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Meditation Experience Associated with Structural Neuroplasticity.

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ABSTRACT

The intention of the review is to evaluate several studies regarding meditation and its association with structural neuroplasticity. The analysis of the studies would be evaluated based on its methods and results, with respect to the implications of various physiological findings as well as the different ways in which neuroplasticity is measured. Sources were gathered from numerous journals and literature posted online. Databases at the Alvin Sherman Library were utilized to further the research process. To synthesize ideas, a holistic approach was taken to the research process, and studies regarding meditation's effects on the chemical, molecular, and genetic aspects of the body were taken into consideration. Analysis of the studies showed meditation's impact on increased gray matter in various regions of the brain as well as microscopic structural changes in white matter. Several regions in the brain showed evidence of plasticity, which shows the extent to which meditation has an impact on the brain and its functions. For future studies, it suggested that different types of meditation are compared in order to clearly evaluate the approach to meditation and its impact on the structure of the brain.

Keywords: Meditation, Neuroplasticity.

INTRODUCTION

Meditation and mindfulness are practices long known for their help in physical and mental relaxation, clarity, and strength. The practices utilize breath as a means of focusing internally and “living in the present moment.” Although many forms of meditation exist, most have certain common characteristics including, a quiet space for concentration, a comfortable sitting posture, and an open attitude. Neurologically, brain scans have shown increased activity in regions correlated with decreased anxiety and depression in brains of expert meditators.^[1] Previous reports have shown differences in types of brain waves and resting electroencephalogram mental states between experienced Buddhist practitioners and inexperienced students.^[2]

While regular meditation practice has been shown to increase electrical activity in certain areas of the brain, increasing reports show meditation's correlation to increased gray and white matter.^[3,4] These reports give evidence of brain plasticity, or neuroplasticity and show that the practice itself may change the structure of the brain. With increased research in meditation's relationship to neuroplasticity, many studies seek to find the medical implications in basic wellness such as

breath control and blood pressure, as well as psychological abnormalities.

This report serves to understand and evaluate the various areas in which meditation can alter and affect the brain. The function of each of these areas is essential in understanding meditation's effects on the human body. Increasing research supporting meditation's ability to increase the number of synaptic connections, the thickness of gray matter, and ultimately the physical and chemical structure of the brain are crucial in the understanding of the brain. The report also seeks to determine the important medical, technological, and social implications of meditation's role in brain plasticity.

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MATERIALS AND METHODS

Several online databases were used to search keywords such as “meditation”, “mindfulness”, and “neuroplasticity.” Several informative sources emerged from numerous journals and other literature posted online. After preliminary research,

a closer look was taken at the problem by examining text sources from the library, which, proved to be extremely useful in filling informational gaps found as the paper was completed.

To synthesize thoughts and ideas, holistic views of meditation's effect on the brain were taken into consideration after considering the specifics of the subject. Although the research focused on increased gray matter in different modules of the brain, research also showed meditation changing certain chemical characteristics of the brain. For example, some sources explained different wave frequencies and increased concentrations of certain chemical neurotransmitters in experienced meditators. Other studies explained meditation's effects using molecular biology and genetic expression. By observing the implications of these studies, the effects of meditation on the physical structure of the brain was more clearly understood. New literature was needed to fill these informational gaps, which was filled by searches from the University's online library database system.

RESULTS & DISCUSSION

First and Significant Discoveries

A report regarding meditation's effect on the brain discussed significant differences in electrical activity, including increased gamma-band frequencies in high-order mental processes.^[5] Previous studies on mindfulness meditation, reviewed by Cahn and Polich in 2006 show increased alpha waves and theta waves during meditation. Conducting experimentation with electroencephalography (EEG), these types of waves indicate meditators to be in relaxation and awareness.^[1] However, it was not until Dr. Sarah Lazar's report on increased cortical thickness associated with experienced meditators, was there evidence of structural changes in the brain, or neuroplasticity. While the report did not show statistical evidence of differences in the entire cortex between meditators and controls, there was evidence of increased gray matter in right anterior insula and Brodmann area. Increased cortical thickness may be attributed to increased arborization, or the branching of the ends of nerve fibers, increased glial volume, or increased vasculature in the brain.^[3]

While the first study to find evidence of meditation's relation with neuroplasticity was located in the cerebral cortex, another study found evidence of increased gray matter density in the brain stem associated with meditation.^[6] The study hypothesized that because meditation required extensive breathing techniques and respiration control, the brainstem, which controls basic autonomic functions, should have experienced

structural neuroplasticity. Results indicated not increased volume, but increased density of gray matter in the medulla oblongata between experienced meditators and controls. It became more common to investigate areas of the brain based on non-quantitative observations of the effects of meditation. For example, the study above sought to evaluate the brain stem based on meditation's use of respiratory control. Lazar's study, which found increase gray matter in the right anterior insula is associated in interoceptive processes, or the signaling of internal bodily sensations.^[3] Another study, noticing the emotional regulation of experienced meditators, investigated and found statistically larger gray matter volumes in the right orbito-frontal cortex and the hippocampus in experienced meditators compared to that of the control group.^[7]

Previously mentioned studies have conducted research using a control group with no meditation experience against expert meditators. Therefore, many confounding factors may cloud the relationship between meditation and structural neuroplasticity. It would be dangerous to state that meditation has a direct, causal relationship with the plasticity of the brain. Studying differences between two groups of people must take into consideration age, sex, genetics, neuropathology, and psychopathology.^[3]

Age is an important factor in determining effects of neuroplasticity. Because portions of cortical thickness decrease as age increases, some studies have tried to evaluate data based on age. One study found that cortical thickness was most significantly different in matched controls and expert mediators of older age.^[3] This may be attributed to the drastic decrease in cortical thickness as age progresses. The average cortical thickness for a 40-50 year-old meditator was the same as the average cortical thickness for a 20-30 year old non-meditator.^[3] This comparison may suggest meditation's ability to slow the degeneration of the cortex.

A study evaluated high-resolution magnetic resonance images (MRIs) of individuals before and after the Mindfulness-Based Stress Reduction (MBSR) program.^[8] Compared to previous studies, which conducted experiments with a control group, this study compared data across one individual, which eliminated many confounding factors. This study demonstrated "longitudinal changes in gray matter concentration" are possible following an eight-week program in MBSR. The left hippocampus was reported have a significant increase in gray matter overall among all participants in the program. This area is important in learning, memory, and emotion and the finding further supports previous studies regarding structural changes in hippocampus.^[5,8]

The key studies analyzed above are crucial in understanding meditation's effect on the physical

structure of the brain. The studies not only show some of the first evidence of structural neuroplasticity, but also evident functions of larger volumes of gray matter. Furthermore, the last-mentioned study, in contrast with the other studies, makes full use of the MBSR program by monitoring the “before and after” brain structures for each participant. The studies come closer to eliminating confounding factors and strengthening the positive relationship of meditation and structural neuroplasticity.

Comparisons to Einstein’s Brain

Many consider Albert Einstein as one of the most prominent physicists of the 20th century. Since the human species may be regarded as the most developed species on Earth, Einstein’s brain serves as an excellent example to identify developed areas of the brain. Fortunately, Einstein’s brain was salvaged after his death at age 76. In a preliminary analysis of Einstein’s brain, several images were taken and analysis was conducted on 240 separate blocks of the brain.^[9] It was concluded that the brain had an abnormally wide, forward projecting frontal lobe and wide, posteriorly projecting occipital lobe, but a relatively normal size brain. It was also noted that the size was not exceptionally large due to decreasing cortical thickness with advancing age.^[9] One the most essential observations of the study was Einstein’s expanded pre-frontal cortices, which may explain his extraordinary cognitive abilities.

In a separate study performed in 1984, blocks of cerebral cortex were removed from the superior frontal gyrus and the inferior parietal lobule from 11 control brains and Einstein’s brain.^[10] The study found that the neuronal to glial ratio was significantly smaller in Einstein’s brain than in the control brains. This finding may indicate a greater neuronal metabolism and activism due to a need of increased glial cells to support the neuronal cells. Further studies were conducted on Einstein’s brain to uncover the differences and reasons for his established cognitive abilities and imagination. One such study found that the corpus callosum in Einstein’s brain was significantly thicker in both a younger brain and older brain control group (Weiwei). When a similar study was performed on expert meditators, evidence showed thicker corpus callosum and enhanced FA in those regions (Luders, Philips). Such evidence may indicate greater coordination and communication between the two hemispheres, which may have also assisted Einstein in his cognitive abilities. Furthermore, these abilities may be related to the skills associated with meditation and mental states achieved during meditation.

It is important to note that research regarding meditation’s effect on neuron to glial has not been conducted. It is suggested that this be an area of

research in order to question the brain’s metabolic activity during meditative processes.

White Matter Structural Changes

White matter is the paler tissue of the brain, compared to gray matter, which consists of mainly nerve fibers and their myelin sheaths. White matter was previously assumed to remain unchanged in the brain after the initial period of development in axonal migration and myelination (Posner). But evidence has shown that structural changes in white matter can occur. A study performed on adult mice showed that social isolation caused degeneration of myelination in the pre-frontal cortex (Liu). The study additionally showed decreased myelin gene transcripts in areas that were responsible for social interaction, for example, the pre-frontal cortex. This data suggested that white matter, like gray matter, is also capable of plasticity due to changes in myelination.

Unfortunately, it is difficult to measure the molecular mechanisms of white matter changes with MRI (Posner). Therefore, diffusion imaging, or the use of water molecules to observe contrasts in MRIs may be utilized to see more prominent changes in myelin variation, axon diameters, axon permeability, and the general geometry of fibers (Zatorre).

As seen in the report study on adult mice and social isolation, degenerating myelination accounted for structural changes in white matter. This may be attributed to decreased activity of oligodendrocyte progenitor cells (OPCs), which repair myelin damage and participate in myelination and unmyelinated axons (Zatorre).

Several studies have reported white matter structural changes under working memory training or juggling (Posner). Gray matter changes are evident when learned skills are mastered. However, experience-dependent white matter changes are suggested in several animal studies (Scholz). A study attempted to measure the microstructure of white matter affected by juggling using Diffusion Tensor Imaging (DTI) of the brain. While no correlation was found between performance level and structural changes, white matter regions showed structural changes, suggesting that the amount of time dedicated to the skill would induce changes (Scholz). This study shows evidence of white matter plasticity in healthy adult brains.

While the above study studied white matter structural changes with learned skills, a study conducted in 2010 found that short-term meditation induced white-matter changes in the anterior cingulate cortex (Tang). The anterior cingulate cortex is the anterior portion of the cingulate cortex, which is the region that surrounds the corpus callosum in a “collar shape.” The anterior cingulate is known to be involved in several autonomic functions, as well as higher-order

functions such as self-control and decision-making. The results reported increased fractional anisotropy (FA), an index regarding the efficiency of white matter, in eleven hours of integrative body-mind training (IBMT) over a one-month period (Tang). The regions affected included the anterior corona radiata associated with the anterior cingulate cortex and the body of the corpus callosum.

Although gray matter structural changes are more evident on a gross level than white matter structural changes, techniques such as DTI show evidence of structural changes in white matter due to experience and learning. These studies further show the effect of meditation and mindfulness on the plasticity of the brain, both in gray and white matters.

Basic Wellness and Correlated Areas in Brain

In the above studies, evidence shows that meditation and mindfulness practice can increase gray matter and structural change white matter to better the state of the brain. The plasticity of the brain, dependent on experience and learning, is essential in understanding the effects of meditation. In this section, several studies regarding specific regions or modules of the brain that have shown plasticity due to meditation will be analyzed.

Perhaps the most well-known region in the brain that is associated with structural plasticity after long-term meditation practice is the pre-frontal cortex (Lazar). Dr. Lazar's research also stated that the more years of practice yields a greater overall size of the pre-frontal cortex. This region of the brain is instrumental in increased decision-making, processing, willpower and decreased anxiety and depression (Lazar).

But the pre-frontal cortex is not the only region in the brain that benefits from meditative practices. In a study, which conducted an 8-week course on meditation training and compassion training, individuals who underwent meditation training showed significant evidence of decreased activity in the amygdala, which is responsible for fear and emotion (Desbordes). Another study further investigated the differences in gray matter structure in the amygdala during different stress conditions. Following an eight-week MBSR intervention, individuals not only reported feeling more stress-free, but also showed positive correlation with decreased gray matter in the right basolateral amygdala (Holzel, Carmody). These studies show that the amygdala is a major region in the brain responsible for important conditions such as stress, emotion, and fear and very much affected by meditative practices.

The right anterior insula, responsible for activities in consciousness, was reported to have increased cortical gyrification, or the degree of folding, in long-term meditators (Luders, Kurth). The report hypothesized that given meditators were skilled in

interoception and awareness, the right anterior insula would exhibit increase gyrification. This study stands out from other studies, in that the investigators used gyrification as a means of measuring meditation's effect. Another study, using MRI, attempted to use empathetic response as means of measuring compassion (Lutz). The investigators inferred that meditative skills would increase empathetic-like behavior. Results showed that strength of activation in the insula was much greater in expert meditators than that of novice when a distresses sound was played. Furthermore, the amygdala, right temporo-parietal junction, and right superior temporal sulcus were all activated for expert meditators, implying a response to human emotion (Lutz).

While fear, emotion, and stress are common mental states influenced by meditation, depression and learning skills are also heavily associated with hippocampal structural changes under meditative processes. The hippocampus is associated with memory abilities, including habit-learning skills and priming (Squire). A recent study reported that meditation practitioners, regardless of sex, had larger hippocampal surfaces and dimensions when compared to control groups matched for age and sex (Luders, Thompson). Such findings associate meditation with increased memory and learning abilities.

An important longitudinal study used novices in an interventional mindfulness program to assess the anti-depressant characteristics of mindfulness meditation. Results showed plasticity in the anterior cingulate and the prefrontal cingulate during resting states (Yang). Depression and anxiety scores reduced for the participants, indicating that mindfulness meditation may be beneficial in reducing such disorders.

The studies show meditation's effects in various regions of the brain and its role in basic wellness and mental states. Plasticity occurs greatly in several regions of the brain and assessing these regions based on function may provide more information about meditation's effects.

Chemical Neurotransmitters Associated with Meditative Practices

Several studies have shown evidence for meditation's association with neuroplasticity in many areas of the brain. Meditation is also associated with the increase in certain chemical substances throughout the brain. For example, a study conducted by scientists at the University of Montreal showed that meditation induced increased serotonin levels (Perreau-Linck). This chemical transmitter is instrumental in mood changes, and the study showed that mood could be controlled through meditation. Another study, conducted using a meditation retreat for participants, showed a direct result in decrease of cortisol levels with

increased meditation (Jacobs). Evidence was also shown that meditation would increase levels of dehydroepiandrosterone (DHEA), a growth hormone that decrease as age progresses allowing more vulnerability to diseases (Giampapa). And most importantly, melatonin levels increased in those who patients who practiced meditation versus patients who did not practice meditation at a study conducted at the Univeristy of Massachusetts Hospital (Massion). Melatonin is critical in maintaining the sleep cycle and according the study, may also be helpful in preventing breast and prostate cancer (Massion).

Meditative practices are shown to be essential in increases certain chemical substances in the brain. This research shows meditation's chemical effect on the brain. It is important to consider this aspect of studies, as we are looking at the brain in both physical and chemical manners.

Holistic View of Meditative Effects

In an effort to consider the topic in a holistic manner, this section provides studies and analysis on meditation's effects on the immune system, genetic and molecular structures, different electrical waves, as well as sleep and awareness. Some of these area correlate to the plasticity of the brain.

A study conducted in 2003 hypothesized that certain biological processes are associated with meditation (Davidson). Therefore, the study sought to test the effects of meditation on the brain and immune function. After undergoing an 8-week meditation program, participants were vaccinated with the influenza vaccine. Results showed that the participants had increased antibody titers to the influenza vaccine compared to those of a control group (Davidson). This study highlights an important research area, the immune system, with respect to meditation.

In addition to the immune system functions, meditation was found to reduce gene expression of the pro-inflammatory gene in adults, which loneliness, "morbidity, and mortality" (Creswell). And on a molecular viewpoint, meditation was also associated with increased telomerase activity, which lengthened telomeres in DNA. Telomeres are an essential molecular structure in human DNA that affects cell age and immortalization (Epel). An increase in telomeres and interference in gene expression may also explain the structural changes in the brain. As meditation uses epigenetics to alter gene expression, certain characteristics of the brain, whether gray or white matter may change.

Sleep is also affected by meditation. Expert meditators show increased amounts of rapid eye movement (REM) sleep, which is associated with a deeper levels of sleep in which muscles are paralyzed and activity in the brain is equal to awareness despite being in sleep conditions

(Maruthai). Changes in REM sleep organization may be associated with the plasticity of the brainstem. Awareness is also a key research field under meditative processes. In 2013, a study showed posterior cingulate cortex deactivation when meditators were experiencing "undistracted awareness", "concentration", and "effortless" doing as participants subjectively described (Garrison). However, in cases where participants were "trying to meditate" and experienced "distracted awareness", "controlling" and "discontentment," the posterior cingulate cortex was activated (Garrison). The study offers insight into clear meditation versus distracted thinking and a wandering mind. The different waves captured by an EEG were also correlated to awareness, sleep and meditation. Increased theta activity is strongly correlated to increased experience in meditation (Ivanoski). These results are very much supported by the earlier mentioned study, in which alpha waves and theta were correlated with experience in meditation.

Understanding meditation's effects in various aspects of the body allows critical analysis of the human body's reaction to such practices. Meditation affects the body at the most miniscule level, at the human DNA. It is interesting to notice that experiential occurrences can change the DNA and eventually the plasticity of brain structures. Furthermore, meditation impacts the brain and parts of the body chemically, altering wave frequencies and chemical substances.

CONCLUSION

Based on several studies, meditation is strongly associated with structural neuroplasticity. First reports showed evidence of increased cortical thickness and gray matter, and following studies further supported these findings, showing increased gray matter in other regions of the brain. It was important to distinguish between studies that used a control group and expert meditators and studies that used participants in a longitudinal study. The latter avoids several confounding factors such as age, sex, and difference in neuroanatomy. While gray matter structural changes were evident in expert meditators, white matter structural changes also became visible through the use of different imaging techniques. Comparisons to Einstein's brain showed that expert meditators had similar structures, which may show evidence of higher cognitive abilities. Several key regions in the brain, such as the pre-frontal cortex, the amygdala, the hippocampus, etc. These regions show the extensive impact of meditation on different regions of the brain, as well as the impact on function. In addition to meditation's association with neuroplasticity, studies regarding meditation and chemical substances, wave frequencies, sleep,

awareness, genetics, and the immune system. The analysis of these studies shows the various other ways meditation's effects can be measured. These studies also show critical fields of study that can be evaluated in the future.

Other suggested areas of research include targeted studies on the different types of meditation and their compared effects on the structure and chemical composition of the brain. While this paper incorporates all types and styles of meditation, a comparison between different styles would give insight into the approaches to meditation and different acquired skills. A previously mentioned study regarding hippocampal differences in meditators and non-meditators also organized data based on sex. Results showed significant differences in the structures of the hippocampus between men and women. Therefore, further studies comparing male and female brain structures under meditative practice would give interesting insight into sex-based brain differences.

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