Impact of Meditation on Brain Function

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Abstract

Meditation can be defined as a collection of mental training techniques aimed at regulating cognition, emotions, and the self. Rooted in spirituality, these practices take many forms in a variety of religions for some, or music and connection with nature for others. Western medical communities have begun to take a deeper look at this ancient phenomenon and have found it has several benefits, including the improvement of neuroplasticity, mental health, multifactorial diseases, and even age-related neurodegeneration. Specifically, Magnetic Resonance Imaging (MRI) has shown positive physical changes and introduced the idea of the Brain Theory of Meditation (BTM). This theory suggests that, through meditation, individuals can surpass previously assumed limitations of the human brain, increasing a multitude of cognitive functions. This change in physiology introduces a new field of discovery that calls for a reexamination of the inner workings of spirituality and health and what the potential for the human mind truly is.

Introduction

Meditation has become a modern focus in research after discovering the many benefits of this ancient practice, especially associated with the brain. Through the use of neuroimaging techniques, specifically EEG, researcher Julio Rodriguez-Larios has found that repetitive meditation practice can lead to increased activation of productive brain sites, strong neural pathways, and reconstruction of the brain over time (Rodriguez-Larios et al., 2021).

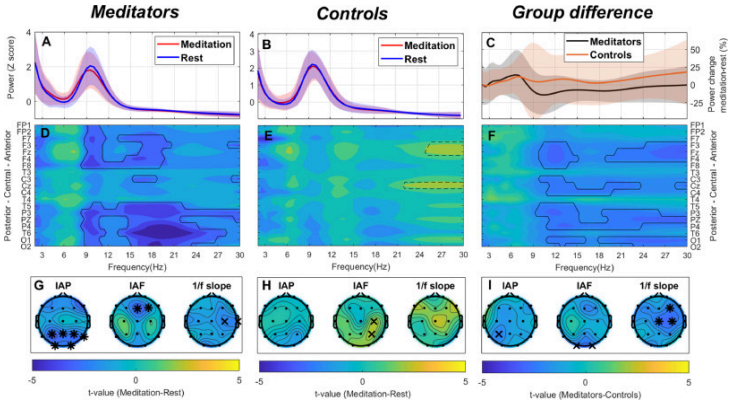

Figure 1. EEG spectral modulations associated with meditation in meditators and control groups (Rodriguez-Larios et al., 2021)

Through MRI experiments, more evidence suggests that over time meditation results in the activation of emotional and cognitive centers of the brain, specifically the prefrontal cortex, amygdala, and hippocampus, potentially lowering the risk for age-related neurodegenerative diseases and increasing cognition in young and middle-aged individuals (Davidson & McEwen, 2012) & (Newberg, 2001). Such drastic changes from a mental exercise suggest that thoughts affect our biology as seen in a slow down of telomerase shortening which increases the longevity of cells by preserving chromosomes throughout the aging process and implying an antiaging effect of meditation. (Epel, E. S., et al. 2009). Gray matter– which plays a critical role in processing information and regulating thoughts, memories, emotions, sensory input, and muscle movements–consists of high concentrations of neuronal bodies, axon terminals, and dendrites. More recent evidence shows that activities like meditation can boost the production of gray matter cells, challenging previous assumptions that brain cells stop developing after childhood. Studies have found that the brain's neuroplasticity continues into adulthood, meaning that the brain can grow and adapt, particularly through practices that stimulate cognitive and sensory engagement, such as mindfulness and other forms of meditation (Lazar et al., 2005; Hölzel et al., 2011). These findings highlight the brain's capacity for ongoing development and regeneration, even in later stages of life.

New studies indicate that meditation may also promote the growth of new neurons in areas of the brain associated with memory, emotion, and stress regulation, suggesting substantial advantages for both mental and physical health (Chaix, R., et al. 2017). Although the field is in its infancy, these discoveries offer promising opportunities for employing meditation not only as a means for mental clarity and relaxation but also as a technique that could enhance brain health at a cellular level. As researchers continue to explore these effects, meditation remains a promising and accessible practice with potential benefits that may surpass our existing understanding. In this paper, we will analyze the physiological effects of meditation on the brain, its long-term effects throughout the aging process, and how assorted meditations manifest in different effects in the brain.

Physiological Effect

In regards to studies conducted determining hot spots during meditation, neuroimaging studies have implied a few candidate regions that are most activated in continuous practice. An 8-week study using structural magnetic resonance imaging (MRI) on long-term mindfulness meditators revealed physical changes in brain structure (Hölzel et al. 2011). Notable findings included increased gray matter density and greater cortical thickness in brain regions associated with cognition, particularly in the posterior areas of the dorsal attention network (DAN). Other commonly activated regions include the precuneus, a region dedicated to Visuospatial processing, episodic memory retrieval, self-relevant processing, consciousness, and prefrontal regions of the default mode network (DMN), a notoriously large brain network most commonly active when the brain is at rest or not actively focused on the outside world. More longitudinal studies (Yang 2019), argue that the effects are more prevalent in longer-practicing meditators (people who meditate) and find more drastic physiological effects, in addition to a reduction in perceived stress and gray matter pathway strength, alluding to a correlation between improvement in mental emotional health and neuroplastic efficiency.

Meditation starts a chain of intricate neurobiological mechanisms that spread its advantages from the mind to the body. Research, exemplified by a study conducted by Hölzel et al. (2011), suggests that meditation can alter the structure and function of brain regions associated with stress, pain, and emotional control. Specifically, MRI scans revealed that engaging in mindfulness meditation can increase the thickness of the prefrontal cortex, a brain region involved in emotional control and decision-making. Improved function in the prefrontal cortex could potentially help the brain handle stress more effectively, leading to lower activation of the sympathetic nervous system, resulting in decreased blood pressure and reduced inflammation in the body.

During pain management, meditation influences the somatosensory cortex and insula, which are important in processing pain. Zeidan et al. (2011) showed that meditation decreased pain perception by influencing these brain regions, leading to less activity in the somatosensory cortex (related to feeling physical pain) and more activity in the anterior insula (connected to thinking about pain). This change assists the brain in reinterpreting pain signals, resulting in decreased pain perception and modifying chronic pain responses by reducing the brain's usual response to pain stimuli.

Moreover, meditation influences the brain's limbic system, particularly the amygdala, to help regulate the body's response to stress. Research conducted by Taren et al. (2013) discovered that participating in mindfulness training resulted in a decrease in the volume of the amygdala and a decrease in its activity when faced with stress. This change assists in controlling the release of cortisol from the hypothalamic-pituitary-adrenal (HPA) axis, which plays a crucial role in the body's response to stress. Decreased cortisol levels aid in cardiovascular health, enhance immune function, and decrease inflammation (Thau et al, 2023), demonstrating how meditation's impact on the brain's structure and function results in tangible physical health advantages in various bodily systems.

Meditation and Aging

Meditation’s most notable benefits are its prevention and improvement of Alzheimer’s, dementia, and other neurodegenerative diseases. Increasing life expectancy across the globe leads to increased cases of these neurocognitive diseases. The Alzheimer's Disease International Association estimates 36 million people worldwide currently suffer from dementia with this number expected to double every 20 years. With meditation research in its infancy, many medical professionals project this technique to be used as a counter mechanism to fight dementia after its onset as well as as a preventative measure for those who are at risk.

A study was conducted at the University of Pennsylvania, of 50 subjects ranging from 52 and 72 who have a history of memory complications or a diagnosis of cognitive impairment (Newberg, A. B., et al. 2006). One group was instructed to practice a 12-minute guided meditation every day for eight weeks while the others were said to have been placed on a waiting list. After examination of cognitive tests and a single photon emission computed tomography (SPECT) scan, measuring cerebral blood flow through brain imaging, it was found that those who practiced meditation showed significantly higher activity in the posterior cingulate gyrus region, associated with learning and memory, and the first area of the brain to decline in function in the onset of Alzheimer's disease. All participants who underwent the meditation regimen saw at least some statistically significant improvement in cognitive ability–

more specifically improvements in verbal memory, executive function, and attention. Principle Investigator Andrew Newberg M.D., assistant professor of radiology at the University of Pennsylvania School of Medicine, added

> **For the first time, we are seeing scientific evidence that meditation enables the brain to actually strengthen itself, and battle the processes working to weaken it.**

More evidence suggests that meditation can even be used as a preventative mechanism before neurodegeneration.

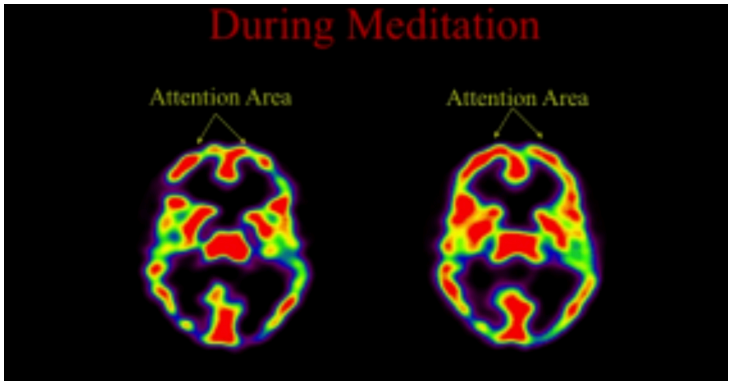

Figure 2. Side by side MRI comparison of brain during meditation with attentional area on the frontal lobe (Newberg et al., 2006)

In 2005, Dr. Lazar conducted a study with 35 participants: 15 control subjects representing the average person and 20 practitioners of Vipassana, a form of mindfulness meditation typically taught over 10 days with 10 hours of daily practice and minimal resources.. The objective was to compare the speed of neurodegeneration between the control and meditation practitioners through observation of cortical thickness in 2 of the commonly at-risk areas of the brain–the right insula and right frontal cortex. Cortical thickness was measured at thousands of points in the vicinity of the area, between inner white and gray matter as well as outer gray and cerebrospinal fluid boundaries. Analysis revealed a significant interaction between group type and age in the right frontal brain region. While participants in the control group demonstrated marked age-related cortical thinning ($r = -0.76$; $P = 0.001$), the study did not find evidence of significant differences in cortical thickness between older and younger meditation practitioners ($r = -0.05$; $P = 0.83$). However, this result does not confirm the absence of a difference and may require further investigation with larger samples. Researchers noted that the average cortical thickness in meditation practitioners aged 40-50 was comparable to that of individuals aged 20-30, including both meditators and controls. This suggests that meditation may help preserve cortical integrity and mitigate age-related neural degeneration and that practicing meditation regularly can slow the rate of natural neurodegeneration at risk locusts and preserve these areas for longer periods of time. Damage to these areas creates at-risk individuals for other neurocognitive diseases that commonly come with age such as Alzheimer's Disease and dementia (Lazar et al, 2005).

Assorted Meditations, with Assorted Effects

Being an ancient technique, meditation has evolved into hundreds of practices worldwide today, some being connected to religion while others being used as relaxation methods in schools. As a result, each form of meditation serves a different purpose and many times a different outcome and physiological change in the body, with some being more effective than others. The most common forms of meditation include Zen, which focuses on seated meditation and breath awareness; Vipassana, a practice rooted in observing sensations and thoughts to develop insight; mindfulness, where attention is brought to the present moment without judgment; Loving-kindness, which involves cultivating compassion and positive feelings toward oneself and others; and Transcendental Meditation, a technique using a mantra to reach a deep state of relaxation and awareness. As a result, no definition of meditation is truly all-encompassing. The scientific community began to study the differences to help categorize but their findings have revealed the benefits of each.

A study published in The Journal of Personality and Social Psychology, aimed to find if there was a difference in effectiveness between the three in terms of retaining cognitive ability, the findings were aimed to determine which would be most beneficial to those suffering with neurocognitive diseases.The study involved 73 seniors with an average age of 81, who were randomly divided into four groups. Three groups practiced different meditation techniques for 12 weeks while the fourth group served as the control group. The techniques included transcendental meditation, mindfulness meditation, and a breath work relaxation program which were to be practiced twice a day for 20 minutes for 12 weeks. The study included a variety of tests to get a cohesive idea of the specific effects each meditation technique was offering, including the Stroops test for cognitive flexibility, associate learning subtest for memory, and word fluency scale/overlearned verbal task for verbal fluency of elderly. The tests were administered before and after the meditation regimen, after 18 months, and after 3 years. The results suggest a strong improvement in measured variables in the group of subjects using

transcendental meditation, followed by mindfulness. Worse results on memory tests were shown in the control group and in the group with the relaxation program. In addition, testing after 3 years revealed 100% maintained effects of enhanced cognitive ability in persons using transcendental meditation and 87.5% in those within the mindfulness program. Other groups had lower scores (65 and 75%) (Alexander et al 1989).

Conclusion

Meditation is emerging as a promising tool with profound effects on the brain and body. Research has shown its ability to enhance neuroplasticity, reduce chronic stress, and improve cognitive functioning, all of which are critical in preventing or slowing neurodegenerative diseases such as Alzheimer's and Parkinson's (Lavretsky et al., 2015). By decreasing brain inflammation, promoting healthy neural connections, and reducing oxidative stress, meditation may serve as a non-invasive, cost-effective preventive strategy for these and other age-related conditions (Creswell et al., 2012).

Ongoing studies are focusing on how meditation can influence specific biomarkers associated with neurodegeneration, such as amyloid-beta plaques in Alzheimer's or alpha-synuclein in Parkinson's. Other research is delving into the role of meditation in enhancing mitochondrial health (Epel et al., 2009) and reducing systemic inflammation—factors linked to many chronic diseases, including cardiovascular issues, diabetes, and autoimmune conditions. Advances in neuroimaging and biomarker analysis are helping researchers identify the precise neural pathways and physiological changes meditation induces, offering insights into personalized prevention strategies.

As this field expands, meditation may become an integral part of preventive healthcare. It holds promise not only for delaying the onset of neurodegenerative diseases but also for improving overall health, reducing the prevalence of chronic conditions, and fostering resilience against the challenges of aging. By combining ancient wisdom with modern science, meditation could redefine our approach to health and disease prevention.

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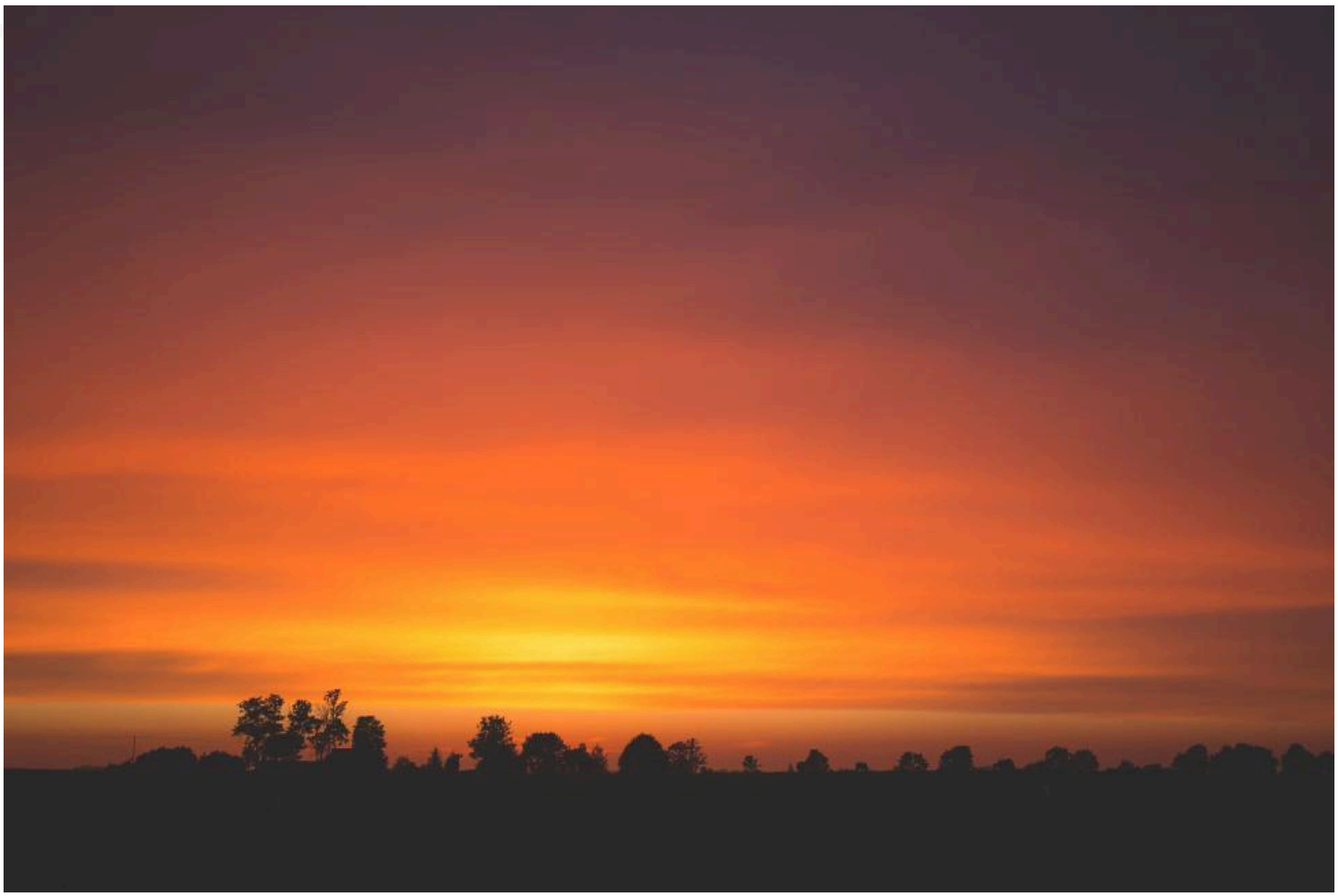

About the Author

Anika Chandola is a Freshman Majoring in MCB with a minor in Psychology and Chemistry on the Pre-Med track. She is currently working in Bagchi Lab researching the environmental impact on reproductive health and volunteered at UChicago's Phlebotomy Clinic. She is also a member of the Gamma Phi Beta Soroity working alongside Girls on the Run. In her freetime she enjoys fashion, swimming, pageants and playing the piano. She hopes to become more involved in the neuroscience field and learn more about this diverse community.