NEURAL CORRELATES OF MINDFULNESS RELATED TO STRESS
How mindfulness promotes wellbeing

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Katja Kärrström

Supervisor: Petri Kajonius
Examiner: Katja Valli
Abstract

Mindfulness practice is used to treat mental and physical symptoms. The problem is that research on the long-term effects and the neural changes involved, correlated with well-being, are inconsistent. The purpose of this review is to create a deeper understanding of mindfulness and its neural correlates related to stress. In mindfulness, one can use focused attention meditation (FA), involving anterior cingulate cortex (ACC), prefrontal cortex (PFC), parietal areas, thalamus, visual cortex, intraparietal sulcus, and amygdala. In open monitoring meditation (OM), ACC, PFC, insula, somatosensory cortex, limbic areas and amygdala are involved. In exposure to a high amount of stress, the grey matter volume decreases in the hippocampus, PFC, and amygdala. Research has also shown that 19 000 hours of mindfulness practice increases activation in areas involved in FA and OM. This increased activation might also enhance the subject’s ability to control emotions. After 44 000 hours of meditation, areas involved in FA showed less activation which might imply that more hours of mindfulness practice involve less cognitive activity and a calmer state of mind. Regardless of hours spent on meditating, a decreased activation in the amygdala and ACC occurs, which correlates with less response towards negative stimuli. The neural changes involved in mindfulness practice was related to less experienced stress and enhanced psychological well-being. For future research, an investigation of the interaction between attentional networks and stress would be of relevance.

Keywords: Mindfulness, stress, psychological well-being, neural correlates, focused attention, open monitoring
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1. Introduction

Studies on subjects that practice mindfulness have indicated that neural changes occur. These neural changes can be short- and long-lasting and associated with these changes subjects have expressed enhanced psychological well-being. Researchers have also suggested that mindfulness practice can be used to relieve symptoms in different mental- and physical diseases (Chan & Woollacott, 2007). With these indications, there is relevance to further investigate how mindfulness practice affects the brain, and how these neural changes affect psychological well-being. Research on psychological well-being is extensive and therefore this literature review focuses on presentation of studies on emotional stress, mindfulness, and how mindfulness practice might reduce emotional stress.

Stress is an emotional condition which results from stressors that involve negative external or internal events which affect one’s physical and mental health (Thoits, 2010). Short-term stress can be beneficial for survival, but when experienced for a long period of time, the grey matter volume in the hippocampus, amygdala, and hippocampus decreases, which can negatively affect behavior and emotions (McEwen & Gianaro, 2011). The white matter and the grey matter are two neural networks in the central nervous system which together are, among other things, involved in cognition. The white matter consists of myelin, axons tracts, and glial cells, while the grey matter volume mostly consists of neurons and synapses. When scientists are mentioning white matter decrease, this involves demyelination and neuronal as well as axonal decrease which impairs a subject’s higher cognitive abilities (Filley & Fields, 2016). The grey matter is the outer layer on top of the white matter. It consists of neuronal cell bodies (soma and dendrite) and is involved in processing signals within different nuclei areas, such as the hippocampus. When mentioning a grey matter decrease, this involves a neuronal cell body decrease and a decreased function of processing information between the areas in the central nervous system (Woolsey, Hanaway & Gado, 2017).

In this literature review, under the section neural correlates of stress the reader is provided with information about the emotional effects involved in short-term stress, chronic stress, posttraumatic stress disorder (PTSD), and in the development of mental illness. In the section following, different research will indicate that mindfulness practice can reverse the negative neural effects different types of stress have, as well as reduce stress and enhance subject’s psychological well-being is presented. Finally, the review discusses problems related to the research field.

1.1. The Problem

The problem in using mindfulness to treat stress is that scientists have received different results about how mindfulness practice affects different areas of the brain and how these neural changes correlate with well-being, especially when looking into long-term effects. That is why it is of relevance to investigate how mindfulness practice affects the brain and how these neural changes impact well-being. The question is how the brain is
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affected by mindfulness practice and how these neural changes affect stress. It is also of interest to see if these changes are persistent or reversible in long-term meditators.

1.2. Purpose and limitations

The purpose of this literature review is to gain a deeper understanding of the neural correlates involved in mindfulness practice and how this is related to stress. In being able to do this, the focus will thus be on neural correlates of mindfulness and stress. To limit the study, I will concentrate on how mindfulness practice affects the brain and if these neural changes contribute to reduced stress. With this limitation, I will later be able to draw parallels and distinctions between mindfulness practice, neural correlates, and stress. This research will hopefully contribute to gain a deeper understanding on how and if mindfulness practice is involved in mental health.

2. Method

This literature review investigates how mindfulness practice affects stress and the neural correlates involved. This review involves the definition of a problem and uses published articles and books retrieved used from Web of Science, Google Scholar, and PubMed.

Mindfulness is a multidisciplinary area of research involving how to conceptualize mindfulness, its neural correlates and its relation to psychological processes as well as behaviors. Research on mindfulness also involves how to apply mindfulness in subjects suffering from mental illness or physical diseases as well as in healthy subjects to enhance well-being (Brown et al, 2015, pp. 1-8). I will discuss both structural and functional neural changes in relation mindfulness and stress, by using neuroimaging studies which utilize Electroencephalography (EEG), Event-related potential (ERP), Positron emission tomography (PET) and Functional magnetic resonance imaging (fMRI) to see possible neural correlates of mindfulness and effects on the brain after mindfulness training. I will also discuss short- and long-term effects of mindfulness to see how mindfulness affects subject’s emotional states. The positive effects of mindfulness can involve a reduction of anxiety, reduction of clinical depression, treatment in subjects with drug abuse and different behavioral disorders (Brown, Creswell & Ryan, 2015).

This essay consists of theory section and result- and discussion section and a conclusion. The theory section focuses on stress and represents summarized research from metanalyses, reviews, and original studies on adults. The theory section will also represent a general overview of mindfulness and current studies on neural correlates of mindfulness which involves a presentation of long-term effects of mindfulness practice in adults. This section will summarize different reviews and original studies in mindfulness. These theory sections will provide an understanding of stress and mindfulness, which will be helpful in the result section. The result section involves representation, analysis, and discussion of the neural correlates of mindfulness related to stress. Conjunctions and parallels between mindfulness practice and stress are discussed to see if the neural differences
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are consistent. The research process is visualized with a flowchart (figure 1) with the purpose to give the reader an insight into the method. In the conclusion author’s own views are discussed, involving general critique and future recommendations for improvements of the field. After the references, an appendix is to be found with explanations of different brain areas and concepts used in this thesis.

**Figure 1: Flowchart representing the research method.**

Handbook in mindfulness → A general insight into mindfulness, utilizing references from the handbook.

Web of science → General keywords: meditation, mindfulness, vipassana, wellbeing, neural correlates, mental illness, stress, stressors, metanalysis. These general keywords were combined in different ways.

PubMed →

Google Scholar →

**Selection**
Document types: Article review, book review, article. Categories: Neuroscience, behavioral science and different types of psychology such as multidisciplinary, social, clinical. Publication years: mostly within 5-10 years. Filter results: Open access that is reviewed. Articles are sorted by: Highest cited articles and sometimes by relevance.
3. Neural Correlates of Stress

3.1. Stress and stressors

Subjects are over a lifetime exposed to different stressful events, called stressors and these stressors have been divided into five different categories. One category involves the possible exposure to negative or traumatic events. Another category involves chronic diseases the subject may develop that cause physical or mental strains. The third type of stressor includes unequal treatment because of differences involving gender, race, ethnic, civil status and social class while the fourth category involves exposure to different kinds of discrimination. Last is the stressor involving poverty and family conditions and its impact on mental health. To not search for help to process exposure to these negative stressors can over time lead to chronic stress. To process the exposure of these stressors can involve applying methods to enhance the subject’s self-confidence and self-esteem (Thoits, 2010).

From a metanalysis involving different neuroimaging studies on subject’s experienced stress, researchers noticed that these five different stressors, categorized as either psychosocial or physiological stressors, differ in experience of stress but involve similar neural responses (Kogler, Müller, Chang, Eickhoff, Fox, Gur & Derntl, 2015). By further comparing the conducted neuroimaging studies, Kogler et al. (2015) noticed that psychosocial stress involves neural changes in right superior temporal gyrus and the striatum. The first mentioned brain area, right superior temporal gyrus, activates, while the other area, striatum, deactivates, in psychosocial stress. These areas are involved in goal-directed behavior and regulation of emotions. When exposed to physiological stressors, brain areas insula, striatum and middle part of cingulate cortex activate. These areas are partly involved in the processing of emotions, as well as informing to act accordingly in dangerous situations. What was further noticed from the metanalysis was that both the inferior frontal gyrus and anterior insula activate when subjects are exposed to both psychosocial and physiological stressors (Kogler et al. 2015).

3.2. Short-term- and chronic stress

In a literature review by McEwen (2006), the neural changes involved in short-term and chronic stress were investigated. It was concluded that exposure to different stressors causes physiological and behavioral changes in the fight-or-flight mechanisms which are activated when we are in dangerous situations. For a short amount of time, these changes are beneficial for survival. But exposure to a traumatic stressor that is experienced as unmanageable by the subject causes an abnormal amount of anxiety, which can lead to chronic stress and long-term neural changes. In chronic stress, the body releases different stress hormones that cause internal bodily reactions to prepare our body for fight-or-flight more often than what is necessary. In the same literature review, it was also found that in chronic stress the pituitary gland produces an abnormal amount of stress hormones that are dysregulated by the sympathetic and parasympathetic nervous system. This is called an allostatic overload.
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Allostasis in itself, is the process of achieving stability, or homeostasis, through physiological or behavioural change. The conducted studies further indicated that the allostatic overload in chronic stress causes a neural decrease in the hippocampus, PFC, and amygdala. Other areas noticed to be affected were memory areas and areas involved in selective attention. The allostatic overload can over time cause cardiovascular diseases (McEwen, 2006). But as earlier research mentioned, stress reduction programs are available to treat chronic stress. Another review by McEwen and Gianaro (2011) investigated how interventions aimed at stress reduction can help subjects that suffer from chronic stress. Here, researchers investigated pathophysiology and how stress correlates with neural plasticity, using neuroimaging studies involving fMRI. The conducted studies involved neural correlations of stress in animals and humans, with a focus on how allostasis and allostatic overload affects neural changes and how these neural changes cooperate with behavioral reactions towards stress. Hypotheses in the review was that the brain changes as a coping mechanism for being able to manage different stressors.

Further, the results from McEwen and Gianaro (2011) indicated that the brain is essential for how subjects react and experience different kinds of stress and that the brain processes external danger as well as internal danger. The brain controls and regulates cognition and therefore tell us when we are in a dangerous situation. The brain also sends the body signals to react accordingly to external danger and internal threats that cause any stress. Allostatic processes, which in stress involves that the HPA- axis together with the autonomous nervous system, dynamically send signals, maintain cortisol level, cytokines, and hormones. How the brain reacts towards different stressors depend on individual differences that can be crucial for whether the stress becomes short or long-lasting. Exposure to chronic stress can cause an allostatic overload. It can also involve a lack of health with excessive intake of fast-food, lack of exercise and use of drugs.

When an allostatic overload occurs, areas of the limbic system, amygdala, hippocampus, PFC and the brainstem change. This change was mostly noticed in hippocampus, amygdala and prefrontal areas, which had a decreased grey matter volume (McEwen & Gianaro, 2011). This decrease occurs as a coping mechanism for being able to process the allostatic overload. The grey matter decrease in hippocampus relates to a decreased function in different kinds of memory areas and an enhanced HPA-axis activity. In the amygdala, the reduced grey matter volume is believed to affect behavior and physiology negatively, which involves that the fear responses become hyperactive and make the subject react fearfully in normal situations. Decreased grey matter volume in the amygdala was related to subjects becoming more aggressive and, in the PFC, the grey matter reduction was related to a decreased ability in making decisions and reduced ability to use higher cognitive functions. The decreased grey matter volume was further noticed to be reversible by using interventions directed toward change, involving a healthier lifestyle with physical and social activity. To help the individual in changing the lifestyle, the use of drugs or pharmacological interventions can be helpful but these need to be used with caution (McEwen et al. 2011).
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In another study, chronic stress on rats and its relation to subtypes of potassium channels was investigated. With this study, researchers hoped that they would be able to see if depression and potassium channels had a relation (Chen, Wang, Rong, Wang & Wang, 2015). In being able to test the relationship between depression and potassium channels, the rats were assigned to a control group or in one out of two test groups. In the test groups the researcher induced different stressors to the rats at an organized random schedule, and to investigate whether the neural effects of chronic stress could be reversed, the rats were then treated with either fluoxetine or saline for three weeks. The stressors could involve heat or cold exposure as well as deprivation of food and water. The shortest amount of time the rats were exposed to these stressors were five minutes and the longest amount of time exposed to the stressors were 24 hours (Chen et al. 2015).

Results from the studies were established with a CMS, a method that is used on rats in being able to identify their levels of depression. The CMS indicated depression in both test groups that had been exposed to the different kind of stressors. In the test groups, an increased number of Kv2.1 and TREK-1, which are subtypes of potassium channels, were observed in PFC. Further, the results showed that three weeks of treatment with fluoxetine had a significant positive effect. In the treated rats, Kv2.1 and TREK-1 channels had normalized in PFC during treatment. In the hippocampus, the potassium channels Kv3.1 and Kv4.2. had decreased in all groups that were exposed to chronic stress. In the group that was treated with fluoxetine, potassium channels in hippocampus had slightly increased after treatment, but not significantly. These results indicate that two different subtypes of potassium channels Kv2.1 and TREK-1 are involved in chronical stress. Further, the results indicate that chronic stress can be treated with fluoxetine (Chen et al. 2015).

3.3. Posttraumatic stress disorder (PTSD)

In a review by Sareen (2014), studies on posttraumatic stress disorder (PTSD), especially on risk factors for developing this condition and how to treat it, were summarized. It was found that PTSD is a psychiatric condition that is, as chronical stress, caused by a traumatic or stressful event. This condition is typically seen in military personnel who have seen and been exposed to war, but the condition can occur in any subject that has been exposed to a traumatic event that causes an sufficient amount of stress for the subject. In PTSD the subject reexperiences the traumatic or stressful event over again in his or her mind, during wakefulness as flashbacks and during sleep as posttraumatic nightmares. Avoidance behaviors and sleep problems are also a central symptom in PTSD. Even after recovery, reoccurrence of symptoms can be triggered by external events that remind the subject of the trauma. PTSD results from stressors, but there are individual and subjective differences in resilience to take into consideration (Sareen, 2014).

Risk factors for developing PTSD can be categorized in following categories: pre-trauma, trauma, and post-trauma. The first category, pre-trauma, involves genetic components and personality traits that can be crucial for whether a person develops PTSD. Other risk factors in pre-trauma category include mental disorders or low
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IQ. Further, it has been found that females are at higher risk of developing PTSD than men. The second category that relates to the direct trauma experience includes the subjective experience of the traumatic event and whether the subject became physically injured in the event. The last category, post-trauma, involves permanent physical and mental damages resulting from the traumatic event. Whether the subject develops PTSD or not can also partially depend on social support and economy after the traumatic event. The condition lasts for months, even years, and subjects suffering from PTSD often have issues involving drug abuse or severe depression. PTSD is treatable, and authors of the review suggest a treatment involving a combination of psychological therapy such as cognitive behavior therapy with antidepressant medication such as fluoxetine or other serotonin reuptake inhibitors or serotonin norephedrine reuptake inhibitors. Other medical suggestions are the ones involving alpha one- adrenergic blocker to reduce posttraumatic nightmares and in some cases, there are recommendations to take antipsychotics medications (Sareen, 2014).

In another study by (Depue, Olson-Madden, Smolker, Brenner & Banich, 2014), researchers investigated the neural correlates in subjects suffering from PTSD and mild traumatic brain injury (mTBI). The purpose of this study was to see if the neural correlates in the combined diagnoses was the same as the two diagnoses individually.

The study included 21 adult veterans with above mentioned combined diagnoses. It also involved one control group of 16 healthy subjects. The experiment involved a go-no go task and self-reports to test the subject’s ability for behavior- and inhibitory control. To investigate the neural differences between the groups, an MRI was used, and analyzed with voxel-based morphology as well as surface-based morphology to be able to study the grey matter volume and its relation to behavior (Depue et al. 2014).

This study indicated that in PTSD and mTBI there is hyperactivation in the amygdala, hippocampus, ventral medial PFC (vmPFC) and ACC. The test group with combined PTSD and mTBI had reduced grey matter volume in the bilateral anterior amygdala as well as in the hippocampus. The reduction in the amygdala was also noticed to correlate with a decreased ability to control impulses. The reduced grey matter volume in the hippocampus was noticed to correlate with the reduced ability of cognitive control. Other significant differences in the test group included higher alcohol intake and difficulties in retention of attention as well as lower self-control (Depue et al. 2014). The main difference between PTSD and mTBI patients was that in mTBI the areas vmPFC and ACC were more hyperactive than the other mentioned areas.

3.4. Stress and development of neuropsychiatric disorders

When investigating how stress is related to the development of neuropsychiatric disorders, the focus will be on how short and long-term stress affects glutamate transmission in PFC. A review by Popoli, Yan, McEwen, and Sanacora (2013) highlights result from studies on short-term- and chronic stress in animals and the studies used in this review concentrate on how stress affects the glucocorticoids, an adrenaline steroid that interacts with
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glutamate neurotransmission through synapses. The studies further involved how changed glutamate neurotransmission changes the brain and might lead to neuropsychiatric disorders or enhance cognitive functions (Popoli, Yan, McEwen & Sanacora, 2013).

In the review by Popoli et al. (2013), results indicated that that the hippocampus, amygdala and especially PFC is highly involved in stress. In short-term stress, there is an increase in glutamate levels because of an increased glutamate transmission in PFC, amygdala, hippocampus and in limbic areas. This increased glutamate transmission in short-term stress had positive effects on the brain, involving an enhanced capacity on these mentioned areas. In chronic stress, the authors noticed a decreased synaptic function that depended on a deviant glutamate neurotransmission. This decreased synaptic function was believed to cause persistent negative plastic effects on the brain, involving a neuronal shrinkage. This decrease was mostly shown in the PFC which involve decreased cognitive functions. The review indicates that glutamate neurotransmission can affect the number of glial cells as well as subject’s metabolism which seem to have a correlation to the neuronal changes observed in chronical stress. The decreased glutamate neurotransmission in the PFC was also noticed to might lead to the development of neuropsychiatric disorders (Popoli et al. 2013). These results are uniform with McEwen. (2006) and (Thoits, 2010) research in that chronic stress have plastic effects on the brain.

In another review by Calcia, Bonsall, Bloomfield, Selvaraj, Barichello, and Howes (2016), the focus was to investigate the impact of stress on microglia to see if microglia have an impact on mental illness. Microglia are cells involved in the immune system and maintaining a healthy brain. The review by Calcia et al. (2016), involves eighteen different original studies on rodents that had been exposed to psychosocial stressors involving social isolation, chronic restraint, social defeat, occlusal disharmony, shock, prenatal stress and different combinations of these stressors. The purpose of this review was to investigate how enhanced proinflammatory cytokines in microglia can be related to structural and functional changes in the brain. The authors suggested that the neural changes occurring from the enhanced activity of microglia, reflecting immune response, might be the reason for why subjects develop different kinds of mental illness involving autism, clinical depression and schizophrenia (Calcia et al., 2016).

This neural change was mostly noticed in the hippocampus and in the PFC. It was also noticed that an enhanced microglia activity is involved in whether a subject develops mental illness or not. The explanation to this is that when subjects are exposed to psychosocial stress in childhood, the microglia react. The reaction involves neural changes in the hippocampus and in the PFC, which affect the neural development and may lead to mental illness later in life (Calcia et al., 2016).

These two reviews propose mechanisms on how stress might lead to different kinds of mental diseases, suggesting that abnormal neural activity results from chronic stress and a decreased grey matter volume might be related to subjects’ emotional and behavioral state.
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4. Mindfulness

4.1. History

Mindfulness has existed in literature for over 2000 years and has its origin in Buddhism, where the definition of mindfulness involves attention, awareness, and memory with the purpose of enhancing well-being and gaining enlightenment or awakening by vipassana. Vipassana simply means that the subject focuses attention on an object, a physical or psychological sensation. This focused attention involves cognition and perception where the subject is reviewing and observing internal and external changes with the purpose of being aware of oneself and one’s mental and physical qualities. This process affects the phenomenal consciousness and attentional biases which are believed to make the subject perceive and sense things as they are.

Since 1990, the interest of studying mindfulness has significantly increased. When looking into statistics over studies in mindfulness from 2000-2014, results show that the area of research has peaked to over 15,000 publications a year since the year of 2000 when the area of research begun to grow. In the year 2000, there were about 1000 publications about mindfulness (Brown et al., 2015, pp. 9-62).

Mindfulness practice no longer only involves that the subject consciously focuses attention on objects or sensations but has also come to involve open monitoring (Lutz, Slagter, Dunne & Davidson, 2008). By practicing mindfulness through focused attention or open monitoring, the subject can over time recognize his or her cognitive and behavioral patterns and train calmness. Research involving focused attention (FA), open monitoring (OM) and consciousness mostly follow the Buddhist conceptualization of mindfulness (Brown et al., 2015, pp. 9-62). However, researchers in the neuropsychological field have drawn away from the Buddhist conceptualization. In this area of research, the focus is on understanding mindfulness, and being able to identify how mindfulness affects different areas of the brain in relation to behavior. This research involves perceptual processing, motivation, and learning-supportive environments. Even though there are many definitions of mindfulness, awareness and attention have been established by many scientists as two of the most important parts (Warren-Brown & Ryan, 2003).

4.2. Current studies on neural correlates of mindfulness

When investigating short-term effects on mindfulness, the focus of research involves emotional, bodily and attentional changes while research on the long-term effects of mindfulness involves investigating whether the neural changes are sustainable and if they are, how they can affect behavioral traits (Chan & Woollacott, 2007). Results from current studies on neural correlates of mindfulness involve different types of attention and attentional networks. Earlier studies of attentional networks in relation to mindfulness have concluded that the executive attention that is used in FA meditation has a central role in mindfulness training. An enhanced white matter volume in certain areas has been observed after mindfulness practice (Brown et al., 2015).
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4.2.1. Focused attention and open monitoring

In a review by Lutz et al. (2008) the neural and mental processes involved when a subject is practicing mindfulness meditation were summarized. In this review, FA meditation and OM meditation were considered as the two different ways to meditate. Whereas OM meditation involves that one brings awareness to external or internal sensations, emotions, and stimuli in the present moment, in FA meditation the subject is asked to maintain and monitor attention to different objects or sensations. In OM meditation, the subject enhances reflective awareness which is considered to enhance one’s ability to cognitively control emotions. It is also thought to enhance bodily awareness. With FA meditation, the subject practices and develops the ability to monitor and sustain attention on chosen sensations or objects, and to eventually develop the ability to ignore distractions and over time learn to consciously direct attention and thoughts to wherever he or she wants (Lutz et al, 2008).

Lutz et al. (2008) also reviewed neuroimaging studies on OM meditation and FA meditation involving fMRI and EEG. They summarize that the neural correlates involved in FA meditation include anterior cingulate cortex (ACC), prefrontal cortex (PFC), parietal areas and thalamus. The conducted neuroimaging studies also provided information on that the FA network is less activated in the PFC, visual cortex, intraparietal sulcus and amygdala in meditators with 44 000 hours of practice compared to meditators with 19 000 hours of experience in mindfulness. The decreased activation in these areas was noticed to correlate with less ability to maintain concentration (Lutz et al, 2008).

However, the different neuroimaging studies on OM meditation provided mixed and uniform results on the areas involved in OM meditation. Yet, some areas seemed to be consistently involved. These areas were ACC, insula and somatosensory cortex, which were noticed to correlate with introspection. Other areas that were noticed to be involved in OM meditation were limbic areas, different areas of the PFC and amygdala. Since these areas were only believed to be involved in OM, the suggestion from the review is to study OM meditation in dynamic global states, meaning that in mindfulness practice, every brain state is dynamic affected in every moment through a top-down processing (Lutz et al, 2008).

In another study by Chan et al. (2007), the effects of mindfulness practice on the attentional networks was studied in subjects from age 25 to 65 years. The experiment involved 60 adult participants that were asked to fill in a questionnaire about what type of meditation they practiced and how many hours they meditated per day. After this, the meditators were selected to one out of two groups based on what type of meditation they practiced. One type of meditation was concentration meditation and the other was opening-up meditation. Concentration meditation involves the same mental practice as FA meditation while opening-up meditation involves the same mental practice as OM meditation. The study also involved a group of non- meditators.
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From the questionnaire in the study by Chan et al. (2007), the meditators mean of mindfulness practice were 82-19,000 hours with six- to 150 minutes a day. All the participants in the experiment did a Stroop test with the purpose to test executive attention, involved in monitoring and control of different thoughts. They also used a global-local letter task to test orienting attention, which is an attention network that helps us orient attention towards objects. A global-local letter task involves congruent, incongruent and neutral stimuli. Results from the global-local letter task indicated that meditators performed faster than nonmeditators. But the results showed no significant differences between the groups in interference test, which means that the results from global-local letter task did not indicate any significant effect on distracting stimuli. Results from the Stroop task showed no significant differences between the two group of meditators but there was a difference between the group of nonmeditators and meditators, where the meditators had a significantly higher score and less interference in the test than nonmeditators. A correlation between time spent meditating and interference was also observed, where the more experience the subjects had in meditation correlated with a higher score and less interference. The meaning of these results is that long-term practice of mindfulness makes the subject less sensitive to distracting stimuli. Further, long-term meditation with 82-19,000 hours of practice was noticed to have a positive significant effect on executive attention, which relates to ACC and PFC. The orienting network on the other hand, which includes the parietal lobes, was not noted to correlate with mindfulness practice (Chan et al. 2007).

The results by Chan et al. (2007) differ from results of Lutz et al. (2008), where meditators with 44,000 hours of mindfulness practice showed less activation in the PFC, visual cortex, intraparietal sulcus and amygdala, while results by Chan et al. (2007) involving subjects with 82-19,000 hours of mindfulness practice had an increased activity in ACC and in the PFC. Therefore, to see if there are any neural differences between meditators that have an average of 19,000 hours of experience from subjects with an average of 44,000 hours, another experiment was conducted.

This experiment conducted by Brefczynski-Lewis et al. (2007) involved 41 subjects that practiced concentration meditation, that again, involves the same mental practice as in FA meditation, used in Lutz et al. (2008) study. This experiment involved two studies where in the first study a control group without any experience in mindfulness was compared to one meditator group with 10,000-54,000 hours of mindfulness practice. In the second study the meditators were separated in two groups: people with an average of 19,000 hours of mindfulness practice and persons with an average of 44,000 hours of mindfulness practice. In the second experiment the researchers also added one non-expert meditating group who were told that they would get a reward if they had significant activation in brain areas involved in concentration meditation (Brefczynski-Lewis et al. 2007).

The first study ran over one week. The control group was asked to perform meditation over this week for one hour per day, while the expert meditators practiced meditation as usual. In being able to see if there were any
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neural differences between the groups, an fMRI was used. The results indicated an activation in areas that are involved in FA meditation involving the frontal areas, lateral occipital lobe, insula, thalamus regions, basal ganglia, and regions by the cerebellum. These areas were activated in both groups, but the activation was greater in the meditators with 10 000-54 000 hours of practice. In the control group without any earlier expertise in meditating, a greater activation in the medial frontal gyrus and ACC was noticed. It was also noticed that the control group had greater activity in thalamus than the meditators, while the meditators had greater activity in frontal areas than non-meditators (Brefczynski-Lewis et al. 2007).

In the second study, the meditators were separated into two groups where one group involved meditators with an average of 19 000 hours of practice and another group that involved meditators with an average of 44 000 hours of practice. The meditators with 19 000 hours of practice had greater activation in FA areas involving ACC, left lateral prefrontal cortex, caudate and pulvinar than the other test groups and the control group. Further, it was noticed that the control group had greater activation in intraparietal sulcus and occipital lobe than the meditator groups. The meditators with 44 000 hours of practice had less activation in amygdala and ACC, which are involved in reaction to (emotional) stimuli. It was also noticed that the group with 44 000 hours of practice had more activation in occipital lobe than the other test groups and control group. The test group that was told they would get a reward if they had significant activation in brain areas involved in concentration meditation had greater neural activation in areas involved in FA meditation than the control group without any earlier experience in mindfulness practice (Brefczynski-Lewis et al. 2007).

The results indicated that the expert meditators with 44 000 hours of practice seemed to have evolved some type of plastic effects after long-term mindfulness practice. These plastic effects were noticed in the left lateral PFC, caudate and pulvinar. Interesting with the results was that the amygdala and ACC still showed less response towards negative stimuli in the group with 44 000 hours of practice. The group with 44 000 hours of practice also showed more activation in lateral occipital lobe than the group of meditators with 19 000 hours of practice. That the group with an average of 19 000 hours of practice had more activation than the meditators with 44 000 hours of practice in areas involved in FA might depend on a development of plastic effect in areas ACC, left lateral prefrontal cortex, caudate and pulvinar. But the results can also involve that the more mindfulness practice the subject have may involve less cognitive thinking, which may involve a calmer mental state of mind (Brefczynski-Lewis et al. 2007). These two studies from the experiment by Brefczynski-Lewis et al. (2007) is coherent with results from Lutz et al. (2008) that mentions that mindfulness practice might have some plastic effects.

4.2.2. Mindfulness-based stress reduction (MBSR)

Now that studies have been presented by Lutz et al. (2008), Chan et al. (2007) and Brefczynski-Lewis et al. (2007) involving investigation of the attentional networks in FA- and OM meditation, it is of relevance to
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present research on how mindfulness might affect wellbeing. Therefore, this chapter will present Mindfulness-based stress reduction program (MBSR) which is applied in psychotherapeutic programs and involves execution of mindfulness practice. The use of MBSR program is believed to be a way to reduce stress (Kabat- Zinn, 1990).

In a study by Anderson, Lau, Segal and Bishop (2007) involving an MBSR program, attentional control was studied. This study included research on FA, switching of attention and inhibitory control. With this study, researchers hoped the results would be helpful in drawing conclusions about what types of attentional networks that are involved when subjects without any earlier experience in mindfulness practice start to practice.

The study involved 72 subjects with no earlier experience of mindfulness. The purpose of the research was to see if the attentional networks involved in mindfulness practice was related to enhanced well-being. These participants were randomly selected into two groups where one group involved an MBSR program. The other group was a waitlist control group who were deceived in believing that they were waiting for a spot in the MBSR program. In both the control group and the test group there was a use of a pretest and a posttest measuring sustained attention, switching of attention, inhibition of elaborative processing and measure of nondirected attention. This was tested with sustained attention task involving switching task, Stroop task, and object detection task. The psychological well-being was measured with a self-report questionnaire. The MBSR program ran over eight weeks and involved a guided two-hour mindfulness practice every day where the test group was taught how to apply mindfulness in their everyday life, apart from the two hours lesson (Anderson et al. 2007).

After the eight weeks of MBSR program, researchers waited four more weeks to hand out the questionnaires again to measure psychological well-being and noticed a higher psychological well-being in the participants that had practiced mindfulness (Anderson et al. 2007). Results from the switching task, Stroop task and object detection task indicated no significant differences between the groups in attentional control but the results from the different attention tasks revealed that the group using MBSR had increased attentional control from pre- to posttest involving an improved present moment awareness. This indicates a correlation between mindfulness and present moment awareness.

In another experiment by Hözel et al. (2013), researchers collected 26 subjects without any earlier experience in mindfulness. The subjects participating in the study consisted of one group of subjects that suffered from general anxiety disorder and one control group without any health issues. The healthy subjects were only used in the pretest to compare the neural activity from subjects suffering from general anxiety disorder (Hözel et al., 2013).

Before the program started, a pretest involving an fMRI to compare the neural activity in healthy subjects from the test subjects suffering from general anxiety disorder was conducted. With the fMRI, researchers noticed neural differences in the subjects that suffered from general anxiety disorder from the control group: the test group had a deviant amygdala activation to neutral stimuli (Hözel et al., 2013).
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The meaning of this is that the amygdala was hyperactivated to neutral stimuli, so amygdala is activated almost in the same way as it is when a subject is exposed to danger. In conjunction with the fMRI, the subjects that suffered from general anxiety disorder were asked to express their psychological well-being with a self-report. After this pretest, the subjects suffering from general anxiety disorder were randomly selected to an MBSR program or a stress management program that ran over eight weeks. There was also a use of a fMRI in all the participants as they were exposed to five different expressive faces in a random manner. After the eight-week program, the test subjects again used a self-report data where they were asked to express their psychological well-being (Hözel et al., 2013).

Results from the self-report data indicated that both groups experienced less stress than before the MBSR or stress management program but there was noticed a neural difference between the participants suffering from general anxiety disorder (GAD) that had used MBSR program and the subject suffering from GAD that had used the stress management program. Both the MBSR and the stress reduction program showed that the participants suffering from GAD had over the eight weeks less activation in the right amygdala when they were exposed to neutral stimuli. But the fMRI also revealed that the subjects that had used MBSR had increased activity in prefrontal areas compared to the participants that had used the stress reduction program. The connection between these two areas was also increased in those participants that had used MBSR program, which correlated with less anxiety (Hözel et al., 2013). These results are congruent with the results from Anderson et al. (2007) in that both had results indicating that mindfulness reduces stress.

In another study by Singleton, Hölzel, Vangel, Brach, Carmody and Lazar (2014), it was investigated how MBSR program might enhance well-being as the grey matter volume in the pons and raphe increase. These are areas that are found in the brainstem which has been stated to be involved in mood regulation. The research conducted 14 late adult participants without any earlier experience in mindfulness practice and the subjects were asked to participate in an MBSR program. Two weeks before the MBSR program, an MRI was used. The subjects were also instructed to fill in a questionnaire about their psychological well-being to compare with the results from the MRI. The questionnaire involved questions about self-perspective, self-determination, positive relations, how to act in the environment to reach personal goals, personal purpose, and growth. After the MBSR program, the subjects were again instructed to fill in the questionnaire about their psychological well-being, and the MRI was again used. The results after the eight weeks of training showed an increased grey matter volume, which was particularly shown in the pontine tegmentum, locus coeruleus, nucleus raphe pontine, and the sensory trigeminal nucleus which are all parts of the brainstem. The subjects also expressed a higher psychological well-being after the mindfulness practice (Singleton et al. 2014).
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4.2.3. Personality traits: possible impact of receptiveness to mindfulness

In being able to investigate if subject’s personality traits can affect their receptiveness to mindfulness, researchers investigated the neural correlates of mindfulness in relation to stress (Taren, Creswell & Gianaros, 2013).

In this experiment, 145 adults’ subjects were asked to participate in filling in a Mindfulness Attention Awareness Scale (MAAS). With the MAAS the researchers could study subject’s receptiveness to mindfulness. The participants selected for the study consisted of both females and males, that were all healthy and in their middle ages. In the experiment, there was a use of MRI to investigate possible grey matter changes in the limbic areas of the brain in relation to the results from the MAAS (Taren et al. 2013).

Results from these studies indicated a correlation between receptiveness to mindfulness and decreased grey matter volume. The decreased grey matter volume was specifically shown in the right amygdala and the left caudate in those that had higher scores in MAAS. These results indicate that there is a neural change that correlates with subjects’ personality traits where the subjects with higher receptiveness to mindfulness had decreased grey matter volume in the amygdala and caudate (Taren et al. 2013).

In summary, all the results in general under the neural correlates of mindfulness indicate that mindfulness correlates with neural changes, even if the areas involved are not coherent.

5. Neural correlates of mindfulness related to stress

In this section, the above presented results from neural correlates of mindfulness and stress will be summarized, discussed and analyzed in terms of congruencies and differences, and in the light of my own interpretations and reflections.

To begin with the results from stress, it was concluded that subjects are exposed to five different types of stressors, categorized either as psychosocial or physiological stressors (Kogler et al. 2010). In research on short-term and chronic stress, McEwen et al. (2006) discussed how exposure to these different stressors causes physiological and behavioral changes that are beneficial when stress is temporary and a necessity for survival in dangerous situations. In chronic stress, the homeostatic process can no longer compensate for the harmful effects of stress, and an allostatic overload can occur. This causes the pituitary gland to produce a deviant amount of stress hormones, regulated by the sympathetic and parasympathetic nervous system. This allostatic overload causes also decrease in the grey matter volume in the hippocampus, PFC, amygdala, areas related to memory and selective attention. In McEwen et al. (2011) review, it was further confirmed that an allostatic overload causes neural damage. The grey matter decrease was found in the limbic system, amygdala, PFC, brainstem and was believed to occur as a coping mechanism for being able to process the allostatic overload. Further it was stated that an allostatic overload not only occurs because of stressors but that it can also occur when the subject doesn’t
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take care of one’s health. The grey matter decrease was, in fact, found to be reversed by a healthier lifestyle combined with medication.

Chen et al. (2015) investigated the relationship between depression and potassium channels and found an increased level of Kv2.1 and TREK-1 channels in PFC when rodents were exposed to mild chronic stress, while the hippocampus had a decrease in the number of Kv3.1 and Kv4.2 channels. After three weeks of treatment with fluoxetine, potassium channels in PFC had normalized, and in the hippocampus, there was a slightly increase. This all indicates that potassium channels are involved in chronic stress.

Further studies on PTSD and mTBI found a reduced grey matter volume in the bilateral anterior amygdala and in the hippocampus, which was correlated with a reduced ability to control impulses and reduced ability of cognitive control (Depue et al. 2014). Lastly, Popoli et al. (2013) found that in short-term stress the glutamate transmission is increased, which enhances functions in PFC, amygdala, hippocampus and limbic areas. In chronic stress, there is a decrease in glutamate neurotransmission which affects the number of glial cells and decreases the synaptic functions. This decrease was mostly shown in PFC and was suggested to be linked to development of neuropsychiatric disorders. Another study found that the development of neuropsychiatric disorders might depend on an increased microglial activity which causes grey matter to decrease in the hippocampus and PFC (Calcia et al. 2016).

According to all these results on stress, a decreased grey matter volume in especially PFC, amygdala, and hippocampus is related to behavioral changes. The decreased grey matter volume in PFC is correlated with fewer abilities to make decisions and deficient use higher cognitive abilities. The decreased grey matter volume in hippocampus involves a decreased function in memory areas and an enhanced HPA-axis activity and a decreased grey matter volume in amygdala involves that the subject becomes more aggressive and reacts fearfully in situations where fear response is not appropriate (McEwen et al. 2011). The grey matter decrease is also believed to be reversible with medications, such as fluoxetine, combined with a healthier lifestyle involving exercise and healthy food.

From these results on stress, decreased grey matter volume in PFC, amygdala and hippocampus relates to psychological ill-being. Thus, conversely, it may seem that an increased grey matter volume in the PFC, amygdala, and hippocampus might be linked to enhanced psychological well-being, as occurs typically when practicing mindfulness. Therefore, we will again look at the results on mindfulness.

In the review by Brown et al. (2015), it was stated that mindfulness practice involves an increased white matter volume in different brain areas. However, I found no further evidence supporting this claim. The research on mindfulness by Lutz et al. (2008) Anderson et al. (2007), Chan et al. (2007), and Brefczynski-Lewis et al. (2007), involving both OM meditation and FA meditation, mentions that areas involved in FA meditation include ACC, PFC, parietal areas, and thalamus. Other areas involved are visual cortex, intraparietal sulcus, and
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amygdala. In OM meditation Lutz et al. (2008) found evidence that ACC, insula, and somatosensory cortex are activated. Further, the limbic areas, PFC, and amygdala were believed to be involved.

What differentiates FA meditation from OM meditation is that in FA meditation the conducted research is coherent in what areas that are involved. Yet, it seems feasible that PFC, ACC, and amygdala are involved in both FA and OM meditation. FA meditation involves parietal areas, thalamus, visual cortex, and intraparietal sulcus while OM meditation involves insula, somatosensory cortex, and limbic areas. To further see how FA meditation and OM meditation differs functionally and how the different types of meditation affect behavior, some of the results will shortly be highlighted again.

In FA meditation, Lutz et al. (2008) found that in subjects that had practiced for 44 000 hours the PFC, visual cortex, and intraparietal sulcus had less activation which correlated with less ability to maintain concentration. Further, it was noticed that amygdala had less activation, which makes the subject less reactive to emotions. In Chan et al. (2007), results on the subjects that had practiced FA meditation and OM meditation from 82 to 19 000 hours showed a positive significant effect on ACC and PFC, which correlated with the subjects being less sensitive for distracting stimuli. In Brefczynski-Lewis et al. (2007), less activation in PFC, ACC, caudate and pulvinar in FA meditators with an average of 44 000 hours practice was observed, which in the study was believed to depend on the plastic effects suggested to result from long-term mindfulness practice. The decreased activation might also be interpreted that more hours of mindfulness practice involves a calmer mental state of mind. Further in Brefczynski-Lewis et al. (2007), less activation towards negative stimuli in ACC and amygdala was observed.

All these results indicate that the OM and FA meditators with 19 000 hours of practice have more activation especially in PFC. This increased activation in PFC seems to correlate with enhanced function in maintaining concentration and it also seems to make the subject less sensitive to distracting stimuli. The lesser activation in ACC and amygdala correlate with less reaction towards negative stimuli. ACC and amygdala still showed less reaction towards negative stimuli after 44 000 hours, even though PFC activation had decreased as well as other areas involved in FA meditation.

To have increased activation in areas involved in FA meditation and OM meditation after 19 000 hours of practice might involve an increased ability to maintain, direct and monitor attention and thoughts to objects or sensations, which might enhance the subject’s ability to cognitively control emotions (Lutz et al., 2008). The decreased activation in the areas involved in FA meditation after 44 000 hours of practice may depend on a development of plastic effect in ACC, left lateral prefrontal cortex, caudate, and pulvinar. But it might also depend on a calmer state of mind (Brefczynski-Lewis et al. 2007).

Anderson et al. (2007), Hözel et al. (2013) and Singelton et al. (2014) investigated the effects of mindfulness-based stress reduction (MSBR) on psychological well-being in subjects without any earlier
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experience in mindfulness practice. All these studies ran over eight weeks and were all uniform in that mindfulness correlated with an enhanced psychological well-being. Anderson et al. (2007) found that the group using MBSR program had enhanced attentional control involving an enhanced present moment awareness. In Hözel et al. (2013), fMRI revealed that the subjects that had used MBSR program had increased activity in PFC which correlated with enhanced cognitive control. Further, lesser activation in the amygdala correlated with less experienced stress. It was also noticed that the connection between these areas had increased which correlated with less anxiety. In Singelton et al. (2014) MRI studies found an increased grey matter volume after eight weeks of MBSR program. This increase was found in pontine tegmentum, locus coeruleus, nucleus raphe pontine, and the sensory trigeminal nucleus which are all a part of the brainstem and involved in mood regulation. All studies on MBSR found that after eight weeks the subjects experienced an enhanced psychological well-being compared to before the MBSR program. The MSBR program also involves an enhanced ability to control and regulate mood which might be reflected in an increased grey matter volume in pontine tegmentum, locus coeruleus, nucleus raphe pontine and sensory trigeminal nucleus.

Combining the results, different kinds of stress involve decreased grey matter volume in PFC, hippocampus, and amygdala and with mindfulness practice, a subject can increase activity in PFC and decrease the activity in the right amygdala. These results from mindfulness practice indicate that the enhanced psychological well-being subjects experience after mindfulness practice might involve the decreased reaction towards negative stimuli and enhanced function in maintaining concentration and it also seems to make the subject less sensitive to distracting stimuli. However, when looking at the study by Taren et al. (2013) that investigated whether personality traits impact a person’s receptiveness to mindfulness showed that decreased grey matter volume in amygdala and left caudate were correlated with the subject’s receptiveness towards mindfulness: decreased grey matter volume in these areas correlated with higher receptiveness to mindfulness. These results are congruent with Brefczynski-Lewis et al.’s (2007) findings were subjects that were told they would get an award if they had more activation in areas involved in FA meditation than a control group. These results indicate that some subjects might not display similar neural activity and enhanced psychological well-being after mindfulness practice.

When further looking into the anatomy and function of brain areas involved in stress and mindfulness, all the areas involved in stress are not the same areas as those in mindfulness. One observation made, when looking into all the areas involved in stress and mindfulness, is that many of the areas are a part of the limbic system. The limbic areas include thalamus, amygdala, cingulate gyrus, hippocampus, bed nucleus and nucleus accumbens that is a part of the anterior cingulate cortex. Further, the limbic system includes the hypothalamus, parts of the brainstem and the basal forebrain (Vertes et al., 2015). The limbic areas also include the orbitofrontal cortex and amygdala as well as its subparts (Gazzaniga et al, 2014, pp. 428-429). In this case, there might not just be the
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changed activation from mindfulness practice that makes the subject less stressed, but it might depend on an enhanced function between the areas that are involved in the limbic system.

When further looking at the results on stress, some of these areas affected by stress are also involved in FA and OM meditation. One possibility for why subjects feel stressed might depend on a defect in the attentional network and not only in a decreased grey matter volume in the PFC, hippocampus, and amygdala. Maybe the stress occurs as a result because the subjects focus attention only on the external and internal negative things in their everyday life but ‘forget’ to focus attention on the positive things in their everyday life. This biased focus might make the subject experience more negative emotions, contributing to the feeling of being stressed.

5.1. Limitations of the studies and present thesis

Problems with the studies presented above include that in much of the research on mindfulness psychological well-being is measured by interviews and self-reporting questionnaires, such as the Mindful Attention Awareness Scale (MAAS), where the participants report their qualitative experiences. Initial studies provided evidence for the adequacy and validity of MAAS, and it was shown to be a reliable and valid instrument for use in both college student and general adult populations (Warren-Brown & Ryan, 2003). Yet, the validity and reliability of (MAAS) has been discussed and criticized (Brown et al. 2015).

This measurement focuses on awareness and attention but leaves out important emotional states, such as different kind of consciousness and cognitive abilities that are, according to some researchers, considered to be involved in mindfulness. There are also indications that a subject’s self-awareness affects the scores on MAAS, as well as individual and cultural differences. Typically, studies utilizing MAAS does not consider that the participants may exhibit a placebo effect where they had expectations of feeling better since they have knowledge that mindfulness should enhance well-being. The other problem from the MBSR studies is that much of the published studies are made over an eight-week period, i.e., measurements are applied before and after the program, but research on what happens after the eight weeks is difficult to find. Another problem is that mindfulness is defined differently by different researchers, which makes mindfulness difficult to operationalize. This creates a problem for measuring mindfulness (Brown et al. 2015). This problem with operationalizing research makes the result on the studies questionable since scientists might unconsciously cherry-pick wanted results depending on how they operationalize mindfulness and stress.

6. Conclusion

This essay has investigated the neural correlates of stress and mindfulness and how these might be opposite to each other. In short-term stress, the brain activates our fight-or-flight mechanisms to tell us that we are in a dangerous situation and to cause physiological and behavioral changes necessary to cope with the situation. This reaction is beneficial for survival during dangerous situations. The gathered research seems to be
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uniform in that the PFC, hippocampus, and amygdala is highly involved in stress. Some other areas have also been noticed to be involved in stress, such as the pituitary gland, HPA-axis, limbic areas, selective attention, memory areas, and superior temporal gyrus, striatum, inferior frontal gyrus and the anterior insula. As opposed to short-term stress, prolonged stress response is harmful. The areas that were mostly mentioned in chronic stress response involve PFC, hippocampus, and amygdala, and all these areas showed a decreased grey matter volume in subjects that suffered from chronic stress. Some research indicates that changes in potassium channels or glial cells as well as metabolism underlie the changes in grey matter volume. The research has also indicated that not only is a subject’s mental health affected by the external environment, the subject’s mental health will affect how he or she acts in the environment. This means that the external and internal bodily states integrate and affect each other bidirectionally.

According to all these results on stress, a decreased grey matter volume in especially PFC, hippocampus, and amygdala is related to behavioral changes in response to prolonged stress. The decreased grey matter volume in PFC correlated with decreased ability to make decisions and use higher cognitive functions. The decreased grey matter volume in hippocampus relates to a decreased function in memory areas and an enhanced HPA-axis activity. A decreased grey matter volume in amygdala involves that the subject reacts fearfuly in situations that do not pose any danger or threat to the individual, although are interpreted to do so. The grey matter decrease is also believed to be reversible with medications, such as fluoxetine, combined with a healthier lifestyle involving exercise and healthy food.

Mindfulness practice also involves neural changes, and mostly to the opposite direction than exposure to chronic stress. Amygdala reactivity is deceased, and prefrontal activity increased after mindfulness practice. From these results, it may seem feasible to hypothesize that an increased grey matter volume in the PFC, hippocampus, and amygdala after long-term mindfulness practice would be the underlying neural correlate for why subjects experience enhanced psychological well-being when practicing mindfulness.

Attention, awareness, and memory are highly involved in mindfulness. The literature is relatively unified in that mindfulness practice increases the activity in PFC and decreases the activity in the amygdala. All the results indicate that the OM and FA meditators with 19 000 hours of practice have more activation in several areas of the brain, especially noticed in PFC areas. This increased activation in PFC seems to correlate with enhanced function in maintaining concentration and it also seems to make the subject less sensitive to distracting stimuli. There are also noticed less activation in ACC and amygdala which correlate with less reaction towards negative stimuli. ACC and amygdala also showed less reaction towards negative stimuli after 44 000 hours, even though PFC activation had decreased as well as activation of other areas involved in FA meditation. These results suggest that mindfulness practice might involve an increased ability to maintain, direct and monitor attention and thoughts to object or sensations, which might enhance the subject’s ability to cognitively control emotions. The
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subjects undergoing MBSR program also showed an enhanced connection between PFC and amygdala which was related to less anxiety. The MSBR program also involves an enhanced ability to control and regulate mood which was shown by an increased grey matter volume in pontine tegmentum, locus coeruleus, nucleus raphe pontine and sensory trigeminal nucleus which are all a part of the brainstem.

To conclude, the results from mindfulness and stress indicate that in stress there is a decreased grey matter volume in PFC which is correlated with less ability to make decisions and use higher cognitive abilities. The decreased grey matter volume in the hippocampus involves a decreased function in memory areas and an enhanced HPA-axis activity. A decreased grey matter volume in amygdala involves that the subject becomes more aggressive and react fearfully in normal situations. With mindfulness practice, the activity in the PFC is increased which correlate with enhanced function in maintaining concentration and it also seems to make the subject less sensitive to distracting stimuli. There is also a decreased activity in amygdala which is related to less reaction towards negative stimuli. These changes might be involved in the enhanced well-being and reduced stress. But this might not be the only reason for the reduced stress in a subject. The reason for why subjects experiences that mindfulness reduces stress can be related to a shift of attention by practicing FA and OM. This would be a relevant investigation for future researchers since much of the research on stress has focused on areas that are involved in emotion.
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Appendix: Glossary

**Amygdala**
This is the area of the brain that is involved in emotions. Amygdala is involved in stress and regulation of emotions, and its activity is related to psychological problems, such as posttraumatic stress disorder, depression, and anxiety. Other mental problems that have been noticed to interact with amygdala are phobias and panic disorders (Anderson, Lau, Segal & Bishop, 2007).

**Anterior cingulate cortex (ACC)**
ACC lies in the limbic area and is highly involved in regulation of cognitive and emotional processing (Bush, Luu & Posner, 2000). This is an empathy area involved in pain processing and perceiving another subject’s pain. The area is also believed to be involved in moral behavior and social interaction (Gu, Liu, Guise, Naidich, Hof & Fan, 2010).

**Attention network**
When investigating the attention network, focus can be on investigating attention and its relation to cognitive control. To do this, research focuses on different areas involved in attention as well as areas involved in cognition and inhibitory or conscious control. Further the investigations involve finding out how neurons and synapses cooperate and work overtime (Medaglia, Lynall & Bassett, 2015). In attentional control, the frontal-parietal lobe has been noted to be highly involved. Results on visual attention indicate that the ventral attentional network and dorsal attentional network activates when subjects perform specific tasks as well as when they are at rest. This neural activation is mostly noted at the parietal and frontal network areas where these areas interact. The white matter pathways are also noted to be involved in different states of attention as well as cognition (Madden & Parks, 2013).

**Brainstem**
The brainstem has come to be known as the area involved in bodily homeostatic regulation such as breathing and motoric movements (Smith, Abdala, Borgmann, Rybak & Paton, 2013). The brainstem interacts with motor areas, cerebellum, basal ganglia and reacts and responds to sensory signals that are transferred from the spinal cord (Gazzaniga et al, 2014, pp. 329).

**Central nervous system (CNS) and peripheral nervous system (PNS)**
The brain and the spinal cord together make up the central nervous system. It integrates information received from the body and environment through various senses and coordinates the activity of all parts of the body. The central nervous system interacts with the peripheral nervous system. The peripheral nervous system is divided into the somatic nervous system and the autonomic nervous system. These two systems interact where the somatic system involves voluntarily controlled movements and autonomic nervous system involves not
Neural correlates of mindfulness related to stress voluntarily controlled movements. The last mentioned involves the sympathetic and the parasympathetic system (Gazzaniga, Ivry & Mangun, 2014, pp. 37-39).

**Focused attention; Executive attention**
Focused attention, also called executive attention, involves the higher cognitive ability to sort different emotions, thoughts and received sensory input to plan, focus and react accordingly. The neural correlates in focused attention are the anterior cingulate cortex, prefrontal areas, parietal areas and thalamus. Other areas involved are visual cortex, intraparietal sulcus, and amygdala (Lutz et al., 2008). When a subject focuses all attention on a specific object, sustained attention and self-monitoring are activated (Brefczynski-Lewis et al., 2007).

**Grey matter volume and white matter volume**
The white matter and grey matter are two neural networks in the central nervous system which together are involved in cognition. The grey matter volume consists mostly of neurons and synapses while the white matter consists mostly of myelin, axons, and glia cells. When scientists talk about white matter decrease, this involves a demyelination and decrease of neurons and axons that impair higher cognitive abilities in a subject (Filley & Fields, 2016). The grey matter area consists of neuronal cell bodies (soma and dendrite) and is noticed at the outer layer of the white matter volume. A decrease in the grey matter volume involves a neuronal cell body decrease which decreases functions of processing information (Woolsey, Hanaway & Gado, 2017, pp. 5-16).

**Hippocampus**
Hippocampus has come to be recognized as the area that consolidates and processes memories. The memories include declarative memories, explicit memories, and motor movements. To note, this area alone does not handle all memories, but is ‘the relay station’ for consolidating short-term memories into long-term memories (Albouy et al., 2008). Hippocampus is also involved in encoding and retrieval of information (Gazzaniga et al., 2014, pp. 402-404).

**Hypothalamus, the pituitary gland, and HPA-axis**
The pituitary gland is one subarea of the hypothalamus. These work together to maintain and regulate hormones and the body’s autonomic functions, to maintain homeostasis (Gazzaniga et al., 2014, pp. 46). Hypothalamic–pituitary–adrenal axis (HPA axis or HTPA axis) is a complex set of direct influences and interactions among the three components: the hypothalamus, the pituitary gland and the adrenal glands. HPA axis is a major neuroendocrine system that controls reactions to stress and regulates many bodily processes, including digestion, the immune system, and mood and emotions.

**Insula**
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This area is known to be correlated with disgust, love, happiness, anger, fear, and trust. These emotions especially involve the anterior part of insula. There has also been noticed an activation of this area in relation to introspection which involves an awareness of internal states (Gazzaniga et al., 2014, pp. 459-461).

Limbic system

Thalamus is the area considered to be highly essential in the limbic system. Thalamus is the area that contributes to receiving sensory information from different nuclei. All sensory information goes through thalamus before reaching the cortex. Other areas considered to be involved in the limbic system is amygdala, cingulate gyrus, hippocampus, bed nucleus, nucleus accumbens that is a part of the anterior cingulate cortex, hypothalamus, parts of the brainstem and basal forebrain (Vertes, Linley & Hoover, 2015). There are some disagreements in which areas that are included in the limbic system. (Gazzaniga et al., 2014, pp. 428-429). The limbic system is considered to circulate at the edge of the corpus callosum. There seems to be a general agreement in that the limbic system contributes to emotions and behavior (Vertes, Linley & Hoover, 2015).

Mindful attention awareness scale (MAAS)

A questionnaire where the subject rates specific qualitative psychological experiences on a Likert scale from low to high (Warren-Brown & Ryan, 2003). MAAS includes questions on how often subjects that practice mindfulness are aware of different everyday tasks. Subjects that score high on the MAAS are considered as highly receptiveness to mindfulness (Taren, Creswell & Gianaros, 2013).

Memory areas: Temporal lobe & superior temporal gyrus

The patient H.M. easily comes to mind when talking about memory. H.M. was a patient suffering from severe epilepsy and with a surgery involving having the medial temporal lobes bilaterally removed, the hope was to end these seizures. The operation was successful in that the seizures ended, but it affected the patient’s memory. H.M. could not form new long-term memories, even though he generally in all other ways was a healthy individual. These findings changed the direction of scientific research since it was now stated the temporal lobes are involved in memory (Squire & Wixted, 2011).

With research on the patient H.M. scientists have been able to map out functions in the temporal lobe, and the area is distinguished in the medial temporal lobe, inferior temporal gyrus, and superior temporal gyrus. Mapping with fMRI has indicated that the superior temporal gyrus is involved in semantic memory and spoken words and language processing (Binder et al. 2011; Correia, Formisano, Valente, Hausfeld, Jansma & Bonte, 2014).

Occipital lobe

This is the posterior part of the brain that lies above the brainstem and consists of cortical visual areas called V1, V2, V3, V4, MT and PO that are all specified for different kind of visual processing. V1 processes
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information through the dorsal or ventral stream together with the other cortical visual areas to eventually form an image of the information that is received through the receptive field (Gazzaniga et al., 2014, pp. 189).

**Open monitoring**

Open monitoring involves that the subject notes and learns about one’s emotional and cognitive sensations in the present moment. Research has indicated that open monitoring involves anterior cingulate cortex, insula and somatosensory cortex which are areas that correlate with introspection. Limbic areas and different areas of prefrontal cortex are also involved in open monitoring.

**Prefrontal cortex (PFC)**

PFC consists of many subparts, each of which has their own specific functions. In general, the prefrontal cortex is involved in higher cognitive abilities such as critical thinking, planning, and control (Gazzaniga et al., 2014).

**Selective attention**

We cannot consciously attend to all sensory input at the same time. When a subject chooses where to direct his or her focus, or highly relevant information is being presented, selective attention is engaged, guiding attention to a specific target while other information is ignored.

**Striatum**

The striatum is a circuit composed of ventral and dorsal striatum. The ventral striatum is often distinguished from the dorsal in that the ventral part is highly involved in reward, while the dorsal striatum is related to motor movements. Through studies on animals, research has indicated that striatum is involved in reward and learning (Marche, Martel & Apicella, 2017).

**Stroop task**

When the name of a colour (e.g., "blue", "green", or "red") is printed in a colour which is not denoted by the name (i.e., the word "red" printed in blue ink instead of red ink), naming the colour of the word takes longer and is more prone to errors than when the colour of the ink matches the name of the colour. Stroop task measures a person's selective attention capacity and skills, as well as their processing speed ability. It is also used to examine a person's executive processing abilities (Chan & Woollacott, 2007).