Neurophysiological Mechanisms of Meditation on Brain Activity and Its Effects on Cognitive Functioning

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Abstract. Currently, individuals encounter more mental tension and opt for meditation practices to alleviate it. The neurological mechanisms behind meditation have been studied in order to apply meditation practice in medical care. To date, researchers categorize meditation based on its impact on mental health, employing distinct meditation techniques in various studies. According to previous studies, the alternative of brain structure is affected by meditation practice. Moreover, the changes in brain waves provide the basic mechanism of meditation. However, the precise process of how meditation affects the brain seems unclear; the process of meditation from neuron activity to the application in treatment is unapparent too. This study researches the origin and classification of meditation, distinguishing the most common types of meditation practice based on the previous study. Also, this study analyzes the development of brain structures like the prefrontal cortex, hippocampus, gray matter density, and the changes in brain waves during the meditation exercise. Psychological and clinical effects of meditation are summarized; the popular study methods about the brain's activity are also given. This study finds the connection between the micro- and macro-mechanisms of meditation and emphasizes the use of meditation in clinical treatment. However, the study didn't focus much on neuron circuit changes in meditation, this field needs to be researched in the future.

Keywords: Meditation; neurology; brain structure; prefontal cortex; hippocampus; brain waves.

1. Introduction

The neurophysiological mechanisms of meditation on brain activity and its effects on cognitive functioning have been a topic of interest in recent research. A study laid a foundation in the molecular mechanisms of medication, which built the connection of mindfulness meditation with neuroscience, giving the explanation of using meditation as a therapy from the view of brain signals and brain structure [1]. Sharma gave a dedicated introduction to the development and history of meditation, which really emphasized the importance of this simple-looking relaxation activity [2]. Sharma sorted meditative movement exercises into different levels such as the senses, mind intellect and emotion, easing later researchers to define and categorize meditation practice discussing the effects on the function and structure of the human brain under the mental training. He pointed out the gray matter and brain regions' changes [3]. The changing gray matter in meditative practices gave strong evidence of how spiritual practice affects brain structure. Marchand figured out part of the brain cortex's function changed after mindfulness practice [4]. The specific changed region of brain surface he noted also supports later research about the function of medication.

Subsequent to doing the studies on brain structures, how meditation affects the brain waves is another essential topic. One example is the study which studies alpha brainwaves in meditation activity [5]. The binaural beats can help researchers to explore how listening to music plays a role in relaxation [6]. After discussing the studies about medication theory, the research about applications for the medical cure should be emphasized. Lots of studies have been done to show medication's function of relieving negative moods, such as stress and anxiety. The related study found that yoga therapy may be helpful to those with anxiety disorders and would decrease the production of negative emotions [7]. Several serious diseases could also adopt meditation as a therapy. The study showed that meditation could help children get out of Post-Traumatic Stress Disorder [8]. From the studies, electroencephalogram, electroretinogram, and function magnetic resonance imaging and neuroimaging were the tools that were frequently applied in the study process [9,10].

Overall, this study will provide a fundamental definition of meditation, especially highlighting contemporary advanced meditative techniques. Then summarize the comprehensive impact on the structure of the human brain and its waves. Subsequently, this research will examine the practical application of meditation in terms of clinical medicine.

2. Meditation

2.1. Concept

Meditation has a strong connection with neurology, even before people figured out the scientific functions behind meditation practice. In the ancient Vedic text, meditation is defined as an exercise of consciousness that results in the enhancement of mental ability. According to Vedic science, the true purpose of meditation is to connect oneself to one's deep inner Self [2]. To some degree, meditation is an achievable exercise for individuals to communicate and effect the deep inner self, which is the source of intelligence and creativity. Meditation may also be an attempt at the conscious mind to realize the unaware part of ourselves. According to the research, it can be determined that meditation is often used to depict the mental training technique engaged by meditators and the resulting changed state of consciousness [2]. However, this study needs to clarify that meditation is a concept rather than a method; it could be divided into different classifications with the diverse practice forms and distinct effects.

2.2. Classification

Meditation had not been sorted systematically until the research of Matko and Sedlmeie was published. Matko and Sedlmeier classify the meditation technique into activation and amount of body orientation. Furthermore, these two dimensions could be divided more precisely into seven clusters: mindful observation, body-centered meditation, visual concentration, contemplation, affect-centered meditation, mantra meditation, and meditation with movement [11]. Every cluster has its unique impact on participants mentally and physically. Therefore, this classification method provides great help for subsequent research.

Zeidan et al. demonstrated that mindfulness-based pain management correlated with increased activation in brain regions linked with the cognitive regulation of pain [12]. Dodich et al. discovered enhanced gray matter density resulting from a 4-week Sahaj yoga meditation regimen and alterations in the consistency of intrinsic brain activity in the right inferior frontal gyrus [13]. From these above studies, researchers are undertaking targeted experimental studies on various meditation techniques, hence reinforcing the value of categorizing meditation. However, the classification needs to be more precise according to the change of brain structures and functions. Electroencephalogram (EEG) and magnetic resonance imaging (MRI) can help detect the variations of brain, thus refining the category.

3. Meditaion Effect the Brain

3.1. Brain structure-- prefrontal cortex and hippocampus

Meditation practice can improve prefrontal cortex (PFC) functions through increasing functional connections of different brain regions. Verma et al. viewed various neuroimaging interventions of functional connectivity on meditators compared with non-meditators. The result shows that meditation practices are related to enhanced neural function and processing in the brain area associated with different parts of the PFC. To be more specific, dorsolateral PFC (dIPFC) and anterior cingulate cortex (ACC) located in the lateral region of the prefrontal cortex are two parts that are being focused on in research [14]. Stronger and greater activation is found in these two areas during the meditation practice [15]. Simultaneously, the dorsomedial prefrontal cortex (dmPFC), which lies in the medial region of the PCF, shows related activation to mindfulness meditation. In the research of Doll et al., healthy controls underwent two weeks of training in mindfulness-based attention-to-

breath meditation and were then exposed to unpleasant images during both attention-to-breath and passive viewing while having fMRI scans [16]. According to the experiment's findings, attention-to-breath (ATB) was generally linked to the left dorso-medial prefrontal cortex. Additionally, ATB decreased amygdala activation and enhanced amygdala–prefrontal integration, which is linked to mindfulness ability. Marchand also supports that mindfulness impacts the function of the medial cortex and associated default mode network as well as insula and amygdala [17].

For another essential part of the brain, the hippocampus, which strongly corresponds with memory and emotional regulation, also shows significant activation during silent mantra meditation [18]. The research uses high-resolution MRI data of 44 patients, setting out to investigate the underlying structural consequences of long-term meditation with various regional specificities. As a result, Luders et al. detect significantly large volumes of the right hippocampus, and this might mean the meditators' habits to develop positive emotions would be strengthened [19].

3.2. Brain Structure-- gray Matter Density

Besides the changes of specific brain components, a wide range of brain areas increase their gray matter density after long-term meditation. Hölzel et al. investigate the changes in brain gray matter with the participants in a Mindfulness-Based Stress Reduction (MBSR) program. According to the experiment, anatomical magnetic resonance (MR) scans from 16 healthy, meditation-naïve volunteers were collected before and after they finished the 8-week program [20]. Changes in gray matter concentration were studied using voxel-based morphometry and compared with a waiting list control group of 17 individuals. The results imply that involvement in MBSR is related to variations in gray matter concentration in brain areas involved in learning and memory processes, mood regulation, and so forth. Moreover, Vestergaard-Poulsen et al. report evidence of higher GMD in lower brain stem regions through using magnetic resonance imaging [21].

3.3. Brain Waves

In the section that follows, the changes in brain waves will be studied, which is another influence of meditation on brain functions. In the research, 8 participants practiced Dynamic Meditation at least 1 month, showing the result that delta brain waves, theta brain waves, and alpha brain waves increase [22]. Gupta et al. argues that alpha binaural beats can help individuals relax and reach a meditative state, which indicates that alpha brainwaves may play an important role in the microprocess of meditation [23]. Gaur et al. do research on yoga, which is a form of meditation and can help in the improvement of muscle strength as well as mental relaxation. These meditation exercises stimulate certain brain regions to enhance brain wave intensity, and long-term practice is associated with the constant changes in the brain's activity [24]. The outcome shows that alpha and gamma brain wave power increases; however, theta and beta brain wave power decreases. A growth in alpha and a reduction in theta power might lead to better memory. The theta activity generates sleepiness, which can cut down the performance in cognitive work. Furthermore, excitement is associated with increased beta brain activity. In the study, a beta wave decreased slightly would imply that there is no animation during yoga exercise [23].

4. Application in Medical Treatment

4.1. Brain Waves

Meditation practice is widely used in releasing negative emotions like stress, depression, and anxiety. Compared with other stress-reducing approaches, meditation exercise is more efficient and achievable for individuals. According to Mohan et al., meditation is related to relaxation, and it can reduce the negative effect of stress when practiced before the stress event. The research includes 32 healthy adults who had never practiced meditation before, exerting the stress emotion by asking them to play a stressful computer game. To judge the stress level of subjects, physical activities like galvanic skin response, heart rate, electromyography, sympathetic reactivity, and cortisol are

evaluated. For examining mental altering, the central nervous system functions are assessed using the Wechsler Memory Scale and Visual Choice Reaction Time (VCRT) [25]. However, Fredrickson et al. finds loving-kindness meditation strongly boosts subjects' positive emotions but has no change in negative emotions. Multilevel models also emphasize the relation between the duration of meditation practice and positive emotions [26].

As for the root cause, Magalhaes et al. (2018) do research on the influence of meditation processing of negative emotional stimuli, finding greater prefrontal activity and increasing recruitment of cognitive control resources in native and long-term meditators [27]. This might explain the generation of interoceptive awareness, which belongs to positive feelings.

4.2. Therapy for Clinical Disease

Besides adjusting emotions for normal people, medication contributes to curing mental and physical disease and is a common method to assist clinical treatment. In the prevention of both Alzheimer's disease and neurodegeneration, Kirtan Kriya (KK), which is a simple and convenient meditation technique, downregulates inflammatory genes, upregulates immune system genes, improves insulin and glucose regulatory genes, and increases telomerase by 43% [28].

Moreover, the research shows that meditation can yield advantageous effects on the cardiovascular (CV) system, particularly with vascular components. Post-meditation, hormone regulation influences effects in the central nervous system and the body. All forms of meditation are linked to blood pressure regulation, improvement in insulin resistance, decrease in lipid peroxidation，and cellular senescence, irrespective of the meditation type [29].

The assistance of meditation practice in curing disease will greatly help patients release body and psychological pain. However, corresponding to which specific meditation method with certain diseases needs to be studied more.

5. Application in Medical Treatment

In research, the methodology is crucial as it dictates the precision of the data. Particular research methods are required for the brain, an organ located in the skull, particularly when identifying changes in its structure and activity. Electroencephalographic measures (EEG) and neuroimaging studies are popular methods to be used in the research. EEG measure from the head surface which is a non-invasive procedure that can be applied repeatedly to subjects with on risk or limitation. EEG has proven to be a very useful tool in the fields of neurology and clinical neurophysiology because of its capacity to reflect both normal and pathological electrical activity of the brain [30]. The study indicates that functional Magnetic Resonance Imaging (fMRI) can detect the changes in gray and white matter, the activation of brain region, and the structural changes of brain [31].

For brain function study, non-invasive methods are popular in terms of safety. As the maturity of invasive neurotechnology increases, more unique and practical brain study methods will emerge, and the detection of deep brain activity will be achievable.

6. Conclusion

This study reviews the history of meditation and gives a category of different meditation practices. Then, the study combines a number of previous research studies to conclude the impact of meditation practice in terms of brain structures and brain activities, indicating that neural functions are enhanced. Moreover, according to the change of hippocampus and gray matter density, meditation promotes memory abilities and the generation of positive mood. Meanwhile, the growth in alpha and the reduction in theta and beta power also show the participants are calmer. Based on these facts, the function of meditation reducing stress levels and raising self-awareness for individuals can be explained scientifically, which provides the possibility to use meditation exercises in treating medical health problems. Additionally, EEG and fMRI techniques play an important role in measuring brain

activities during medication. This study deepens the connection between meditation and medical treatment. Through depicting the changes of the brain well-rounded aspects, this study focuses on drawing daily mindfulness practice into medical treatment, giving a new possibility to treat the disease and train the brain's abilities without surgery or input neurotechnology. This study can provide the neural-level evidence for the function of meditation and emphasize the mental effect of meditation. Nonetheless, this study didn't include the neuron functions; future studies need to be conducted.
Meditation is a way for individual to change themselves and their inner feelings and can thus affect one's actions in a positive way. Future studies need to develop new mental practices in order to enhance the human brain's other essential functions and contribute to treatments.

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