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MEDITATION, ATTENTION AND THE BRAIN: FUNCTION, STRUCTURE AND ATTENTIONAL PERFORMANCE

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Abstract

Meditation has been practiced around the world for thousands of years and has during the past decade become increasingly popular in the Western world. Meditation can be seen as a form of mental exercise and refers to a family of complex emotional and attentional regulatory practices that involves different attentional, cognitive monitoring and awareness processes. Clinical research on meditation has demonstrated that meditation seem to reduce stress, anxiety, and depression. Recent interest in how meditation affect the human brain and body have lead to an increase in research regarding the neural correlates of meditation, structural changes induced by meditation, and the potential attentional and emotional benefits mediated by meditation. This thesis investigates expert related changes in neural activity, brain structure, and attentional performance induced by focused attention meditation (FAM) and open monitoring meditation (OMM). The research on meditation and the brain is still in its infancy but despite this, there seem to be some converging evidence of meditation's impact on the human brain and mind. The results from the included studies in this thesis indicates that expert meditators show greater activation in some meditation related brain areas, as well as less activation in other areas when compared to novice meditators. The results also suggest that long-term meditation practice induce some structural changes in the brain and that meditation seem to enhance the practitioners' attentional control.

Keywords: meditation, focused attention meditation, open monitoring meditation, expert meditators, FAM, OMM, neural activity, structural changes, attentional performance

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Introduction

The word meditation derives from the Latin *meditari,* which means to participate in deliberation or contemplation (Marchand, 2014) and refers to a family of complex cognitive and emotional practices aimed at focusing attention and awareness (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Lutz, Slagter, Dunne, & Davidson, 2008; Marchand, 2014).

Meditation has been practiced around the world for thousands of years and has been used as a tool to train the mind (Fox et al., 2016). The earliest known reference to meditation practice comes from the Hindi traditions of Vedantism in ancient India and is dated back to around 1500 BC. Around the seventh to fifth centuries BC other forms of meditation developed in Buddhist India and Taoist China (Zimmer, 1951; Everly & Lating, 2002).

During the past decade the practice of meditation has become increasingly popular in the Western world (Murphy & Donovan, 1997) as well as the interest in scientific research on meditation to increase our understanding of meditation's effects on human brain and body and how it leads to beneficial mental and physical effects in daily life (Brefczynski-Lewis et al., 2007; Cahn & Polich, 2006; Fox et al., 2016; Hasenkamp & Barsalou, 2012; Manna et al., 2010).

Many view meditation as a relaxation ritual and while meditation seems to induce a feeling of relaxation of mind it also seems to have other effects (Lippelt, Hommel, & Colzato, 2014). Clinical research on meditation has demonstrated that meditation seem to reduce stress, anxiety, and depression (Chiesa & Serretti, 2009; Miller, Fletcher, & Kabat-Zinn, 1995; Shapiro, Astin, Bishop, & Cordova, 2005; Shapiro, Schwartz, & Bonner, 1998; Vøllestad, Nielsen, & Nielsen, 2012), and improve the immune system (Chiesa & Serretti, 2009; Davidson et al., 2003). Meditation also seems to lead to changes in cognitive and affective processing (Sedlmeier et al., 2012), influencing how we interpret and process the world around us as well as changing the way we regulate attention and emotion (Lippelt et al., 2014). Interest in how meditation mediates these cognitive and affective changes has lead to an increase in research regarding the neural correlates of meditation, structural changes induced by meditation, and the potential attentional and affective benefits from meditation (Brefczynski-Lewis et al., 2007; Cahn & Polich, 2006; Fox et al., 2016; Kang et al., 2012; Lutz et al., 2008). Evidence suggests that meditation activates certain neural networks (Baron Short et al., 2010; Brefczynski-Lewis et al., 2007; Manna et al., 2010; Hasenkamp & Barsalou, 2012; Kang et al., 2012; Kozasa et al., 2012), which may lead to alterations in brain structure (Fox et al., 2014; Hasenkamp & Barsalou, 2012; Hölzel et al., 2008; Kang et al., 2012; Lazar et al., 2005; Vestergaard-Poulsen et al., 2008) and function (Cahn & Polich, 2006; Hasenkamp & Barsalou, 2012; Hölzel et al., 2008; Kang et al., 2012). There seem to be suggestions that some meditation-related benefits are associated with the amount of time spent in meditation (Baron Short et al., 2010; Brefczynski-Lewis et al., 2007; Hasenkamp & Barsalou, 2012; Manna et al., 2010).

Meditation refers to a family of complex emotional and attentional regulatory practices that involves different attentional, cognitive monitoring and awareness processes (Brefczynski-Lewis et al., 2007; Lutz et al., 2008; Manna et al., 2010; Tang et al., 2015). Meditation can be seen as a form of mental exercise (Lazar et al., 2005) where the focus can be directed outwards (e.g. to particular objects or sensory stimuli) or be directed inwards (e.g. to the content of the mind and felt experiences of the body) (Fox et al., 2016). A common principle across all different meditation practices is that they involve monitoring of attention and disengaging attention from distracting thought (Sedlmeier et al., 2012) and that the ability to monitor and regulate these mental processes can be developed through specific and regular practice (Fox et al., 2016). Even though meditation practices have the general goal of monitoring attention in common there are a lot of different ways of doing meditation and there are several different types of meditations techniques and hence different techniques can differ greatly with regards to their aim, difficulty, scope, and in recruitment of brain regions (Brewer et al., 2011; Manna et al., 2010; Fox et al., 2014). This is because different meditation practices can vary greatly in the mental processes that they use, how these mental processes are used (e.g. actively, passively, forcefully, effortlessly) and the object to which these mental processes are directed (e.g. thoughts, feelings, concepts, images) (Sedlmeier et al., 2012). The obtained effect of meditation is therefore assumed to differ depending on the kind of meditation technique that is practiced (Lutz et al., 2008).

Some examples of different meditation techniques are Samatha meditation, Zen meditation, Kundalini meditation, Loving Kindness meditation, Mindfulness meditation, Chakra meditation, and Vipassana meditation (Dienstmann, 2015). These practices have a different focus, where some are involved in focusing the attention on a specific object or thought, others place emphasis on a more open focus of attention. Other practices incorporate a focus of compassion and loving-kindness and some include a repetition of a mantra. There are practices that draw upon a focus of both the feelings in the body and thoughts in the mind, while some incorporate a focus of the chakras in the meditation (Dienstmann, 2015). These various meditation practices can, in general, be categorized into two main styles of meditation - focused attention meditation (FAM) and open monitoring meditation (OMM) (Cahn and Polich, 2006; Lutz et al., 2008). Both practices deal with the cultivation of attention but FAM place emphasis on focused attention through requiring the practitioner to focus their attention on only one thing (e.g. object, thought, feeling or event) while OMM instead place emphasis on an open form of attention where the practitioner allows any internal or external experiences or sensations to enter awareness without reacting to it (Cahn and Polich, 2006; Davidson & Lutz, 2008; Lutz et al., 2008; Manna et al., 2010). However, it should be noted that many meditation techniques involve a combination of these two styles (Sedlmeier et al., 2012).

Since these two meditation styles differ in their attentional focus it can be assumed that they also will lead to different engagement of the attentional networks which in turn should lead to different patterns of neural activity in the brain (Hölzel et al., 2008; Manna et al., 2010; Tang et al., 2012). With this in mind, it is also reasonable to presume that as meditation experience increases it will lead to neuroplastic changes in the brain due to the repeated activation of certain attentional networks and cognitive functions. These neuroplastic changes will in turn probably mediate positive outcomes in attentional tasks such as a better control of attention (Hasenkamp & Barsalou, 2012; Hölzel et al., 2008).

The aim of this thesis is to investigate expert related changes in neural activity, brain structure, and attentional performance induced by focused attention meditation and open monitoring meditation.

First, a description of focused attention meditation and open monitoring meditation will be described followed by a brief explanation of different attentional networks, cognitive functions and, the default mode network. Third, research on the neural correlates of these two meditation styles will be presented as well as research on structural changes potentially induced by meditation. Lastly, this thesis will look at the attentional benefits that seem to come with meditation practice before ending with a discussion.

Meditation Techniques

Focused Attention Meditation

One of the most basic forms of meditation is FAM and often, a novice practitioner will start with FAM. FAM is meditation practices that require voluntary focusing of attention on a single object during the whole meditation (Brefczynski-Lewis et al., 2007; Kozasa et al., 2012; Lutz et al., 2008). This object can be a candle flame, the sensation of the breath, a picture, a mantra, the mental visualization of an image or physical experience (Lutz et al., 2008; Sedlmeier et al., 2012; Fox et al., 2014). Distractions, such as environmental noises, intrusive thoughts or bodily sensations, might tend to attract the practitioner’s attention and is therefore attempted to be actively ignored by the practitioner by constantly redirecting attention back to the chosen object of attention (Colzato, Ozturk, & Hommel, 2012).

Initially, this kind of meditation requires a high level of effortful concentration, but with time, it becomes less effortful. The practitioner’s ability to keep attention on the chosen object becomes greater and external distractions get more momentary and less common. When it requires minimal effort for the practitioner to sustain his attention on the chosen object for a substantial amount of time, the practitioner usually progresses to OMM (Brefczynski-Lewis et al., 2007; Lutz et al., 2008).

The goal of FAM is to train different aspects of attention, enhance awareness of cognitive states and developing attentional control (Lutz et al., 2008). When practicing FAM it requires the practitioner to sustain focus of attention on a single object, such as the breath, a thought, or a feeling (FOCUS). When trying to sustain focus on an object the practitioner will unavoidably experience mind wandering (MW) and will then at some point become aware of the distracting thoughts and that the mind is not focused on the object anymore (AWARE). The practitioner will then disengage from the distracting thoughts and redirect the attention back to the object of focus (SHIFT) where the practitioner stays focused for some time (FOCUS) before mind wandering again. With practice, it will become easier to maintain the awareness on the object of focus and the end goal is to be able to keep attention effortlessly (Hasenkamp et al., 2012; Lutz et al., 2009; Sedlmeier et al., 2012). Engaging in this kind of technique train the meditator’s ability to sustain attention on a single chosen object, which leads to a disengagement of the meditator’s normal mental processes. This, in turn, enhances the practitioner's attentional skills since both the depth and steadiness of the practitioner's attention are developed (Sedlmeier et al., 2012; Lippelt et al., 2014; Marchand, 2014).

These monitoring and attentional functions that the practitioner engage in when practicing FAM have been related to different systems in the brain that is involved in selective and sustained attention, and conflict monitoring (Manna et al., 2010). A prediction is therefore that neural systems associated with selective attention (e.g., ventrolateral prefrontal cortex (vlPFC), the temporoparietal junction (TPJ), intraparietal sulcus, and frontal eye fields), sustained attention (e.g., right parietal and frontal areas and the thalamus), and conflict monitoring (e.g., dorsal anterior cingulate cortex (ACC) and dorsolateral prefrontal cortex (dlPFC)) might be involved when inducing and maintaining a state of FAM (Baron Short et al., 2007; Hasenkamp et al., 2012; Posner, & Rothbart, 2007; Lutz et al., 2008; Lutz et al., 2009). When engaging in regular practice of FAM it is thought to develop the practitioner's skill in these cognitive processes and hence also develop the practitioner's basic attentional processes and over time, the practice of FAM is thought to lead to improvements in binocular rivalry tasks, selective attentional tasks, and continuous performance tasks (Lutz et al., 2008).

Open Monitoring Meditation

OMM involves nonreactive moment-by-moment monitoring of the content of experience. There is no specific object or event to focus on in OMM but is rather a monitoring of awareness itself, monitoring all aspects of the experience. It involves focus attention to internal experiences with an open, non-judgmental, and receptive attitude towards all experiences in the present moment despite them being external or internal, positive, negative, or neutral (Cahn and Polich, 2006; Lutz et al., 2008; Fox et al., 2014; Marchand, 2014).

The goal of OMM is to be in a monitoring state, attentive to any experience, thoughts, emotions, or sensations that enters awareness without focusing, selecting, judging, or reacting to any particular thought, feeling or object. Continued mindfulness meditation practice is thought to lead to a shift in perspective, a deeper awareness of thoughts and emotions that helps the practitioner to stand back and take an objective and open approach when observing their thoughts, experiences, and emotions instead of being absorbed in them and reacting to them with other thoughts or emotions in the way one would normally do. This can then lead to a nonjudgmental acceptance and emotional serenity within the practitioner (Shapiro, Carlson, Astin, & Freedman, 2006; Sedlmeir et al., 2012).

In OMM the practitioner practices the ability to have an open form of attention and to process multiple mental contents in parallel, or at least items close in time with a non-judgmental awareness of the ongoing stream of experience which can be expected to lead to activations in neural systems involved in monitoring, vigilance and disengaging attention from stimuli that distracts the ongoing stream of experience (Doll et al., 2015; Lutz et al., 2008; Lutz et al., 2009). Based on this, OMM can be expected to lead to a more flexible and open mental state and hence enhance the practitioner’s performance in flexible-tasks (Hommel & Colzato, 2017) as well as lead to an improved attentional control in the practitioner (Sedlmeir et al., 2012).

Attentional Networks

Cognitive functions are processes that occur in the brain when we receive, process and convey information and it helps us to comprehend and learn. There are different definitions of cognitive functions, but most of them include thought and behavior control through different related processes. Cognitive functions, in general, include a series of complex skills, such as attention, executive functions, intentional behavior verification, planning, regulation where executive functions are the most complex cognitive functions that we carry out. Attention is the cognitive function that is used when selecting which stimuli to concentrate on when several stimuli are reaching the brain simultaneously. Those stimuli can be both internal (e.g.

thoughts, feelings) and external (e.g. images, sounds, smells) and the one chosen depends on how useful they are for carrying out the mental or motor action one is engaging in. There are several different types of attention (Brain Function, 2018; Gazzaniga, 2004; Posner, 2011).

One commonly used model for the evaluation of attention in clinical settings is the model of Sohlberg and Mateer. In this model, attention is divided into 5 different types. These 5 types are focused attention, sustained attention, selective attention, alternating attention, and divided attention (Sohlberg, & Mateer, 1989).

Focused attention is the ability to respond to stimulus and to being alert. Sustained attention is the ability to sustain attention on a chosen object for at least three minutes. This is what we normally call ”concentration” (e.g. we are concentrated when we read a book). Selective attention is the ability to maintain attention on an object or a task and at the same time inhibit distractions from the internal or external world (e.g. reading a book while listening to music from the radio). Alternating attention is what allows us to shift our attention smoothly from one object or task to another. (e.g. when reading a book and suddenly hearing a song we like, we are able to stop reading for a while and instead, listen to the song and then quickly shifting back to reading again). Divided attention is the ability to respond to several tasks at a time (e.g. cooking and talking on the phone at the same time). Despite these distinct attentional types, there is not one single part of the brain that is in charge of attention, but rather a cooperation between several circuits in the brain. (Brain Function, 2018; Sohlberg, & Mateer, 1989)

Another model for the attention system is a model proposed by Michael Posner that divides attention into three neural networks (Posner & Petersen, 1990). These three networks, where the first carries out the function of alerting, the second the function of orienting and the third the function of executive control, are thought to be relatively independent regarding their functions and anatomical structures and hence are thought to be linked to separable brain regions even though it seems to be some interactions between the networks (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Malinowski, 2013; Posner & Petersen, 1990).

The alerting system is a subcortical network that has been associated with thalamus as well as the frontal and parietal regions of the right hemisphere. This system is responsible for achieving and maintaining an alert state with high sensitivity to incoming stimuli. The alerting system corresponds to sustained attention (Fan et al., 2002; Fan et al., 2005; Gazzaniga, 2004; Lutz et al., 2008; Lutz et al., 2009; Posner, 2004; Posner & Petersen, 1990; Posner & Rothbart, 2007).

The orienting system is a posterior cortical network that has been associated with areas of the frontal and parietal lobes, including the superior parietal lobe, temporoparietal junction, ventrolateral prefrontal cortex, intraparietal sulcus, and the frontal eye fields (when visual events are present). This system is responsible for the selection of information from incoming sensory input through directing the body, eyes, ears, and head towards a specific stimulus such as an object, activity or experience of interest or that is alarming. The orienting system corresponds to selective attention (Corbetta & Schulman, 2002; Fan et al., 2002; Gazzaniga, 2004; Lutz et al., 2008; Posner, 2004; Posner & Petersen, 1990; Posner & Rothbart, 2007).

The executive control system is an anterior cortical network that has been associated with midline frontal areas, more specific the dorsal ACC, and the dlPFC. This system is responsible for monitoring and resolving conflict between multiple attention cues such as different thoughts, feelings, events, objects, and images through enhancing the perception of the selected target of attention and suppressing distracting information such as other thoughts, feelings, events, objects, and images (Fan et al., 2002; Gazzaniga, 2004; Lutz et al., 2008; Posner, 2004; Posner & Petersen, 1990; Posner & Rothbart, 2007).

Another network involved in attention is the default mode network which is a network commonly activated during passive rest or involuntary activities, such as daydreaming or mind-wandering and can, therefore, be thought to be activated when attention involuntary drifts away during meditation. This network includes several different areas in the brain such as posterior cingulate cortex, precuneus, the medial prefrontal cortex, angular gyrus, the posterior lateral parietal/temporal cortices, and the parahippocampal gyrus (Brewer et al., 2011; Hasenkamp et al., 2012; Malinowski, 2013).

As have been said, meditation techniques differ in their focus of attention. Both FAM and OMM cultivates sustained attention but FAM places emphasis on focused attention while OMM on a more open form of attention (Lutz et al., 2008). It is hence reasonable to expect that these two different techniques will lead to different engagement of the attentional networks and therefore activate different neural correlates.

Neural Correlates of Meditation

Several studies have investigated the brain activation during meditation and have identified some typical regions that are involved in meditation. These areas include the ACC and areas in the dlPFC (Baron Short et al., 2010; Cahn & Polich, 2006; Dickenson et al., 2013; Hölzel et al., 2007), regions associated with the active regulation of attention (Hölzel et al., 2007). Regions associated with the DMN (e.g. precuneus, posterior cingulate cortex) also seem to be involved during meditation (Hasenkamp et al., 2012; Manna et al., 2010; Fox et al., 2016). FAM seems to involve the ACC to a greater extent than OMM (Lazar et al., 2000; Manna et al., 2010) as well as activating regions involved in attentional orienting (e.g., the superior frontal sulcus and intraparietal sulcus (Lutz et al., 2008). OMM, on the other hand, seem to involve insula more, which is involved in interoceptive processing (Fox et al., 2016; Lutz et al., 2008; Marchand, 2014).

Focused Attention Meditation

As mentioned above, FAM place focus on sustaining attention on a chosen object as well as monitoring the attention when encounter intrusive thought. FAM can, therefore, be expected to activate brain regions involved in these attentional processes.

In a functional magnetic resonance imaging (fMRI) study, Manna et al. (2010) investigated the neural correlates of FAM and OMM as well as potential differences between expert meditators and novice meditators. The expert group consisted of eight Theravada Buddhist monks with 15,750 hours on average of balanced Samatha (FAM) and Vipassana (OMM) meditation practice and the novice group consisted of eight novice meditators without prior meditation. The novice group were given oral and written instructions on how to perform Samatha and Vipassana meditation and practiced these meditations for 30 minutes each per day during 10 days before doing the fMRI scanning. The experimental phase consisted of 6 min FAM and 6 minutes OMM meditation with 3 minutes non-meditative resting state before and after each meditation. The participants did these sessions three times. To perfrom FAM, the participants were instructed to "gently engage in sustaining the focus of your attention on breath sensations, such as at the nostrils, noticing with acceptance and tolerance any arising distraction, as toward stimuli or thoughts, and return gently to focus attention on the breath sensations after having noticed the distraction source" (Manna et al., 2010, p. 47) and for OMM "observe and recognize any experiential or mental content as it arises from moment to moment, without restrictions and judgement, including breath and body sensations, percepts of external stimuli, arising thoughts and feelings" (Manna et al., 2010, p. 47). The results for OMM will be presented later in this thesis.

When comparing the FAM state to the resting state in the novices, the researchers found a single activation in the left posterior cingulate cortex.

When the researchers compared the meditation state to a resting state in monks they found that FAM was associated to increased activity in three medial frontal areas, located in the left and right dorsal ACC, and in the right medial anterior prefrontal cortex (aPFC). The researchers found deactivations in both the left and right hemisphere. The deactivations in the left hemisphere comprised multiple clusters in the middle frontal gyrus (MFG), dlPFC, lateral aPFC, precuneus, transverse temporal gyrus (TTG), and anterior and posterior insula. In the right hemisphere, they found a deactivation in the inferior frontal gyrus (IFG) and in the superior temporal gyrus.

The results also showed that the monks, compared to the novices, increased their dorsal ACC and right medial frontal gyrus activity bilaterally when engaging in FAM. Additionally, they found a positive correlation between meditation expertise and deactivations of right IFG and of the left posterior insula with larger deactivations observed in more expert practitioners. The researchers suggest that the disengagement of these areas might be related to a more effortless maintenance of attentional focus.

Regarding the left and right dorsal ACC activations observed in the monks, the researchers suggest that this is in line with their predicted involvement in conflict monitoring and that the right medial aPFC activation can be due to its plausible involvement in focused awareness. The positive correlation between these three midfrontal areas suggests, according to the researchers, that they interact in a unitary circuitry. No activations associated to selective attention (temporal–parietal junction, ventrolateral prefrontal cortex, intraparietal sulcus and frontal eye fields) or sustaining attention (right frontal and parietal areas, and the thalamus) were observed.

The deactivation in dlPFC, mainly in the left hemisphere, suggests, according to the researchers, that sustaining the attentional focus leads to a deactivation of dlPFC areas. The investigators also found a negative correlation in the resting state between the right and left dorsal ACC clusters and a left dlPFC cluster and suggest that these areas play a contrasting role in the executive control of the attention setting, where ACC is involved in maintaining cognitive focus and dlPFC in opening the field of cognitive monitoring.

Manna et al. (2010) conclude that FAM is associated with an increased (predominantly right) medial frontal activation and a decreased (predominantly left) lateral prefrontal activation compared to rest. With regards to the monks, most of the deactivations were found in the left hemisphere, with a massive reduction of activation of left anterior and posterior insula, as well as a deactivation in the precuneus when comparing with rest.

In future studies, the researchers suggest that the groups should be larger and that a quantitative measure of effort (e.g. self-ratings on a Likert-scale) should be used to give a better understanding of potential differences in the effort for maintaining a FAM state. The researchers also suggest that motivation, intensity, and stability while meditating, as well as structural differences in the brain anatomy, are aspects that can confound the results and hence should be taken into account (Manna et al., 2010).

In another fMRI study, Brefczynski-Lewis et al. (2007) investigated the neural correlates of FAM in 14 expert meditators following Tibetan Buddhist traditions with 10,000-54,000 h of practice and 27 age-matched novice meditators. The novice meditators had no prior experience of meditation except during the week before the fMRI scanning session. The novice meditators were given written instructions on how to perform three different meditation practices, one concentration based and two others (not defined in the study) and meditated for 1 hour per day (20 min per meditation practice) for 1 week. The participants altered between a state of FAM where the participants were instructed to place focus on a small fixation dot on a screen and a neutral resting state during the experimental phase. To investigate the potential that expert meditators would be less disturbed by external stimuli during meditation than novice meditators and hence show less activation in brain areas associated with task-unrelated thought, daydreaming, and emotional processing a distracting external stimulus (positive, neutral, or negative sounds) were presented during meditation and resting state.

In this study they found that both groups activated a large overlapping network of attention-related brain regions, with regions involved in monitoring (dlPFC), engaging attention (visual cortex), and attentional orienting (the superior frontal sulcus and intraparietal sulcus) when engaging in FAM compared to the resting state condition. Expert meditators showed more activation than novice meditators in several attentional and other regions including frontoparietal regions, cerebellar, temporal, parahippocampal, and posterior occipital cortex when comparing meditation to rest state. However, the novice meditators showed greater activation than expert meditators in medial frontal gyrus/ACC and in the right mid-insula to the posterior insula, which are regions that have been shown to negatively correlate with performance in a sustained attention task. To control for misleading results due to structural differences between participant-group brains the authors performed a separate analysis where structural differences were taken into account and found that all significant regions remained significant.

The authors also investigated if the results correlated with hours of practice. They divided the expert group into those with the most hours of practice with mean hours of 44,000 hours and those with the least hours of practice with mean hours of 19,000 hours. The results were consistent with an inverted u-shaped function, where expert meditators with mean hours of 19,000 hours showed the strongest activation compared to the other expert group and the novice group. This is consistent with the view that long-term practice can lead to decreased activation may be due to increased processing efficiency. However, there was a difference in the strength and time course of activation between expert meditators and novice meditators where the experts showed greater activation than novice meditators in several attentional regions indicating that activation patterns depend on the level of expertise in the meditation practitioners.

The researchers propose there should be multiple control periods to compare the meditation state against because the novice group might have varied in how they carried out their resting state so this is a proposal to isolate different cognitive aspects of the meditation (Brefczynski-Lewis et al., 2007).

In another fMRI study, Raffone et al. (2007) investigated the neural correlates of eight Theravada Buddhist monks with 1 to 28 years of meditation practice. The monks participated in Samatha (FAM) meditation with the focus of attention placed on the breath and Vipassana meditation (OMM) with the focus being placed on an open attention and awareness.

In this study, the researchers found that FAM was related to activations in subgenual ACC and medial orbitofrontal cortex (OFC) when comparing to a resting state. A deactivation in the dlPFC, ACC, and left frontopolar gyrus was also found. The areas exhibiting deactivations in FAM showed an activation in OMM, with reference to the rest condition. The authors suggest that this finding indicates that a differentiation between FAM and OMM when looking at specific brain areas using fMRI (Raffone et al., 2007).

Baron Short et al. (2010) investigated 13 meditators with at least four years of regular practice (average was 30 minutes per day) from any meditative tradition in a fMRI study. The meditators were instructed to focus and only observe inhalation and exhalation. The practitioners meditated for four sessions of 12 minutes and performed four sessions of a 6 minutes control task. During the control task, the participants viewed a series of geometric images and were asked to determine whether the images were blue or yellow and select the appropriate button on a functional imaging glove system. They did not find any significant activations or deactivations in their whole brain analysis. But, when they used a region-specific and time-sensitive methodology of plotted time courses they found that the entire group-averaged time courses revealed significant increases in ACC and DLPFC during the meditation tasks compared to control tasks. They also found that the activation patterns of ACC and dlPFC differed between long-term (>10 years, n=5) and short-term (<10 years, n=8) practitioners. Long-term practitioners had significantly more consistent and sustained activation in the dlPFC and the ACC during meditation compared to the control state, in comparison to short-term practitioners. The researchers suggest that there may be attentional state differences between subjects with long- and short-term meditation practice and that dlPFC may be involved in attentional maintenance while ACC is involved in error monitoring of wandering attention (Baron Short et al., 2010).

In a review and meta-analysis conducted by Fox et al. (2016), the researchers reviewed fMRI and PET studies on FAM and found that FAM resulted in activations in regions involved in cognitive control that require monitoring performance and voluntary regulation of attention and behavior. Two significant clusters of activation were found, namely the dorsal ACC and premotor cortex extending into the posterior dlPFC, regions associated with voluntary regulation of thought and action. They also observed two slightly subthreshold clusters in dlPFC and in left mid-insula, areas involved in top-down focusing attention. These finding of activations in executive brain areas are consistent with the focus of effortfully sustaining attention practiced in this meditation technique. In the ventral posterior cingulate cortex and left posterior inferior parietal lobule, regions associated with the default mode network, episodic memory retrieval, simulation of future events, mind-wandering, and conceptual processing, they instead found clusters of deactivation.

The researchers propose that deactivations in these areas indicate that FAM might reduce spontaneous thoughts about future and past events and their conceptual elaboration. They did a supplementary meta-analysis where they excluded studies only investigating practitioners with a short-term training and found nearly identical results (Fox et al., 2016).

Open Monitoring Meditation

In the fMRI study mentioned above Manna and colleagues (2010) investigated the neural correlates of OMM as well as potential differences in activated brain areas between the eight Theravada Buddhist monks and eight novice meditators.

With regards to the novice, the researchers found four clusters of activations when comparing the meditation state to the resting state. These activations were found in the left dorsal ACC, the right rostral ACC, the right lateral orbitofrontal cortex, and the right medial anterior PFC. When comparing the meditation state to a resting state in the monks the researchers found that OMM lead to three main regions of activation in the left hemisphere, namely the medial aPFC, superior temporal gyrus (STG), and superior parietal lobule (SPL) extending medially in the precuneus. Additionally, the researchers found that the monks increased the left precuneus/SPL, the right dorsal ACC, and the right parahippocampal gyrus activity more compared to novices. The novice participants, on the other hand, showed a greater increase in the right rostral ACC, bilateral IFG, right orbitofrontal, and right medial aPFC compared to the monks when engaging in OMM. No correlation with expertise level was found in the monks. The three main regions of activation that were found in the monks when comparing OMM to rest are areas typically associated with self-referential processing.

The researchers propose that the left dorsal ACC activation in the novice group might be due to the executive demand on the novice in OMM. The researchers also found a positive correlation in the novice group between left dorsal ACC and right medial aPFC and suggest that these two areas cooperate in enabling cognitive focus. The activations in the novice group mainly involved the right prefrontal cortex and the researchers suggest that the activations of right rostral ACC and right lateral orbitofrontal cortex, areas that were not activated in the monks, may reflect an evaluation-based stance since these two areas have been related to involvement in cognitive and affective evaluation processes.

The researchers conclude that OMM is associated with an increased (predominantly left) medial frontal activation compared to rest. The researchers also conclude that OMM, compared to FAM, was associated with a more lateral prefrontal activation in both hemispheres (Manna et al., 2010).

In another fMRI study, Raffone et al. (2007) investigated the neural correlates of eight Theravada Buddhist monks with 1 to 28 years of meditation practice. The monks participated in Samatha (FAM) meditation with the focus of attention placed on the breath and Vipassana meditation (OMM) with the focus being placed on an open attention and awareness. In this study, the researcher found that OMM, when compared to a resting state, activated the dlPFC, anterior cingulate and left frontopolar gyrus. They also found a left relative lateralization of activation of frontoparietal regions, including precuneus and superior parietal lobule.

The investigators suggest that the activation of left frontoparietal areas might be due to their involvement in conscious access to sensory and mental content that arises in the present moment. This kind of open awareness is consistent with the focus of OMM. They also propose that the overall left lateralization of the prefrontal cortex activation is likely due to the unselective non-judgmental acceptance of mental content and the relation to positive emotions associated with OMM. The researchers also observed a deactivation in the medial orbitofrontal cortex, a region involved in choice behavior and encoding of reward values, and suggest that the deactivation in this area is likely due to the unselective open acceptance of the mental content entering awareness (Raffone et al. 2007).

Ives-Deliperi, Solms, and Meintjes (2011) conducted a fMRI study where they investigated 10 mindfulness meditators (OMM). All the participants had undergone an 8-week MBSR program and had practiced mindfulness meditation on a daily basis for at least four years. The participants first did a 2 minutes control task characterized by the random generation of numbers. Then the participants meditated for 12 minutes with the instruction “to open awareness to present-moment bodily sensations, thoughts, and emotions without judging or reacting to these mental and physical events” (Ives-Deliperi et al., 2011, p.234), followed by a 2 minutes control task again.

In this study, the researchers found that OMM was associated with decreased activity in midline cortical structures associated with interoception, including bilateral anterior insula, left ventral ACC, right medial prefrontal cortex, and bilateral precuneus. They also found evidence of activations in right posterior cingulate cortex. These brain regions have all been implicated in the process of self-referential thought and the attribution of subjective significance to emotions (Northoff & Bermpohl, 2004). The decrease in activity in these areas suggests that the practitioners are able to refrain from subjective appraisal, which is the focus in OMM (Ives-Deliperi et al., 2011)

In the review and meta-analysis mentioned above (Fox et al., 2016) the researchers reviewed fMRI and PET studies on OMM and found that OMM activated inferior frontal gyrus, posterior dlPFC/premotor cortex, and dorsal ACC/pre-supplementary motor area. These regions are involved in the voluntary regulation of thought and action. They also found activation in the insula, which is a region that is involved in interoceptive processing. They observed activations in rostrolateral prefrontal cortex and left mid-dlPFC, even though these regions did not exceed their threshold. These two areas, together with the dorsal ACC, constitute essential parts of a frontoparietal control system (Vincent et al., 2008; Spreng et al., 2010) that is involved in cognitive control, a system that coordinates and monitors attention, both internally and externally.

This is, according to the researchers, in line with what is expected from OMM since it involves non-judgmental attention to the mental content of information from within the body, from thoughts and memories, and from the outside world and hence should recruit numerous areas from the frontoparietal control system. With regards to deactivations, they only observed one significant deactivation and that was in the right thalamus. Another deactivation in the left thalamus was found, but it did not exceed the sub-threshold. The thalamus is a relay center for the majority of incoming sensory information and also plays a role in filtering out relevant stimuli from the incoming sensory signals. An interesting finding was that, when results from the novice practitioners were filtered out, the deactivations in thalamus were even more prominent. This indicates that extensive training in OMM lead to greater deactivations in the thalamus (both left and right) which suggests decreased sensory gating which is in line with the goal of OMM, being receptive and open to incoming information (Fox et al., 2016).

Structural Changes in The Brain

Research have suggested that long-term meditation practice can induce structural changes in brain regions activated during meditation, such as changes in grey and white matter concentration, increased cortical thickness, and increased functional connectivity (Davidsson & Lutz, 2008; Brefczynski-Lewis et al., 2007; Jang et al., 2011; Lutz et al., 2008). For example, long-term meditation practice been associated with structural changes in areas involved in attention, interoception, sensory processing (Lazar et al., 2005), learning and memory processes, emotion regulation, self-referential processing, and perspective taking (Hölzel et al., 2011), and in the default mode network (Hölzel et al., 2011; Jang et al., 2011), such as right anterior insula (Lazar et al., 2005; Hölzel et al., 2008), frontal areas (Hölzel et al., 2008; Kang et al., 2012; Lazar et al., 2005; Luders et al., 2009), temporal areas (Hölzel et al., 2008; Kang et al., 2012; Luders et al., 2009), hippocampus (Hölzel et al., 2008; Hölzel et al., 2011; Luders et al., 2009), cerebellum (Hölzel et al., 2011), and brainstem (Vestergaard-Poulsen et al., 2009). Enhanced connectivity within attentional networks and between attentional networks and the DMN (Hasenkamp & Barsalou, 2012) have been found as well as deactivations within the DMN (Brewer et al., 2011; Hasenkamp & Barsalou, 2012).

Lazar et al. (2005) conducted a magnetic resonance imaging study to investigate cortical thickness in twenty long-term Insight meditators (9.1 ± 7.1 years of meditation experience and an average of 40 minutes meditation each day) which is a form of FAM where the focus is directed to internal experience. In the control group were fifteen matched participants with no prior meditation experience. Cortical surface models were created for all participants and were then aligned to an atlas of cortical folding patterns using a high-dimensional nonlinear registration technique.

In this study they found that participants with extensive meditation practice had thicker brain regions in areas associated with attention, sensory processing and interoception compared to matched controls. These areas included the prefrontal cortex (right middle and superior frontal sulci) and right anterior insula. The researchers also found that differences in prefrontal cortical thickness between long-term meditators and the matched control group were most evident in older participants, which may suggest that meditation can offset cortical thinning related to aging. There was no difference between the groups in mean thickness across the entire cortex for either hemisphere. The insula is associated with interoceptive processes and internal awareness (Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004) which are central parts in Insight meditation which may explain the differences in thickness in the insula between the two groups. Most of the regions identified in this study were found in the right hemisphere. The right hemisphere is essential for sustaining attention (Posner & Petersen, 1990) which is a central part of Insight meditation. The researchers propose that these findings provide evidence that meditation practice promotes cortical plasticity in regions that are involved in the meditation tradition practiced (Lazar et al., 2005).

Luders et al. (2009) examined high-resolution MRI data for 22 meditators (mean average of 24.18 years of meditation practice) and 22 matched controls using a voxel-based morphometry (Ashburner and Friston, 2000) combined with an automated parcellation approach (Tu et al., 2008), to investigate possible links between meditation and alterations in brain structure on a global, regional, and very local level. The meditator styles practiced by the meditators differed but more than half of all meditators indicated that deep concentration was an essential part of their practice.

One large cluster of increased grey matter was found in the right orbitofrontal cortex, located at the border between inferior and middle frontal gyrus, as well as larger volumes of the right hippocampus in meditators compared to the control group. When co-varying for age and/or lowering applied statistical thresholds increased grey matter volumes were also found in the right thalamus and left inferior temporal lobe in long-term meditators. Several studies have provided evidence that the OFC is associated with emotion and with suppressing or reappraising negative emotional stimuli. The researchers, therefore, suggest that the increased grey matter observed in the OFC might be due to the meditators superior abilities in emotional self-regulation and behavioral flexibility and in disengaging from automatic thoughts and habits (Luders et al., 2009).

Hölzel and colleagues (2008) examined 16 Vipassana (OMM) meditators (mean of 8.6 years of meditation practice) and 17 matched control participants without any meditation experience. MRI brain images were used to compare the regional grey matter concentration between meditators and non-meditators. The researchers found that grey matter concentration in right anterior insula and in the right hippocampus was significantly greater in meditators compared to non-meditators. They also found that the left inferior temporal gyrus showed a trend towards significance (Hölzel et al., 2008).

Fox et al. (2014) conducted a systematic review and meta-analysis of morphometric neuroimaging from 21 neuroimaging studies (16/21 studies involved long-term practitioners) examining ~300 meditation practitioners, both long-term (with thousands of hours of meditation experience) and short-term (5–60 h of meditation experience) meditators with no specific emphasis on type of meditation technique used. The researchers found, via ALE meta-analysis, several regions with an altered structure. When including data from both long-term and short-term practitioners the researchers found nine regions that were reported in ≥3 studies to be consistently altered. These regions were rostrolateral prefrontal cortex, anterior/mid-cingulate cortex, insular cortex, somatomotor cortices, inferior temporal gyrus, fusiform gyrus, hippocampus, corpus callosum, and superior longitudinal fasciculus. When looking at the two groups separately the results are almost identical, with the exception of anterior/mid-cingulate cortex, and superior longitudinal fasciculus only being reported twice in studies of long-term practitioners and hence are not included in the regions being altered in long-term meditators. This similar result in structural differences for long-term and short-term practitioners indicate that even just a few hours of meditation practice can lead to neuroplastic changes (Fox et al., 2014).

Hasenkamp and Barsalou (2012) examined differences in functional connectivity that may be related to amount of meditation experience during a resting state. The participants consisted of 14 meditators with higher and lower FAM experience. The researchers found that participants with more meditation experience had an increased connectivity within attentional networks, more specific an increased connectivity between right dlPFC and right insula, left dlPFC, and mid-cingulate gyrus. They also found an increase in connectivity between attentional networks and the DMN, more specific an increased functional connectivity between medial PFC/ACC and bilateral regions of the inferior parietal lobule. A third finding was a reduced connectivity within the DMN, more specific a decreased connectivity between ACC regions and left posterior cingulate cortex as well as an increase in connectivity between DMN regions and left orbitofrontal cortex/ventromedial PFC. The researchers propose that these neural connections may be involved in the development of cognitive skills, such as maintaining attention on a chosen object and disengaging attention from distractions. Since these alterations in connectivity between brain regions were observed during a resting state it suggests that long-term practice of meditation is associated with connectivity changes in the brain, and especially in attentional regions when engaging in FAM (Hasenkamp & Barsalou, 2012).

Attentional Performance

As mentioned above, meditation is a form of mental training, and evidence suggests that meditation practice leads to long-lasting changes in our brain. These structural changes induced by meditation can be expected to have an effect on our cognitive functions and lead to changes in attentional processing, perhaps through affecting how we process and perceive stimuli (Lutz et al., 2008; Lutz et al., 2009; Tang et al., 2007).

Studies have shown that meditation seems to improve performance on several components of attention (Moore & Malinowski, 2009; Jha et al., 2007; Lutz et al., 2008; Valentine & Sweet, 1999). FAM has been associated with improvements in sustained attention (Carter et al., 2005; Brefczynski-Lewis et al., 2007), selective attention (Chiesa, Calati, & Serretti, 2011) and executive attention (Tang et al. 2007, Chiesa, Calati, & Serretti, 2011; Colzato et al. 2015). OMM, on the other hand, has been associated with improvements in unfocused sustained attention (Chiesa, Calati, & Serretti, 2011).

For example, evidence suggest that meditation improves the practitioner’s ability to control perceptual rivalry (Carter et al., 2005), decrease attentional blink (Slagter et al., 2007), and reduce interference in the Stroop task (Chan & Woollacott 2007; Kozaka et al., 2012; Moore & Malinowski, 2009).

Carter et al. (2005) investigated 23 Tibetan Buddhist monks with meditation experience varying from 5 to 54 years. In this study, they tested binocular rivalry via display goggles presenting horizontal and vertical green stationary gratings to the right and left eye, respectively. The monks served as their own control group and participated in three different conditions. The first condition was rivalry during compassion meditation, the second condition was rivalry after FA meditation and the third was rivalry during FA meditation. In the first and second conditions, the monks pressed a button or reported verbally when button-press was not possible to indicate what picture was being presented. In the third condition, they only reported verbally. In this study, they found that FA meditation, compared to compassion meditation, appears to slow down perceptual rivalry switching meaning that the monks could hold one picture in focus without switching for a longer time. Since the monks served as their own controls the authors suggest that the observed results indicate that the increases in perceptual dominance durations are due to the monks practiced ability to control and stabilize the contents of their minds. The authors also conclude that these findings support the notion that long-term practice of FAM leads to improvements in the practitioner's ability to sustain attention on a chosen object for a prolonged period of time (Carter et al., 2005).

Slagter and colleagues (2007) conducted a longitudinal study investigating whether meditation training (OMM) had an impact on the distribution of attentional resources by measuring performance in an attentional-blink task and scalp-recorded brain potentials. Attentional-blink task is a test where two targets (T1 and T2) are embodied in a rapid stream of distractors (Shapiro, Raymond, & Arnell, 1997). When these two targets are presented close in time, approximately 500 ms between them, the second target is often not perceived. When presented with more than 500 ms between each other or when being instructed to ignore the first target (T1) participants can report the second target (T2) accurately. The reason for this is that our mind is limited and has limits in its capacity of processing information and hence when two targets are presented close to each other there is a competition between the two targets for the limited attentional resources. So, when the attentional resources are devoted to processing the first target (T1), the second target (T2) is likely to be missed (Shapiro, Raymond, & Arnell, 1997).

This study consisted of 17 participants that were part of a 3-month Vipassana meditation retreat (experimental group). The participants meditated for 10-12 hours per day. The meditators differed in their styles of meditation previously practiced. 23 matched participants with no prior experience in meditation constituted the control group. The participants in the control group received a 1 hour Vipassana meditation class and were then instructed to meditate for 20 minutes each day for 1 week before pretest and posttest. Vipassana cultivates an open attention but often start with a focus on the breath. The participants had to identify two targets (numbers in this case) embedded in a stream of letters. In total, between 15 and 19 items were presented. Regarding the temporal distance between the targets, the second target either was presented 336 ms after the first target or it was presented 672 ms after the first target. When presented 336 ms after T1, T2 was within the attentional blink span, and when T2 was presented 672 ms after T1 is was presented outside the attentional blink span.

The two groups performed equally in the pretest before meditation. In the posttest, however, the experimental group performed significantly better as compared to the control group. The experimental group showed higher detection rates for the second target (T2) compared to the control group when T2 was presented within the attentional-blink time-window. The experimental group also showed a decrease in brain resources allocated to the first target and participants with the greatest reduction in brain resources allocated to T1 also generally showed highest detection rates for the second target. The results indicate that the meditation retreat improved the participants ability to control their attention and not “get stuck” on the first target “as reflected in less elaborate stimulus processing and the development of efficient mechanisms to engage and then disengage from target stimuli in response to task demands” (Lutz et al., 2008, p. 166) which suggests that OMM leads to a more open and flexible attentional state (Slagter et al., 2007).

In a study, Chan and Woollacott (2007) investigated the performance of participants with different levels of meditation practice in an attentional task. The participants were 50 meditators and 10 non-meditators. 20 of the meditators were classified as FAM and the other 30 as OMM and they ranged in experience from 82 to 19,200 hours of meditation practice and between 6 to 150 minutes each day. In this study, the participants did the Stroop Word-Colour Task (SWCT) which is a test that presents words in different colors (red, green or blue) and requires both attention and impulse control. The participants were presented single words divided into three conditions. The first condition consisted of names of colors (red, green, blue) that was printed in black ink. In the second condition (color condition) different words were printed in red, green, or blue ink and participants were instructed to name the color in which the word was printed as fast as possible. The third condition (Colour-Word condition) consisted of the names of colours from the first condition printed in the colours from the second condition (the names of the colours and the colours the names were printed in were incongruent) and in this condition the participants were instructed to name the colour in which the words were printed. Since there is a conflict in the third condition the participant needs to inhibit the interfering information (the written color name).

The results showed a significant reduction in interference in the Stroop task associated with meditation experience. This result suggests that meditation practice improves the practitioner’s ability to inhibiting automatic responses in favor of the desired response suggesting that meditation increases the efficiency of the executive attentional network. A surprising finding was that it is mainly the amount of time spent in meditation each day and not the total amount of hours spent in meditation overall that affects the performance in the Stroop task. The researcher did not find a significant difference between FAM and OMM practitioners and suggest that it is due to their fundamental similarities (Chan & Woollacott (2007).

Jha and colleagues (2007) used the Attentional Network Test (ANT) which is a test designed to evaluate alerting, orienting, and executive attention (Fan et al., 2002; MacLeod et al., 2010). The researchers used this test to investigate if meditation alters or enhances specific aspects of attention in three different groups. The first group, a mindfulness-based stress reduction (MBSR) group consisted of 17 participants recruited from MBSR courses offered to students at the University of Pennsylvania. These participants had no prior experience in meditation before partaking in the study. They participated in an 8-week MBSR course that emphasized the development of concentrative meditation skills and was instructed to meditate for 30 minutes daily. The second group consisted of individuals experienced in concentrative meditation techniques (mean practice was 60 months) who participated in a 1-month intensive mindfulness retreat. The participants practiced meditation for 10–12 hours per day each day during the retreat and were instructed to place full attention on the out-breath during the meditation. In the control group were 17 participants naïve to meditation. The participants were tested prior to training (Time 1) and after training (Time 2).

The researchers found that individuals in the retreat group showed an improved conflict monitoring performance compared to the MBSR and control group at Time 1. When testing the groups again, at Time 2, the researchers found that participants in the MBSR group improved their orienting performance after participating the MBSR course, compared to the retreat group and the control group. The participants in the retreat group, on the other hand, demonstrated altered performance on the alerting component, with improvements in exogenous stimulus detection when compared to the control and MBSR groups. There were no differences between the groups in conflict monitoring performance at Time 2. Participating in the retreat group seems to have allowed for the development and emergence of receptive attentional skills, which improved the exogenous alerting-related process. Participation in the MBSR program instead seemed to improve the participants' abilities to endogenously orient attention. The authors suggest that these results indicate that FAM may improve attention-related performance by enhancing functions of attention-related networks (Jha et al., 2007).

There are accumulating evidence supporting the assumption that long-term experience of meditation leads to improvements in attentional tasks. However, some recent studies suggest that short-term meditation practice as well can impact the practitioner's performance in attentional tasks (Lippelt et al., 2014).

For example, did Tang et al. (2007) investigate how short-term meditation affects our attention. In this study, 80 Chinese undergraduates without any training in meditation participated. They were randomly assigned to the experimental group or the control group, 40 participants in each group. The experimental group participated in 20 minutes each day of Integrative body-mind training meditation (IBMT) (FAM) meditation for 5 days and the control group participated in group sessions, 20 minutes each day for 5 days, where they received information about relaxation of the body. IBMT is a mind-body approach that combines relaxation exercises, breathing exercises, posture exercises and mental visualization. Each participant did the Attention Network Test (ANT) before and after training. (Fan et al., 2002). Before training, there were no differences between the two groups in their alerting, orienting, and executive networks scores. After 5 days of meditation and group sessions, the experimental group showed significantly greater improvement for the executive network, but no differences were found for alerting or orienting networks after training. The authors conclude that since the participants were randomly assigned, the researchers blind to the condition and objective tests were used, the IBMT training influenced the efficiency of executive attention (Tang et al., 2007).

In another study, Valentine and Sweet (1999) investigated meditations effect on sustained attention. The participants were 19 long-term (25 months or more) and short-term (24 months or less) meditators from a Buddhist center, with practice in both FAM and OMM.

The control group consisted of 24 participants without any meditation training. In this study the researchers found that both long-term and short-term FA meditators and OM meditators showed a superior performance on the Wilkins' counting test (Wilkins, Shallice, & McCarthy, 1987), a test of sustained attention in which participants count the number of random-interval auditory beeps that they hear in a series, compared to a control group without any meditation experience. They also found that long-term meditators performed better compared to short-term meditators. When the stimulus was unexpected the OM meditators demonstrated superior performance compared to FA meditators, but no differences were found between the different meditation techniques when the stimulus was expected, indicating that OMM leads to a more receptive attentional focus (Valentine & Sweet, 1999).

These results suggest that meditation enhance performance on attentional tasks, that FAM and OMM lead to both similar and different cognitive improvements and that short-term practice can induce improved performance even though long-term practice seem to lead to greater enhancements in attentional tasks. To confirm this idea that mental processes can be trained through meditation there is a need for studies examining changes due to meditation within the same individuals as well as longitudinal studies.

Discussion

Meditation, practiced around the world for thousands of years, has the last decades gained interest in the field of scientific study. The research on meditation is still in its infancy but despite this, there seems to be some converging evidence of meditation's impact on the human brain and mind. This thesis has looked at the neural correlates of FAM and OMM in long-term and novice practitioners, investigated structural differences between expertise meditators and novice meditators and has also looked at attentional improvements induced by meditation.

The results from the included studies in this thesis suggest that certain, to some degree differential, brain networks are activated during FAM and OMM. The results also indicate that meditation induces some structural changes and that meditation seems to enhance the practitioners' attentional control.

Results from studies investigating the neural correlates of FAM show that this meditation style is associated with activations in regions that are involved in attention and cognitive control. Increased activation in the frontal lobe areas was found, especially in the prefrontal cortex, which is a part of the brain involved in attention and executive functions. The most evident findings are activation in the ACC, often bilaterally, (Baron Short et al., 2010; Dickenson, Berkman, Arch, & Lieberman, 2013; Hölzel et al., 2007; Manna et al., 2010; Raffaone et al., 2007) and in the dlPFC (Baron Short et al., 2010; Brefczynski-Lewis et al., 2007; Dickenson et al., 2013; Hasenkamp et al., 2012; Hölzel et al., 2007). The ACC and dlPFC are regions part of the executive control system and the activation of these areas are thought to be due to the active regulation of attention during FAM (Fan et al., 2002; Fox et al. 2016; Hölzel et al., 2008).

This is in line with what can be predicted from FAM since the focus of this technique is to keep the attention focused on a chosen object, and to redirect the attention back to the object of focus whenever the mind is drifting away. This monitoring and voluntary regulation of attention are modulated by areas part of the executive control system. Activation in regions involved in selective attention such as the temporoparietal junction (Dickenson, Berkman, Arch, & Lieberman, 2013) and intraparietal sulcus (Brefczynski-Lewis et al., 2007) was found in some studies. Greater activation in frontoparietal regions, an area involved in sustained attention were found to be more activated in experts compared to controls when comparing to a resting state (Brefczynski-Lewis et al., 2007).

Some deactivations were also evident in the studies examined. For example, in the precuneus (Manna et al., 2010) and in the ventral posterior cingulate cortex and left posterior inferior parietal lobule (Fox et al., 2016) areas involved in the DMN (Hasenkamp et al., 2012; Malinowski, 2013). Deactivation in posterior insula was found in the monks, and larger deactivations were found in more expert meditators (Manna et al., 2010). Insula and ACC are areas thought to be involved during mind-wandering (Hasenkamp & Barsalou, 2012), and therefore deactivations in these areas might relate to a decrease in mind-wandering which is something that can be expected in long-term practitioners.

Results seem to be inconsistent with regards to deactivations or activations in certain areas, as well as in what areas are recruited during meditation. There have mainly been findings of activations in the ACC and dlPFC, but Manna et al. (2010) found a deactivation in the dlPFC when engaging in FAM and Brefczynski-Lewis et al. (2007) found that the activation of ACC was greater in the novice group compared to the monks, and similar results were obtained by Raffone et al. (2007). Since meditation is a subjective experience it is difficult to investigate, and studies can yield very different results depending on for example subjects in the study, the inner experience of the meditator, the instructions given to participants, methodology, and measures used. Meditation techniques might differ a bit in their focus, even though being defined as a FAM. Another aspect that can be a reason for these differences in activations is the amount of practice that the participants have. There seems to be some evidence for long-term practice leading to a decrease in activations in involved brain areas compared to meditators with less experience. (Brefczynski-Lewis et al., 2007; Manna et al., 2010). It has been proposed that the neural activation follows an inverted U-shape where novice meditators show less activation compared to short-term meditators, and long-term meditators showing less activation compared to short-term meditators. It seems like practitioners with long-term experience of meditation can more effortlessly control their attention and hence their activation in involved brain regions smaller compared to short-term meditators (Brefczynski-Lewis et al., 2007).

Regarding the neural correlates of OMM, there seem to be findings of activation in the ACC and OFC among novices which have been proposed to reflect cognitive and affective evaluation processes. This can be expected in a group unaccustomed to OMM since the open monitoring focus applied in OMM is quite hard to achieve and hence, novice practitioners are likely to still evaluate and judge the mental content arising (Manna et al., 2010). Deactivations in this area in a group of long-term meditators have been found (Raffone et al., 2007) which indicates that there indeed seem to be a relation in the level of activation and amount of meditation practice where long-term meditators achieve a more unselective open acceptance of the mental content entering awareness compared to novices.

There also seem to be activations in areas involved in the voluntary regulation of thought and action, such as the inferior frontal gyrus, posterior dlPFC/premotor cortex, and dorsal ACC/pre-supplementary motor area (Fox et al., 2016), which is in line with regulating attention towards an open awareness.

The left dorsal ACC, the right rostral ACC, the right lateral orbitofrontal cortex, and the right medial anterior PFC activations that were found in the monks when compared to a resting state are areas associated to self-referential processing (Manna et al., 2010). Contradictory results were found in another study where deactivations in areas relating to self-referential were found (Ives-Deliperi et al., 2011).

When looking at structural changes induced by meditation there seem to be some recurring areas of change. With regards to FAM practice, Luders et al. (2009) found that expert meditators, compared to the control group, had increased grey matter in the right orbitofrontal cortex, located at the border between inferior and middle frontal gyrus. They also found larger volumes of the right hippocampus in expert meditators. Increased grey matter volumes were also found in the right thalamus and left inferior temporal lobe when the researchers co-varying for age and/or lowering applied statistical thresholds in long-term meditators (Luders et al., 2009).

OFC plays a crucial role in emotion regulation (Quirk & Beer, 2006) and the increased grey matter found in the OFC might reflect expert meditators enhanced abilities linked to emotional self-regulation and behavioral flexibility and in disengaging from automatic thoughts and habits (Brown and Ryan, 2003).

Hippocampus is involved in attentional and emotional processes (Davidson, Jackson, & Kalin, 2000; Newberg and Iversen, 2003), and the increase in hippocampal volume might be due to meditators' recurrent direction of attention towards external and internal stimuli and events as well as due to their potential habits to cultivate positive emotions, retain emotional stability, and engage in mindful behavior (Luders et al., 2009). The hippocampus has also been proposed to be involved in modulating cortical arousal and responsiveness via interconnections with the prefrontal cortex as well as the thalamus (Newberg and Iversen, 2003), and in this study the researchers found larger volumes of grey matter in right hippocampus and orbitofrontal cortex, as well as in the right thalamus (when co-varying for age and/or lowering applied statistical thresholds) which is in line with this proposal (Luder et al., 2009).

It has been suggested that thalamus works as a regulator of the flow of sensory information and that an increase in thalamic activation during meditation might be correlated with a decrease of sensory input entering the posterior superior parietal lobule which, in turn, lead to an increased sense of focus (Newberg and Iversen, 2003). The focus is a central part of meditation and hence it is not surprising that regular practice of meditation, lead to structural changes in thalamus due to its recurring activation during meditation.

The temporal lobe has been involved in religious activity and mystical experiences (Saver & Rabin, 1997) and hence might be involved when experiencing a mindful state and feelings of “deep pleasure and insights into the unity of all reality” (Hölzel et al. 2008).

Hasenkamp and Barsalou (2012) found that participants with more FAM practice had an increased connectivity within attentional networks, between attentional networks and the DMN, between DMN regions and left orbitofrontal cortex/ventromedial PFC. They also found a reduced connectivity within the DMN, more specific a decreased connectivity between ACC regions and left posterior cingulate cortex. The researchers propose that these neural connections may be involved in the development of cognitive skills, such as maintaining attention on a chosen object and disengaging attention from distractions. Since these alterations in connectivity between brain regions were observed during a resting state it suggests that long-term practice of meditation is associated with connectivity changes in the brain, and especially in attentional regions when engaging in FAM (Hasenkamp & Barsalou, 2012).

Two studies incorporated more of an OMM approach an in the first, Lazar and colleagues (2005) found that long-term practitioners had thicker brain regions in areas associated with attention, sensory processing and interoception compared to matched controls. These areas included the prefrontal cortex (right middle and superior frontal sulci) and right anterior insula. The researchers also found that differences in prefrontal cortical thickness were most evident between long-term meditators and the matched control group, which they propose might indicate that meditation can offset cortical thinning related to aging (Lazar et al., 2005). Hölzel et al. (2008) also found evidence of increased grey matter in right anterior insula, as well as in the right hippocampus in expert meditators compared to novice. Left inferior temporal gyrus showed a trend towards significance. The researchers found that the grey matter volume in left inferior temporal gyrus and medial OFC correlated with the hours of meditation practice while the right anterior insula showed a trend towards significance (Hölzel et al., 2008). The insula is associated with interoceptive processes and internal awareness, such as monitoring and conscious awareness of internal body states (Craig, 2004; Critchley et al., 2004; Craig, 2009; Farb et al., 2013), something that these expert meditators have engaged in during their OMM where they have placed emphasis on awareness of bodily sensations.

When looking at the potential attentional improvements due to meditation practice Carter et al. (2005) found that FAM, compared to compassion meditation, appeared to slow down perceptual rivalry switching, enabling the monks to sustain their focus for a longer period of time. The authors suggest that this finding support the assumption that long-term practice of FAM leads to improvements in the practitioner’s ability to sustain attention on a chosen object for a prolonged period of time (Carter et al., 2005).

Jha et al. (2007) found that individuals experienced in FAM showed an improved conflict monitoring performance compared to individuals without any training in meditation. The researchers also found that 8-weeks of FAM practice (an 8-week MBSR program) lead to an improvement in orienting performance, which suggests that even short-term meditation practice can lead to improvements in attentional tasks. Another finding was that the meditators with prior experience in FAM demonstrated altered performance on the alerting component, with improvements in exogenous stimulus detection after partaking in a 1-month intensive mindfulness retreat where they were instructed to focus on out-breath during the meditation. The researchers conclude that participating in the mindfulness retreat allowed for the development and emergence of receptive attentional skills, which improved the exogenous alerting-related process. They also conclude that participation in the MBSR program leads to improvements in the participants’ abilities to endogenously orient attention. The authors suggest that these results indicate that FAM may improve attention-related performance by enhancing functions of attention-related networks (Jha et al., 2007).

Slagter and colleagues (2007) found that OMM lead to a more open flexible attentional state where practitioners showed higher detection rates for the second target (T2) compared to the control group in an attentional blink task (Slagter et al., 2007).

Chan and Woollacott (2007) found that meditation experience, in general, was associated with the practitioner's ability to inhibiting automatic responses in favor of the desired response, suggesting that meditation increases the efficiency of the executive attentional network. The researcher did not find a significant difference between FAM and OMM practitioners and suggest that it is due to their fundamental similarities. An interesting finding in this study was that it was the amount of time spent in meditation each day that affects the performance in the Stroop task, and not the total amount of hours spent in meditation overall (Chan & Woollacott (2007).

Valentine and Sweet (1999) investigated sustained attention in FAM and OMM practitioners and found that both long-term and short-term practitioners showed a superior performance on the Wilkins' counting test compared to the control group. The results also showed that long-term practitioners performed better compared to the short-term practitioners, indicating that meditation practice leads to improvement in sustaining attention. When the stimulus was unexpected the OM meditators demonstrated superior performance compared to FA meditators, but no differences were found between the different meditation techniques when the stimulus was expected. The authors suggest that this indicates that OMM leads to a more receptive attentional focus (Valentine & Sweet, 1999).

In another study, Tang et al. (2007) investigate how short-term meditation affects the attention and found that five days of FAM training lead to improvements in executive attention as measured by the Attentional Network Test (Fan et al., 2002) (Tang et al., 2007).

As mentioned in the introduction FAM and OMM place different emphasis on the focus of attention, but despite this, they are not easily separated when investigating them. In research studies of OMM, a focus on the breath is often incorporated which makes the OMM practice more similar to a FAM. This incorporation of focus on the breath might be explained by the difficulty for novices to keep a purely open focus of attention and hence is a means to help the meditators. But, despite the reason for this, it makes the interpretation of these two different meditation styles problematic since the neural correlates exerted during meditation is quite similar and hence leads to similar results.

When looking at the structural changes in expert meditators the results indicate that the right anterior insula (Hölzel et al., 2008; Lazar et al., 2005), right OFC (Luders et al., 2009), left inferior temporal gyrus (Hölzel et al., 2008; Luders et al., 2009) and right hippocampus (Hölzel et al., 2008; Luders et al., 2009) tend to be structurally changed in expert meditators. The results also indicate that meditation leads to altered connectivity in the brain between attentional regions (Hasenkamp & Barsalou, 2012). There also seem to be evidence of meditation being related to an offset cortical thinning related to aging (Lazar et al., 2005). Alterations in the structure in areas activated during meditation, such as the dlPFC and ACC were not found and Hölzel et al. (2008) propose that it might be due to some brain regions being more adaptive to structural changes than other areas (Hölzel et al., 2008).

The results from the studies investigating meditations effect on attention indicate that FAM is associated with improvements in expert meditators with regards to alerting (Jha et al., 2007), orienting (Carter et al., 2005; Jha et al., 2007; Valentine & Sweet, 1999), and executive functions (Chan & Woollacott, 2007; Jha et al., 2007; Tang et al., 2007). The results also suggest that OMM leads to a more flexible and open state of mind (Slagter et al., 2007; Valentine & Sweet, 1999), and improvements in executive attention (Chan & Woollacott, 2007). There also seem to be results indicating that even short-term meditation practice can lead to attentional improvements (Jha et al., 2007; Tang et al., 2007; Valentine & Sweet, 1999). Another finding was that it might be the amount of time spent in meditation each day that affects the performance in attentional tasks, and not the total amount of hours spent in meditation overall (Chan & Woollacott (2007).

Conclusion

Taken together, these results imply that there are some expert related changes in neural activity and in the structure of the brain as well as in attentional performance induced by meditation. Long-term practitioners seem to show less activity in distraction-related regions (brain regions that are associated with task-unrelated thoughts, daydreams, and emotional processing) compared to novice. It also seems like long-term practitioners show more activity in attention-related regions. Further, it seems like neural activation follows an inverted U-shape where novice meditators show less activation compared to short-term meditators, and long-term meditators showing less activation compared to short-term meditators. This indicates that practitioners with long-term experience of meditation can more effortlessly control their attention and hence their activation in involved brain regions smaller compared to short-term meditators. Long-term meditation practice also seems to lead to structural changes throughout the entire brain. The studies in this thesis show that long-term practitioners indeed seem to have larger brain regions, with thicker cortices and more brain tissue, compared to people with no experience in meditation. There also seem to be indications that long-term practice enhances the practitioners' attentional control. Long-term practitioners seem to be able to control their attention in a greater manner and distractors do not seem to disturb their attention to the same extent as in non-meditators.

Limitations

A problem when investigating neural activity during meditation is that meditation in itself is a subjective experience. Even though we have the quantitative measures to examine neural correlates during meditation, we do not know anything about the meditator's inner experience. This second aspect, the first-person perspective of the experience is an important aspect to be able to fully understand the brain activity during meditation. A report obtained from the meditators of their attentive state, spontaneous thought processes, and the strategy used to carry out the task can help researchers to identify and interpret variability in brain activity during meditation (Lutz et al., 2008). Lutz and colleagues (2002) examined the usefulness of such a tool and found correlations between synchrony patterns and reported cognitive contents which according to the researchers illustrate that information about moment-to-moment variations in the meditators subjective experience can help in the study of brain dynamics (Lutz et al., 2002)

Another problem when investigating meditation is that most research is comparing long-term practitioners with controls that are naïve to meditation. These cross-sectional studies can shed light on differences between the groups, but they do not account for if it was the meditation training that induced the changes in the brain or if the long-term practitioners had pre-existing differences in the brain that predisposed them to engage in long-term meditation practice.

Another aspect when investigating long-term practitioners is that they are likely to have engaged in several different meditation practices and hence the result obtained in the studies might include the impact from both different meditation techniques even though the study only investigating one of the styles.

Differences in lifestyle is another aspect that can have implications for the interpretation of research results. Meditators might tend to have a different diet compared to controls. Amount of physical training, sleep patterns and stress levels might also differ between meditators and controls and should, therefore, be controlled for as much as possible (Fox et al., 2014)

There is evidence of a decline in grey matter when aging and hence the results obtained from studies investigating long-term practitioners should take into account the potential of a decrease in grey matter due to aging.

Throughout these studies investigating meditations effect on the human brain, there is a wide variety with regards to the control groups. In some studies, the expert meditators serve as their own control group when comparing the meditative state with a resting state. Some studies compare the meditators to a control group that has no prior experience of meditating while other studies have a control group consisting of meditators without any prior experience but who are instructed to practice meditation before taking part in the study. This differences in the control group can have implications when trying to interpret the results.

Future Studies

In the future, longitudinal studies investigating and comparing different meditation styles and their effects on the brain and mental function is needed (Slagter et al., 2007). Longitudinal studies that investigate naïve meditators is needed to be able to draw conclusions about meditations impact on the brain and mind. Subjective reports, as mentioned above, is also needed to more accurately interpret obtained results, and the groups should be larger (Lutz et al., 2008; Manna et al., 2010).

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