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Meditation for Human Mind and Brain: Findings from Functional Neuroimaging Investigations

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Abstract

Meditation is generally described as being in the present moment or being alert in the present moment, instead of constantly struggling to change or to become. Meditation is an essential part of Yoga philosophy and the seventh limb of Astanga Yoga described by sage Patanjali in the ancient text Patanjali Yoga Sutra. Yoga including meditation, is an ancient technique invented to unite the individual consciousness with the universal consciousness, however, scientific studies have demonstrated the vast health advantages associated with it. Mindfulness as a non-judgmental awareness of the present-moment is also a part of yoga philosophy, however, most of the mindfulness practices those are being practiced in modern days are also rooted in Buddhist philosophy. Some well-known meditation techniques are Buddhist meditations, Hindu meditations, Chinese meditations, Christian meditation, Islamic meditations, Guided meditations etc. Meditation influences brain systems involved in attention, awareness, memory, sensory integration, emotion regulation, and higher-order cognitive functions. Meditation has also been found to be very effective in relieving stress, regulating emotions and promoting mental health. A significant increase in grey matter volume was found in the meditators as compared to non-meditators. The larger grey matter volume overall, and with regional enlargement in several right hemispheric cortical and subcortical brain regions are associated with sustained attention, self-control, compassion and interoceptive perception. Several functional neuroimaging studies showed that some brain regions are recruited consistently across different meditation techniques including insula, pre/supplementary motor cortices, dorsal anterior cingulate cortex, and frontopolar cortex.

Keywords: Meditation; Mindfulness; Yoga; Brain; Neuroimaging; Mental Health; Cognition

Abbreviations: TM: Transcendental Meditation; fMRI: Functional Magnetic Resonance Imaging; PET: Positron Emission Tomography; EEG: Electroencephalography, BMRM: Body Mind Relaxation Meditation; MDDs: Major Depressive Disorder; fNIRS: Functional Near Infrared Spectroscopy; LK: Loving and Kindness; WMC: Working Memory Capacity.

Introduction

Meditation is generally described as 'being in the present moment' [1,2]. In other words, meditation is an art of being alert in the present moment, instead of constantly struggling to change or to become [3]. Meditation is often associated

with a relaxed state of mind and body. However, some meditation techniques can also be associated with mental tasks and mental efforts [4]. The word 'meditation' refers to a broad variety of techniques, ranging from techniques designed to promote relaxation to exercises performed with a more far-reaching goal, such as a heightened sense of well-being. Hence, meditation can be understood as a family of complex attentional and emotional regulatory for well-being and emotional balance [5]. Meditation is an essential part of Yoga philosophy and the seventh limb of Astanga Yoga. The science of Astanga Yoga was clearly presented by sage Patanjali in the ancient text Patanjali Yoga Sutra. According to Patanjali, Astanga Yoga involves eight limbs namely Yama (abstinences), Niyama (observances), Asana (physical postures), Pranayama (breath regulation), Pratyahara (withdrawal of the senses), Dharana (concentration), Dhyana (meditation), and Samadhi (absorption) [6]. Yoga including meditation, is an ancient technique created to unite the individual consciousness with the universal consciousness, however, scientific studies have demonstrated the vast health advantages associated with it [7]. The physical postures, breath regulation and meditation have been being used most commonly for health purposes for some decades [8].

Mindfulness meditation is one of the most popular and very common form of meditation. Mindfulness as a non-judgmental awareness of the present-moment is also a part of yoga philosophy, however, most of the mindfulness practices those are being practiced in modern days are also rooted in 2500 years old Buddhist philosophy [9]. The mindfulness or mindfulness meditation is to maintain awareness every moment while disengaging oneself from strong attachments towards material world. The major goal of mindfulness meditation is to alleviate suffering and cultivate compassion according to Buddhist philosophy [10]. Mindfulness based techniques have been found to improve a wide spectrum of clinically relevant health outcomes [11]. The mindfulness meditations were also found to be effective in improving psychiatric conditions including depression, anxiety and stress [12].

Meditation has been practiced in many civilizations for thousands of years as a means of creating a state of well-being and for religious purposes [13]. Some well-known meditation techniques are Buddhist meditations (Zen meditation, Vipassana meditation, Mindfulness meditation, Loving Kindness meditation etc.), Hindu meditations (Mantra meditation, Transcendental meditation, Yoga meditations, Kundalini meditation, Self-Enquiry meditation etc.), Chinese meditations (Taoist meditations, Chi Kung etc.), Christian meditation (Contemplative prayer, Contemplative reading, Sitting with God etc.), Islamic meditations (Dhikr etc.), Guided meditations etc. Among these various techniques, there are two common meditation styles that are commonly studied. One style, focused type meditation, entails the voluntary focusing of attention on a chosen object. The other style, open monitoring or effortless type meditation, involves non-reactive monitoring of the content of experience from moment to moment [5].

Focused Meditation or Focused Attention Meditation	Directing and sustaining attention on a selected object (e.g. breath sensation)
	Detecting mind wandering and distractors (e.g. thoughts)
	Disengagement of attention from distractors and shifting of attention back to the selected object
	Cognitive reappraisal of distractor (e.g. 'just a thought', 'it is okay to be distracted')
Effortless Meditation or Open Monitoring Meditation	No explicit focus on objects
	Nonreactive meta-cognitive monitoring
	Nonreactive awareness of automatic cognitive and emotional interpretations of sensory, perceptual and endogenous stimuli

Table 1: Focused meditation and Effortless meditation [5].

Role of Meditation on Cognition

Meditation influences brain systems involved in attention, awareness, memory, sensory integration, cognitive regulation of emotion, and higher-order cognitive functions [14]. Meditation techniques have shown various psychological benefits including the improvement in cognition as those techniques were found to be effective in enhancing cognitive reserve capacity [15]. Meditation practices enhance the anterior cingulate cortex that is the region associated with attention [16]. Studies suggested that mindfulness meditation is intimately linked to improvements of attentional functions and cognitive flexibility [17]. Studies also demonstrated that meditators counted more accurately in challenging concentration task, identified a greater number of alternative perspectives in multiple perspectives images, and showed less interference from invalid cues in a visual selective attention task as compared to non-meditators [18].

A study tried to examine the effects of a single session of 25 minutes of mindfulness meditation compared with a sham meditation and a book-listening control. Results of the study, however, showed that one session of meditation was not sufficient to affect the cognitive tasks used in this study. Both mindfulness meditation and sham meditation positively affected mood states and heightened state mindfulness [19]. Whereas, in another study, participants with no prior meditation experience participated in four sessions that involved training in either meditation or listening to a book recording. The results of this study showed that the brief meditation has beneficial effects on some measures of mood and cognition [20].

A cross-sectional study compared the cognitive performance between meditators and non-meditators. Results of the study showed that the long-term meditators have superior cognitive abilities than non-meditators [21]. Similarly, the effects of 12 months Transcendental Meditation on the cognitive ability were tested in 362 school students. Test for Creative Thinking-Drawing Production, Constructive Thinking Inventory, Group Embedded Figures Test, State and Trait Anxiety, Inspection Time, and Culture Fair Intelligence Test were assessed before and after intervention. The Transcendental Meditation was found to be effective in improving cognitive ability [22]. Further, the beginning stages of loving-kindness meditation training impact the tendency to learn to associate positivity with neutral stimuli and cognitive control [23]. Similarly, Findings of another study suggest that four days of meditation training can enhance the ability to sustain attention, and improve working memory, and executive functioning [24]. Another study was conducted to know the effects of meditation on stress levels, intelligence, emotional quotients, and cognitive functions. The results of the study showed that the practice of meditation reduced psychological stress responses and improved cognitive functions [25].

Mental Health Associated with Meditation

Meditation has been found to be very effective in relieving stress, regulating emotions and promoting physical and mental health [26]. Meditation can improve emotion regulation and reduce stress through fronto-limbic networks [16]. Meditation practice leads to decreased physiological markers of stress as meditation were found to reduce cortisol, C - reactive protein, blood pressure, heart rate, triglycerides and tumour necrosis factor-alpha [27]. One study was conducted with the patients with anxiety disorder. The results of the study demonstrated that the 8-week meditation-based stress management program can be effective in relieving anxiety symptoms in patients with anxiety disorder [28]. Similarly, a 6-week training of focused meditation appeared to be effective in improving emotion regulation processes and anxiety in healthy college students compared with progressive relaxation and a wait-list control [29]. Further, the transcendental meditation (TM) practice was also found to be helpful in treating different kinds of psychiatric disorders including anxiety and depression [30]. Another similar study also demonstrated that TM practice was helpful in treating anxiety disorder [31]. One study investigated the effect of five days focused meditation on positive and negative affect, and state and trait anxiety. Positive Affect and Negative Affect Scale, and State and Trait Anxiety Inventory were employed as assessment tools. The meditation group demonstrated the reduction in negative affect and trait anxiety [32]. These findings showed that even short-term focused meditation training has potential to improve psychological variables [32]. Another study attempted to investigate the effect of Vipassana meditation on stress and anxiety levels in regular practitioners (1 hour per day for 6 months) of Vipassana meditation. The results of the study demonstrated that the practice of Vipassana meditation is associated with reduced level of stress and anxiety [33].

Mediation techniques were also found to have strong relationship with subjective happiness. A study has demonstrated positive influence of meditation techniques including mindfulness meditation and self-compassion meditation, on happiness [34]. Similarly, the practice of loving kindness meditation also appeared to improve people's lives, helping them to cultivate true happiness inside and genuine compassion for others. This simple meditation technique was found to be effective in cultivating love, compassion, and joy [35]. In another study, novice meditators were found to be significantly happier after a 9-day intensive meditation retreat programme as compared to control [36]. A brief 3-week period of self-compassion meditation training was given to improve body satisfaction in a multigenerational group of women. Women were randomized either to the meditation intervention group or to a waitlist control group. Women in the meditation group experienced significantly greater reduction in body dissatisfaction and body shame, as well as greater improvement in self-compassion and body appreciation as compared to control [37].

Impact of Meditation on Human Brain

Meditation practices were found to be effective in improving human mind and brain. Many studies demonstrated a significant increase in grey matter volume in the meditators as compared to non-meditators [38-40]. Increased grey matter volume in meditators was found in several predominantly right hemispheric regions: in insula, ventromedial orbitofrontal cortex, inferior temporal and parietal cortices as well as in left ventrolateral prefrontal cortex and left insula [39]. The larger grey matter volume

overall, and with regional enlargement in several right hemispheric cortical and subcortical brain regions are associated with sustained attention, self-control, compassion and interoceptive perception [39]. Rather than affecting only specific brain regions, meditation was found to be associated with structural and functional changes in large-scale brain networks [40]. However, several functional neuroimaging including Functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET) and Electroencephalography (EEG) studies showed that some brain regions are recruited consistently across different meditation techniques including insula, pre/supplementary motor cortices, dorsal anterior cingulate cortex, and frontopolar cortex [41,42].

Recent studies also demonstrated the associations of meditation practices with neuronal plasticity of the brain [40]. Meditation was found to be associated with decreased activity of default mode network and activation of brain regions involved in cognitive and emotional control [40]. In a study, fMRI was used to identify and characterize the brain regions that are active during a simple form of meditation. Significantly increased signal was observed in the dorsolateral prefrontal and parietal cortices, hippocampus/para-hippocampus, temporal lobe, pregenual anterior cingulate cortex, striatum, and pre- and post-central gyri during the meditation [43]. Results of the study demonstrated that the meditation activates brain areas involved in attention and control of the autonomic nervous system [43]. Another fMRI study investigated whether dorsal lateral prefrontal cortex and anterior cingulate cortex were activated during meditation, and the study concluded that meditation involves attentional regulation and may lead to increased activity in brain regions associated with attention such as dorsal lateral prefrontal cortex and anterior cingulate cortex [44]. Another study also found a strong correlation between depth of meditation and neural activity in the left inferior forebrain areas including the insula, inferior frontal cortex, and temporal pole [45].

In a fMRI study, foci of consistent activity related to mindful meditation were found in the frontal regions, anterior cingulate, and insula [46]. A focus was found in the insula in novice participants, whereas, foci in the medial frontal gyrus and globus pallidus were observed in the experienced participants [46]. In a similar study, during mindfulness meditation practice, decreased signal was observed in midline cortical structures associated with interoception, including bilateral anterior insula, left ventral anterior cingulate cortex, right medial prefrontal cortex, and bilateral precuneus [47]. Similarly, Zen meditation practitioners have been scanned by fMRI during the conscious switch from normal consciousness state to a meditative state of mind. the study also demonstrated a deactivation of the anterior cingulate, an area associated with our will [48]. Thirty-one experienced meditators were experimented during sustained meditation. Extensive deactivations had been observed in white matter in the right hemisphere, mainly in the posterior occipito-parieto-temporal area and in the frontal lobes [49]. Similarly, another fMRI study investigating the effect of Acem meditation in experienced meditators demonstrated the activation of the bilateral areas of the inferior frontal gyrus more during repetition of a meditation sound than during concentrative meditation-like cognitive tasks. The results showed that meditation with a relaxed focus of attention may activate distinct areas of the prefrontal cortex [50].

In another fMRI study, during Transcendental Meditation (TM) practice, blood flow patterns were significantly higher in executive and attention areas (anterior cingulate and dorsolateral prefrontal cortices) and significantly lower in arousal areas (pons and cerebellum) [51]. This pattern demonstrates that TM practice requires minimum effort, and the attentional system was active during meditation [51]. A blood oxygenation level dependent (BOLD) based fMRI study demonstrated brain activation on the region of thalamus, anterior cingulate, posterior cingulate, middle temporal gyrus, as well as putamen during meditation [52]. Findings of another fMRI study with patients with major depressive disorder supported the hypothesis that body mind relaxation meditation induction regulates the activities of the prefrontal cortex [53]. Results of another study also suggest that body–mind relaxation meditation (BMRM) is associated with changes in thalamocortical functional connectivity in major depressive disorder (MDDs) [54]. BMRM may act by strengthening connections between the thalamus and the default mode network, which are involved in a variety of executive functioning, such as attention and self-related processes [54]. Pain relief through mindfulness meditation was also found to be correlated with greater activation in brain regions associated with the cognitive modulation of pain, including the orbitofrontal, subgenual anterior cingulate, and anterior insular cortex [55].

Recently, many studies on meditation have used functional near infrared spectroscopy (fNIRS) to investigate the effects of meditation on cerebral hemodynamic [42]. The fNIRS is a non-invasive optical method that measures real time changes in oxygenated haemoglobin and deoxygenated haemoglobin concentrations and total haemoglobin or blood volume in brain areas. Functional near-infrared spectroscopy (fNIRS) suggests activation (increase in oxygenation) or deactivation (reduction in oxygenation) of the particular area of brain [56]. An fNIRS device has very good temporal resolution and the results of fNIRS are physiologically comparable to fMRI and PET results [57]. For the hemodynamic measures of oxygenated-haemoglobin, deoxygenated-haemoglobin, and total-haemoglobin,

findings of a study showed significant differences in Stroop colour word task performance before and after loving and kindness (LK) meditation. The LK meditation can result in improvements in cognitive, physiological, and behavioural outcomes of first-time meditators after a short-term session [42]. In another study, compared to the control group, meditation experts had a more widespread pattern of activation in the auditory cortex, while resting. Meditation experts had some highly activated brain areas beyond the meditative task itself, indicating possible long-term changes in the brain and their positive effects on empathy, meta-cognitive skills and health [58]. As per a recent study, in the focused attention meditation group, working memory capacity (WMC) increased, and the bilateral dorsolateral prefrontal cortex (DLPFC) was activated during the intervention as compared to control [59]. In another study, increased oxygenated haemoglobin and total haemoglobin concentration with reduced deoxygenated haemoglobin concentration over the right prefrontal cortex had been found during meditation, whereas increased deoxygenated-haemoglobin with reduced total haemoglobin concentration on the right prefrontal cortex had been found in random thinking. Results of the study suggest that meditation increased cerebral oxygenation and enhanced performance, which was associated with activation of the prefrontal cortex [60]. One recent study also showed that oxygenated haemoglobin levels in the prefrontal cortex increased in the yoga meditation group during the Flanker tasks after the intervention [61].

Conclusion

Meditation influences brain systems involved in attention, awareness, memory, sensory integration, emotion regulation, and higher cognitive functions. Meditation has also been found to be very effective in relieving stress, regulating emotions and promoting mental health. A significant increase in grey matter volume was found in the meditators as compared to non-meditators. The larger grey matter volume overall, and with regional enlargement in several right hemispheric cortical and subcortical brain regions are associated with sustained attention, self-control, compassion and interoceptive perception. Meditation techniques can be useful to improve mental health, energy levels and quality of life in general population as well as in patients suffering from various psychiatric conditions and neurological disorders.

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