have a very high nerd quotient to get*

interested in this book. It weighs several pounds and thus is not suitable for one-handed operation.

[KAKU] The Future of the Mind, by Michio Kaku

As with other books by the author, he takes cutting edge research and speculates on what is possible. It is more speculative than the other books; and because it is speculation, it has a healthy dose of the author's opinion – which you may or may not agree with and they might irritate you. But the science is impeccable. Kaku, being a physicist, gives a definite physics oriented slant to neuroscience, which I found very interesting.

[WIKI 1] Brain Activity and Meditation.

http://en.wikipedia.org/wiki/Brain_activity_and_meditation

The article itself is very cautious and not very detailed. But the list of references are canonical. Use this as a jump-off point for further research.

[WIKI 2] Neural Mechanisms in Mindfulness Meditation

http://en.wikipedia.org/wiki/Neural_mechanisms_of_mindfulness_meditation

Wiki article which attempts to summarize current findings around what happens in the brain during mindfulness meditation (Hong Sau is an example of mindfulness meditation). Unfortunately, the article is poorly written, wishy-washy, and appears to be "designed by committee". But the list of references at the end are quite good.

9 Research Articles

The following lists some of the research articles that have been used as a basis for this class.

9.1 Meditation and Brain Wave Activity

9.1.1 Meditation increases Alpha & Theta activity; meditators experience Alpha Blocking

[KASAMATSU 1966] AN ELECTROENCEPHALOGRAPHIC STUDY ON THE ZEN MEDITATION (ZAZEN)

Akira Kasamatsu M.D. and Tomio Hirai M.D.

Psychiatry and Clinical Neurosciences, Volume 20, Issue 4, pages 315–336, December 1966

Zen meditation (ZAZEN) is a spiritual exercise held in the Zen sect of Buddhism. Apart from its religious significance, the training of Zen meditation produces changes not only in the mind but also in the body—these influences are of interest to scientific studies, from the stand point of psychology and physiology.

In the present study the EEG changes accompanied with Zen meditation have been revealed and described in detail. The authors discussed further these electro-graphic changes in relation to the consciousness with its underlying neurophysiological background, comparing with that of the hypnotic trance and sleep.

In our study, 48 priests and disciples of Zen sects of Buddhism were selected as the subjects and their EEGs were continuously recorded before, during and after Zen meditation. The following results were obtained;

1. The appearance of alpha waves were observed, without regard to opened eyes, within 50 sec. after the beginning of Zen meditation. These alpha waves continued to appear, and their amplitudes increased. And as Zen meditation progressed, the decrease of the alpha frequency was gradually manifested at the later stage. Further the rhythmical theta train with the amplitude modulated alpha-background was observed in some records of the priests. These EEG changes could be classified into 4 stages; the appearance of alpha waves (stage I), an increase of alpha amplitude (stage II), a decrease of alpha frequency (stage III) and the appearance of rhythmical theta train (stage IV).
2. These 4 stages of EEG changes were parallel with the disciples' mental states, which were evaluated by a Zen master, and disciples' years spent in Zen training.
3. These electrographic changes were also compared with that of the hypnotic trance and sleep. From the electroencephalographic point of view, the changes of stages I, II and III could not be clearly differentiated from those seen in hypnagogic state or the hypnotic sleep, though the changes during Zen meditation were more persistent and did not turn into deeper sleep pattern. The rhythmical theta train is suppressed by click stimulation and turns into a desynchronized pattern, whereas the drowsy pattern turns into alpha waves (the alpha arousal reaction).
4. The alpha blocking to the repeated click stimuli with regular intervals was also examined in Zen meditation with opened eyes and the ordinary conditions of control subjects with closed eyes. The former showed a fairly constant blocking time (3–5 sec.) to every stimuli repeated 20 times and the habituation was not recognized. On the other hand, in control subjects the habituation of alpha waves occurred very quickly. This alpha blocking, which is less susceptible to habituation, is of importance to consider the neurophysiological basis of the mental state during Zen meditation.

These electroencephalographic findings lead to the following conclusions; In Zen meditation, the slowing of EEG pattern is confirmed on the one hand, and the dehabituation of the alpha blocking on the other. These indicate the specific change of consciousness. The authors further discussed the state of mind during Zen meditation from the psychophysiological point of view.

9.1.2 Synchronized Gamma Wave Activity Characterizes Conscious Perception

[MELLONI 2007] Synchronization of neural activity across cortical areas correlates with conscious perception.

Melloni L1, Molina C, Pena M, Torres D, Singer W, Rodriguez E.

Journal of Neuroscience. 2007 Mar 14;27(11):2858-65.

Subliminal stimuli can be deeply processed and activate similar brain areas as consciously perceived stimuli. This raises the question which signatures of neural activity critically differentiate conscious from unconscious processing. Transient synchronization of neural activity has been proposed as a neural correlate of conscious perception. Here we test this proposal by comparing the electrophysiological responses related to the processing of visible and invisible words in a delayed matching to sample task. Both perceived and nonperceived words caused a similar increase of local (gamma) oscillations in the EEG, but only perceived words induced a transient long-distance synchronization of gamma oscillations across widely separated regions of the brain. After this transient period of temporal coordination, the electrographic signatures of conscious and unconscious processes continue to diverge. Only words reported as perceived induced (1) enhanced theta oscillations over frontal regions during the maintenance interval, (2) an increase of the P300 component of the event-related potential, and (3) an increase in power and phase synchrony of gamma oscillations before the anticipated presentation of the test word. We propose that the critical process mediating the access to conscious perception is the early transient global increase of phase synchrony of oscillatory activity in the gamma frequency range.

http://www.ncbi.nlm.nih.gov/pubmed/17360907

9.1.3 Meditation Produces Synchronized Gamma Waves

[LUTZ 2004] Long-term meditators self-induce high-amplitude gamma synchrony during mental practice

Antoine Lutz, Lawrence L. Greischar, Nancy B. Rawlings, Matthieu Ricard, and Richard J. Davidson

Proceedings of the National Academy of Sciences (PNAS), vol. 101 no. 46, 16369–16373, Nov 2004

Practitioners understand “meditation,” or mental training, to be a process of familiarization with one's own mental life leading to long-lasting changes in cognition and emotion. Little is known about this process and its impact on the brain. Here we find that long-term Buddhist practitioners self-induce sustained electroencephalographic high-amplitude gamma-band oscillations and phase-synchrony during meditation. These electroencephalogram patterns differ from those of controls, in particular over lateral frontoparietal electrodes. In addition, the ratio of gamma-band activity (25-42 Hz) to slow oscillatory activity (4-13 Hz) is initially higher in the resting baseline before meditation for the practitioners than the controls over medial frontoparietal electrodes. This difference increases sharply during meditation over most of the scalp electrodes and remains higher than the initial baseline in the postmeditation baseline. These data suggest that mental training involves temporal integrative mechanisms and may induce short-term and long-term neural changes.

http://www.pnas.org/content/101/46/16369.full

9.2 Neuroscience of Hong Sau Meditation

9.2.1 Which Parts of the Brain are concerned with Attention and Emotion?

[YAMASAKI 2002] Dissociable prefrontal brain systems for attention and emotion

Hiroshi Yamasaki, Kevin S. LaBar, and Gregory McCarthy

Proceedings of the National Academy of Sciences (PNAS), vol. 99, no. 17, pp. 11447–11451, August 2002

> The prefrontal cortex has been implicated in a variety of attentional, executive, and mnemonic mental operations, yet its functional organization is still highly debated. The present study used functional MRI to determine whether attentional and emotional functions are segregated into dissociable prefrontal networks in the human brain. Subjects discriminated infrequent and irregularly presented attentional targets (circles) from frequent standards (squares) while novel distracting scenes, parametrically varied for emotional arousal, were intermittently presented. Targets differentially activated middle frontal gyrus, posterior parietal cortex, and posterior cingulate gyrus. Novel distracters activated inferior frontal gyrus, amygdala, and fusiform gyrus, with significantly stronger activation evoked by the emotional scenes. The anterior cingulate gyrus was the only brain region with equivalent responses to attentional and emotional stimuli. These results show that attentional and emotional functions are segregated into parallel dorsal and ventral streams that extend into prefrontal cortex and are integrated in the anterior cingulate. These findings may have implications for understanding the neural dynamics underlying emotional distractibility on attentional tasks in affective disorders.

http://www.pnas.org/content/99/17/11447.full

9.2.2 Focused Attention Activates Medial PFC, including ACC

[ISHII 1999] Medial prefrontal cortex generates frontal midline theta rhythm

Ishii R, Shinosaki K, Ukai S, Inouye T, Ishihara T, Yoshimine T, Hirabuki N, Asada H, Kihara T, Robinson SE, Takeda M

Neuroreport. 1999 Mar 17;10(4):675-9

> Frontal midline theta rhythm (Fm theta) is a distinct theta activity of EEG in the frontal midline area that appears during concentrated performance of mental tasks in normal subjects and reflects focused attentional processing. To tomographically visualize the source current density distributions of Fm theta, we recorded Fm theta by using a 64-channel whole-head MEG system from four healthy subjects, and applied a new analysis method, synthetic aperture magnetometry (SAM), an adaptive beam forming method. Fm theta was observed in the MEG signals over the bilateral frontal regions. SAM analysis showed bilateral medial prefrontal cortices, including anterior cingulate cortex, as the source of Fm theta. This result suggests that focused attention is mainly related to medial prefrontal cortex.

http://www.ncbi.nlm.nih.gov/pubmed/10208529

9.2.3 ACC and Medial PFC Activated More in Meditators than Mere Focused Attention

[HOLZEL 2007] Differential engagement of anterior cingulate cortex and adjacent medial frontal cortex in adept meditators and nonmeditators

Hölzel BK, Ott U, Hempel H, Hackl A, Wolf K, Stark R, Vaitl D

Neuroscience Letters, Volume 421, Issue 1, 21 June 2007, Pages 16–21

> This study investigated differences in brain activation during meditation between meditators and non-meditators. Fifteen Vipassana meditators (mean practice: 7.9 years, 2 h daily) and fifteen non-meditators, matched for sex, age, education, and handedness, participated in a block-design fMRI study that included mindfulness of breathing and mental arithmetic conditions. For the meditation condition (contrasted to arithmetic), meditators showed stronger activations in the rostral anterior cingulate cortex and the dorsal medial prefrontal cortex bilaterally, compared to controls. Greater rostral anterior cingulate cortex activation in meditators may reflect stronger processing of distracting events. The increased activation in the medial prefrontal cortex may reflect that meditators are stronger engaged in emotional processing.

http://www.ncbi.nlm.nih.gov/pubmed/17548160

9.2.4 "Calm Concentration" in Experienced Meditators

[BREFCZYNSKI 2007] Neural correlates of attentional expertise in long-term meditation practitioners

J. A. Brefczynski-Lewis, A. Lutz, H. S. Schaefer, D. B. Levinson, and R. J. Davidson

PNAS vol. 104, no. 27 pp. 11483–11488. July 3, 2007

> Meditation refers to a family of mental training practices that are designed to familiarize the practitioner with specific types of mental processes. One of the most basic forms of meditation is concentration meditation, in which sustained attention is focused on an object such as a small visual stimulus or the breath. In age-matched participants, using functional MRI, we found that activation in a network of brain regions typically involved in sustained attention showed an inverted u-shaped curve in which expert meditators (EMs) with an average of 19,000 h of practice had more activation than novices, but EMs with an average of 44,000 h had less activation. In response to distracter sounds used to probe the meditation, EMs vs. novices had less brain activation in regions related to discursive thoughts and emotions and more activation in regions related to response inhibition and attention. Correlation with hours of practice suggests possible plasticity in these mechanisms.

http://www.pnas.org/content/104/27/11483.full.pdf+html

9.2.5 Meditation helps you Live in the Present

[FARB 2007] Attending to the present: mindfulness meditation reveals distinct neural modes of self-reference

Norman A. S. Farb, Zindel V. Segal, Helen Mayberg, Jim Bean, Deborah McKeon, Zainab Fatima, and Adam K. Anderson

Social Cognitive & Affective Neurosci 2007 Volume 2, Issue 4, Pp. 313-322

> It has long been theorised that there are two temporally distinct forms of self-reference: extended self-reference linking experiences across time, and momentary self-reference centred on the present. To characterise these two aspects of awareness, we used functional magnetic resonance imaging (fMRI) to examine monitoring of enduring traits ('narrative' focus, NF) or momentary experience ('experiential' focus, EF) in both novice participants and those having attended an 8 week course in mindfulness meditation, a program that trains individuals to develop focused attention on the present. In novices, EF yielded focal reductions in self-referential cortical midline regions (medial prefrontal cortex, mPFC) associated with NF. In trained participants, EF resulted in more marked and pervasive reductions in the mPFC, and increased engagement of a right lateralised network, comprising the lateral PFC and viscerosomatic areas such as the insula, secondary somatosensory cortex and inferior parietal lobule. Functional connectivity analyses further demonstrated a strong coupling between the right insula and the mPFC in novices that was uncoupled in the mindfulness group. These results suggest a fundamental neural dissociation between two distinct forms of self-awareness that are habitually integrated but can be dissociated through attentional training: the self across time and in the present moment.

http://scan.oxfordjournals.org/content/2/4/313.full

9.2.6 "Watchfulness" results in a sense of well-being

[SIEGEL 2007] Mindfulness training and neural integration: differentiation of distinct streams of awareness and the cultivation of well-being

Daniel J. Siegel

Social Cognitive & Affective Neurosci 2007, Volume 2, Issue 4 Pp. 259-263

> In recent years, the ancient practice of being aware of one's sensory experience in the present moment—of 'being mindful'—has taken a prominent place in discussions among clinicians, educators and the general public (Epstein, 1999; Kabat-Zinn, 2003; Bishop et al., 2004; Germer et al., 2005). Found in most cultures throughout history and now resurfacing in modern times, in both the East and in the West, the practice of living in the present has been offered as a way to cultivate well-being in our minds, our bodies, and even in our relationships with each other (Kornfield, 2008). Science has taken note of these suggestions and a number of investigators have focused their objective lens on this form of subjective, inner focus of the mind on present experience. Evidence from these studies supports the notion that being mindful, being aware of the present moment without grasping on to judgments, does indeed improve immune function, enhance a sense of equanimity and clarity and may even increase empathy and relational satisfaction (Davidson et al., 2003, and see Siegel, 2007, for a summary of these research studies).

http://scan.oxfordjournals.org/content/2/4/259.full

9.3 Meditation, Ageing, and Neuroplasticity

[HOLZEL 2008] Investigation of mindfulness meditation practitioners with voxel-based morphometry

Britta K. Hölzel, Ulrich Ott, Tim Gard, Hannes Hempel, Martin Weygandt, Katrin Morgen, and Dieter Vaitl

Social Cognitive & Affective Neurosci Volume 3, Issue 1, Pp. 55-61.

> Mindfulness meditators practice the non-judgmental observation of the ongoing stream of internal experiences as they arise. Using voxel-based morphometry, this study investigated MRI brain images of 20 mindfulness (Vipassana) meditators (mean practice 8.6 years; 2 h daily) and compared the regional gray matter concentration to that of non-meditators matched for sex, age, education and handedness. Meditators were predicted to show greater gray matter concentration in regions that are typically activated during meditation. Results confirmed greater gray matter concentration for meditators in the right anterior insula, which is involved in interoceptive awareness. This group difference presumably reflects the training of bodily awareness during mindfulness meditation. Furthermore, meditators had greater gray matter concentration in the left inferior temporal gyrus and right hippocampus. Both regions have previously been found to be involved in meditation. The mean value of gray matter concentration in the left inferior temporal gyrus was predictable by the amount of meditation training, corroborating the assumption of a causal impact of meditation training on gray matter concentration in this region. Results suggest that meditation practice is associated with structural differences in regions that are typically activated during meditation and in regions that are relevant for the task of meditation.

http://scan.oxfordjournals.org/content/3/1/55.full

[LAZAR 2005] Meditation experience is associated with increased cortical thickness

Sara W. Lazar, Catherine E. Kerr, Rachel H. Wassermanb, Jeremy R. Gray, Douglas N. Greve, Michael T. Treadway, Metta McGarvey, Brian T. Quinn, Je¡ery A. Dusek, Herbert Benson, Scott L. Rauch, Christopher I. Mooreh and Bruce Fischl

NeuroReport Vol 16 No 17, pp. 1893-1897, 28 November 2005

> Previous research indicates that long-term meditation practice is associated with altered resting electroencephalogram patterns, suggestive of long lasting changes in brain activity. We hypothesized that meditation practice might also be associated with changes in the brain's physical structure. Magnetic resonance imaging was used to assess cortical thickness in 20 participants with extensive Insight meditation experience, which involves focused attention to internal experiences. Brain regions associated with attention, interoception and sensory processing were thicker in meditation participants than matched controls, including the prefrontal cortex and right anterior insula. Between-group differences in prefrontal cortical thickness were most pronounced in older participants, suggesting that meditation might offset age-related cortical thinning. Finally, the thickness of two regions correlated with

meditation experience. These data provide the first structural evidence for experience-dependent cortical plasticity associated with meditation practice.

http://www.kripalu.org/pdfs/IEL/Lazar05.pdf

[LUDERS 2009] The underlying anatomical correlates of long-term meditation: larger hippocampal and frontal volumes of gray matter.

Luders, E., Toga, A. W., Lepore, N., & Gaser, C.

Neuroimage, 45(3), 672-678, 2009

Although the systematic study of meditation is still in its infancy, research has provided evidence for meditation-induced improvements in psychological and physiological well-being. Moreover, meditation practice has been shown not only to benefit higher-order cognitive functions but also to alter brain activity. Nevertheless, little is known about possible links to brain structure. Using high-resolution MRI data of 44 subjects, we set out to examine the underlying anatomical correlates of long-term meditation with different regional specificity (i.e., global, regional, and local). For this purpose, we applied voxel-based morphometry in association with a recently validated automated parcellation approach. We detected significantly larger gray matter volumes in meditators in the right orbito-frontal cortex (as well as in the right thalamus and left inferior temporal gyrus when co-varying for age and/or lowering applied statistical thresholds). In addition, meditators showed significantly larger volumes of the right hippocampus. Both orbito-frontal and hippocampal regions have been implicated in emotional regulation and response control. Thus, larger volumes in these regions might account for meditators' singular abilities and habits to cultivate positive emotions, retain emotional stability, and engage in mindful behavior. We further suggest that these regional alterations in brain structures constitute part of the underlying neurological correlate of long-term meditation independent of a specific style and practice. Future longitudinal analyses are necessary to establish the presence and direction of a causal link between meditation practice and brain anatomy.

http://www.appliedmeditation.org/dome/201/attention/grey_matter.pdf