Meditation and Neuroplasticity

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Thesis submitted for the
Professional Program in Clinical Psychology

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Abstract

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The brain's capacity for cellular and synaptic change, neuroplasticity, underlies an organism's ability to respond in an adaptive manner to changes in its environment. Recent studies find evidence of functional and structural changes in the brain following meditation practice, indicating that meditation harnesses the brain's inherent ability to change in response to experience. An open question exists, however, of whether meditation *enhances* neuroplasticity. If this is the case, meditation might be employed in order to facilitate learning and flexibility. Through a literature review of current research, it is found that meditation might enhance neuroplasticity specifically through the mechanisms of relaxation and training of attention. These findings have potential practical applications in areas such as therapy, education, and age-related cognitive decline.

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Figure 1: Meditation will affect neuroplasticity only if the factors that enhance plasticity (circle A), overlap with features of meditation (Circle B). 4

1 Introduction

You could not step twice into the same river;

for other waters are ever flowing on to you.

Heraklitus (fl. c. 500 BCE)

The world of the human is in a state of constant flux, perhaps even more so now than when Heraklitus uttered his famous words. With the advent of new information technology like the Internet, invention and technological progress as well as political and social trends spread faster than ever. As a species, humans are amazingly adaptable to changes in their environments. The brain's capacity for cellular and synaptic change, neuroplasticity, underlies an organism's ability to respond flexibly in an adaptive manner to environmental changes. Over the last two decades, there has been a surge in research on neuroplasticity. Researchers have established that the brain has potential for experience-induced change ranging on levels from synapses to functional networks.

Around the same time as neuroscientists started grappling with issues of neuroplasticity, a separate trend emerged in the scientific landscape, namely meditation research. Meditation began appearing in scientific journals in the late 1960s (e.g. R. K. Wallace, Benson, & Wilson, 1971), and since then, a large number of studies have accumulated on the effects of meditation on a range of physical and psychological measures. As the field of meditation research is growing, meditation is gradually losing its "new age" image. Still, the field suffers from a lack of common nomenclature and a range of other methodological issues, cautioning anyone trying to draw firm conclusions from research findings.

Recently, the fields of research on neuroscience and meditation have met, and interest is growing on how meditation practice changes the brain. For example, in 2004, The Mind and Life Institute, a research institute centered on integrating knowledge from Buddhism and neuroscience, held its seventh annual conference at the home of the Dalai Lama in India[1]. At the convention, Buddhist scholars and western neuroscientists discussed whether, and how,

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[1] For more information on this conference, see The Mind and Life Institute's webpage: http://www.mindandlife.org/dialogues/past-conferences/ml12/

meditation might harness the brain’s ability to change. Studies indicate that a range of different meditation practices induce functional and structural changes in the brain, especially in areas known for attention and emotion regulation (Lutz, Dunne, & Davidson, 2007). However, it is unclear whether meditation changes the brain just like any repeated activity would, or if there is something about meditation that enhances the brain’s potential for neuroplasticity.

Uncovering whether meditation enhances neuroplasticity might have consequences in all areas where flexibility and learning are important. Firstly, the area of therapy might benefit from this knowledge. In most forms of therapy, at least if we stick to a western conceptualization, a central goal is that the patient sees his own situation or behavior in a new light by making connections between formerly separated elements, be they past and future, action and consequences, or thoughts and emotions. In other words, successful therapy involves some degree of learning, which in turn corresponds to plastic changes in the brain. As Nancy Andreasen puts it: “The techniques of behavior therapy and psychotherapy have relied on the principles of brain plasticity, generally without realizing it, for nearly one hundred years” (Andreasen, 2001, pp. 331 - 332). If meditation practice enhances neuroplasticity, it might be included in the treatment in order to increase the client’s benefits of therapy.

Stretching beyond therapy, the enhancement of plasticity is important in all situations where learning takes place. In educational settings, efforts are done to ensure that the students absorb as much knowledge as possible during the time they spend at school. It is a common idea that for learning to occur, the students have to focus their attention on what is being taught. Studies support the role of attention in learning (Heimann, Tjus, & Strid, 2010). If we find that meditation increases neuroplasticity in the brain, then this knowledge can be used in order to increase the potential for learning in both student and teachers.

Thirdly, enhancement of neuroplasticity is relevant in the area of age-related cognitive decline. Studies have demonstrated age-related shrinkage of human gray matter volume in prefrontal cortex, hippocampus, cerebellum and caudate nucleus (Resnick, Pham, Kraut, Zonderman, & Davatzikos, 2003; Salat et al., 2004), as well as pervasive white matter loss especially in prefrontal cortex (Madden et al., 2004). Further, efficiency of certain attentional and memory processes generally decline with age (Verhaeghen & Cerella, 2002). However, research is appearing that might counterbalance this glum portrayal of old age. For example, several strands of evidence have appeared that point to environmental factors that contribute to preserving neuroplasticity in old age (Kramer, Bherer, Colcombe, Dong, & Greenough, 2004). One study conducted on meditators in the Zen-tradition showed that experienced meditators had thicker cortices in prefrontal areas of the brain compared to non-meditators in the same age group (Pagnoni & Cekic, 2007). They also performed better on tests measuring memory and attention. This points to the possibility of the use of meditation for prevention and treatment of age-related neural atrophy and cognitive decline.

Meditation refers to a wide variety of methods and techniques, many of which can be easily learned by most age groups, can be performed practically anywhere and anytime, and does not require instruction beyond the initial training period or expensive equipment. We are just starting to realize the potential of the brain to control and alter physical and psychological processes. Harnessing the brains ability for change may help a diverse range of individuals, from young to old, with or without psychological or physical illness.

1.1 Research hypotheses and methods

Until now, only one brief review article has been published that directly pose the question of whether meditation enhances neuroplasticity. Xiong and Doraiswamy (2009) review studies that indicate neuroanatomical, neurophysiological, and hormonal changes following meditation experience, particularly focusing on evidence indicating that meditation might attenuate the aging process by preserving cortical thickness and cognitive function (e.g. Lazar et al., 2005). Based on their review, the authors propose that meditation might enhance neuroplasticity and preserve cognition through multiple pathways, such as stress-reduction. This intriguing proposal sets the stage for a more thorough investigation, which will be attempted in this thesis.

In order to investigate whether meditation enhances neuroplasticity, we will start by looking at some of the factors that up until now been have suggested to affect plasticity, ranging from factors in the environment to the level of hormones and neurotransmitters. We continue with looking at different meditation practices, with a specific focus on what might be common factors across meditation practices. The reasoning behind this is that meditation will affect plasticity only if the features of meditation in some way coincide with the factors that enhance plasticity. This can be visualized in the following way:

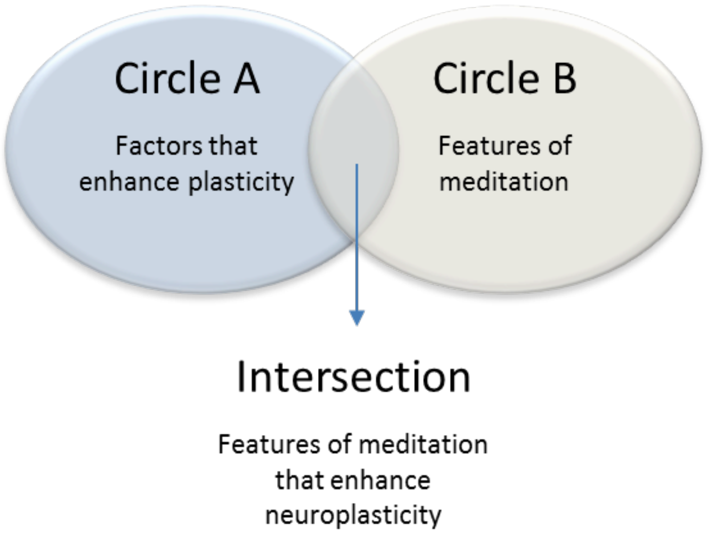

Figure 1: Meditation will affect neuroplasticity only if the factors that enhance plasticity (circle A), overlap with features of meditation (Circle B).

The next step in the investigation is to determine *how* meditation might affect neuroplasticity, in other words, what lies in the intersection between neuroplasticity and meditation. The questions this thesis will explore are the following:

1. Does meditation enhance neuroplasticity? In other words, does there exists an intersection between circle A and B?
2. How does meditation enhance neuroplasticity? In other words, what lies in the intersection between meditation and neuroplasticity?

The research included in this thesis is based on a literature search mainly in ISI Web of Knowledge, PubMed and Google Scholar. The search has been dynamic and has followed a range of sidetracks and digressions, making it difficult to provide a comprehensive list of search terms used. Some of the most central search terms have been “neuroplasticity”, “meditation”, “structural plasticity”, “functional plasticity”, “neurogenesis”, “neurological correlates”, “attention”, “relaxation” and “stress”. The terms were combined in diverse ways, such as “neurological correlates AND meditation”, “structural plasticity AND stress” and so on. The initial searches were focused around the subject of neuroplasticity, then moved on to meditation, before exploring the relationship between the two. This order of investigation is reflected in the structure of the thesis.

In choosing what articles to include, I have followed some general guidelines. Because of a general lack of scientific rigor in many of the early studies done on meditation to which we will return later, I have limited the selection mainly to articles published from the year 2000 up until today. Where older articles are cited, they are mainly classical, or containing information that has presumably not changed since their writing.

In many cases, those who conduct research on meditation are themselves affiliated with a specific school of meditation. This might pose a problem for the validity of the research, if the researchers are biased towards their personal method. I have mainly chosen articles from acknowledged peer-reviewed journals, to ensure a certain quality of research. Articles with numerous citings have been preferred for the same reason. Meta-analyses have been preferred over single studies when available. I have also specifically focused on finding articles that oppose or contradict each other, in order not to make the presentation one-sided.

I was originally introduced to meditation through my interest in neuropsychology. I believe that knowledge derived from the field of neuropsychology can illuminate the beneficial effects reported from meditation, and that studying meditation practitioners through the methods of neuroscience in turn can increase our understanding of the human mind. Because of my interest in these questions, there is always the possibility that I myself have been biased towards a specific result, and have thereby selected articles that fit with my initial hypotheses. The above measures have been undertaken in order to make the discussion as scientifically sound as possible.

2 What is neuroplasticity?

In this section, we will investigate what neuroplasticity is, and what factors have been found to enhance neuroplasticity (circle A in Figure 1).

Brain plasticity refers to the brain's ability to change its structure and functioning during maturation, learning, environmental challenges or pathology (Lledo, Alonso, & Grubb, 2006). William James (James, 1890) was one of the first to introduce the term "plasticity" referring to the possibility of change in human behavior and corresponding brain tissue:

> Plasticity [. . .] means the possession of a structure weak enough to yield to an influence, but strong enough not to yield all at once. Each relatively stable phase of equilibrium in such a structure is marked by what we may call a new set of habits. Organic matter, especially nervous tissue, seems endowed with a very extraordinary degree of plasticity of this sort; so that we may without hesitation lay down as our first proposition the following, that the phenomena of habit in living beings are due to the plasticity of the organic materials of which their bodies are composed. (p. 105)

So far, so good. He adds, however: "Could the young but realize how soon they will become mere walking bundles of habits, they would give more heed to their conduct while in the plastic state. We are spinning our own fates, good or evil, and never to be undone" (p. 127).

This view of the brain as a more or less static entity, capable of little change after a critical period of malleability, survived until a couple of decades ago. The "neurological fatalism" that dominated the brain sciences, has been in clear opposition to the field of psychotherapy and other disciplines that are built on the basis of changeability also of the adult mind, which might partly explain the traditional separation between these fields of knowledge. The expansion of psychopharmacology in the 1980s and the continuous development of brain-scanning techniques starting in the 1990s both contributed to a dawning integration of biology-based and mind-based knowledge (Cozolino, 2002).

Although the greatest changes in the brain clearly happen during critical periods of early development, the old view of the adult brain as static has been progressively challenged by contemporary neuroscience. Research has uncovered a brain that is constantly adapting and changing in response to new information, environmental changes and subjective experiences of emotions. It now seems that plasticity is not merely a state or attribute of the brain that can be employed when needed, but it is a fundamental trait of the organization of the nervous system (Pascual-Leone, Amedi, Fregni, & Merabet, 2005).

Neuroplasticity can occur on different levels of organization, ranging from molecules to systems; through the modulation of signal transmission across synapses, changes in the organization of local circuits, in the relationship between different functional networks, and in supportive tissue elements such as glia and blood vessels (Lledo, et al., 2006; Trojan & Pokorny, 1999). A seminal study also demonstrated evidence of neurogenesis (the birth of new neurons) in the human adult hippocampus - a finding that startled a whole community of neuroscientists (Eriksson et al., 1998). Neurogenesis in the adult human brain has later been found in the olfactory cortex (Alvarez-Buylla & Garcia-Verdugo, 2002), and evidence indicate that it may be a common property in other areas of the brain as well, including the prefrontal cortex, although the latter is still controversial (Rakic, 2002). Furthermore, it seems that neurogenesis is not activated on a static basis or as merely a restorative mechanism, but it is an adaptive response to challenges in the external or internal environment (Lledo, et al., 2006).

In the literature, it is common to separate between functional and structural plasticity. We will review these two forms of plasticity briefly.

2.1 Functional plasticity

The most commonly known mechanism for plasticity is based on professor Donald Hebb’s principles of association (Hebb, 1949), often summarized as “neurons that fire together, wire together”. Neurons are organized so that if one neuron repeatedly activates another at a high frequency rate, the synapse between them becomes stronger. The most studied example of this form of plasticity is called Long-Term Potentiation (LTP). LTP can be defined as “a long-lasting increase in synaptic efficacy following a high-frequency stimulation of afferent fibres” (Shors & Matzel, 1997, p. 597). When a group of neurons repeatedly fires simultaneously, they are linked together in functional networks. However, it is probable that the brain also functions under the parole “use it or lose it”, as associations between neurons will become weaker if they co-fire at a low frequency (Salthouse, 2006). This process is generally called LTD, Long-Term Depression (Ito, 1989).

Neuronal networks are shaped mainly by activity in critical periods during development. Evidence of functional plasticity in the neuronal networks in adult brains began to emerge in the 1980s when Michael Merzenich, Jon Kaas and their colleagues started looking into how the brain's sensory and motor maps change with experience. The brain's sensory cortex is organized so that body parts that are next to each other on the body are represented by groups of neurons that lie next to each other in the cortex. This is known as somatotopy, and these cortical areas are called somatotopic maps (Kaas, 1987). Merzenich and Kaas demonstrated that these maps change when the input from the body changes, for example if one finger is amputated, the area that represented that finger will eventually start responding to the other fingers instead (Merzenich et al., 1984). Similar functional reorganization has been observed in the auditory (Recanzone, Schreiner, & Merzenich, 1993) and visual cortices (Gilbert & Wiesel, 1990; Sterr et al., 1998).

We see from these studies that the cortex organizes itself in a use-dependent manner, where connections that are frequently in use become stronger and more efficient, and connections that are no longer in used are weakened.

2.2 Structural plasticity

Structural plasticity generally involves changes in matter, e.g. the forming or breaking of synapses, spine motility, and re-routing of axonal or dendritic branches (Butz, Wörgötter, & van Ooyen, 2009), as well as neurogenesis (Eriksson, et al., 1998).

Up until recently, structural plasticity (also called neuroanatomic plasticity) in the human brain has been difficult to measure due to lack of appropriate methods. Recent advances in neuroimaging techniques have enabled researchers to investigate the relationship between behavioral and structural changes (Engvig et al., 2010). Structural gray matter changes measured by MRI have been reported in young and elderly subjects after learning how to juggle (Boyke, Driemeyer, Gaser, Buchel, & May, 2008; Draganski et al., 2004), after extensive studying (Draganski et al., 2006), and after involvement in a memory training program (Engvig, et al., 2010), to name a few. The specific neurobiological mechanisms for these changes in matter are not yet clear, but they may be a result of adjustments in spines and synapses, changes in the size of the soma and nucleus of neurons, glia and capillary dimensions (Muotri & Gage, 2006).

We see that a range of different experiences induce structural changes in the brain. It is interesting to note that most of these studies have in common that they focus on the impact of external factors, such as the learning of new skills. When we look at the structural changes following meditation practice, the change-causing stimuli are endogenous: in most forms of meditation, the focus of attention is on one or more elements of the mind itself. As professor Daniel Siegel puts it: "(…) mental activities, such as purposely paying attention to the present moment, actually stimulate the brain to become active in specific ways that then promote growth in those regions. Here we see the notion that the mind is using the brain to create itself" (Siegel, 2007, p. 32). This poses interesting philosophical questions regarding the relationship between mind and brain.

Functional and structural plasticity are probably not completely dissociable. An example comes from the context of learning and memory. There is evidence that during memory formation strengthening of existing synapses takes place according to the principles of functional plasticity (LTD and LTP), while structural plasticity may over time "hardwire" those functional changes (Butz, et al., 2009).

2.3 What enhances neuroplasticity?

The question of what factors affect plasticity in the brain can be answered on a range of different levels: the level of the environment, the psychological level (such as attention and stress), the level of chemicals in the brain and body (such as neurotransmitters and hormones), the level of electrical wave-patterns in the brain, and the levels of genes, just to name a few. Processes on these levels will in turn interact with one another. For example, it has been reported that newborn rodents exposed to varying levels of maternal licking and grooming developed in very different ways (Meaney, 2001). The animals that received a high amount of this parental nurture developed as more relaxed and adaptable adults than those that received low amounts. Varying degrees of maternal care also altered the expression of genes that regulate behavioral and endocrine responses to stress, as well as hippocampal synaptic development in the offspring. The following discussion will not be able to cover all factors possibly involved in enhancement of neuroplasticity, but rather outline some important research findings.

It seems that a central factor that enhances neuroplasticity is stimulation through mental or physical activity. A growing number of studies in primate and non-primate animals in the last decade have shown that *enriched environments* enhance functional and structural reorganizations in the brain, as well as changes in behavior and stress levels (Draganski & May, 2008). Enriched environments stimulate activity of various sorts, both mental and physical. Similarly, *exercise* have consistently been reported to stimulate neuroplasticity; recent studies demonstrates that exercise is followed by neurogenesis in the hippocampus of mice (Pereira et al., 2007).

On the biochemical level, neurotrophins have received attention as molecular mediators of functional and structural plasticity. The neurotrophins comprise of at least four proteins – nerve growth factor (NGF), brain-derived neurotrophic factor (BDNF), neurotrophin-3 (NT-3), and neurotrophin-4/neurotrophin-5 (NT-4/5). It is thought that the neurotrophins act by protecting nerve cells from degeneration, as well as affecting synaptic plasticity in the nervous system (McAllister, Katz, & Lo, 1999). Many environmental and psychological factors probably enhance neuroplasticity partly through the stimulation of neurotrophins, such as running (Bjørnebekk, Mathé, & Brené, 2005).

On a psychological level, and of particular interest in this thesis, it has been shown that chronic stress disrupts neuroplasticity (Pittenger & Duman, 2007). On the chemical side, this is partly because stress hormones inhibit the expression of certain neurotrophins (Smith, Makino, Kvetnansky, & Post, 1995).

Another psychological factor that might be an eligible candidate for enhancing neuroplasticity is attention (Siegel, 2007). A study by Recanzone, Schreider and Merzenich (1993) highlights this point. Monkeys in the experimental group were trained to listen to and discriminate between small differences in the frequency between sequentially presented tones. Only some of the frequencies were determined as “behaviorally relevant”, meaning that the monkeys were to report when they heard them, but not others. They were also subjected to tactile stimuli that were unrelated to the task. Monkeys in another group were subjected to the same auditory stimuli, but were trained to pay attention to the tactile stimuli. After several weeks of this training, it was shown that the monkeys in the group that paid attention to the auditory task demonstrated not only increases in perceptual acuity and decreases in response-time, but the cortical representation of the behaviorally relevant frequencies increased in size. In the control group that paid attention to the tactile task, none of these changes were evident, even though the two groups received the exact same stimulation. This experiment illuminates the importance of attention in neuroplasticity. We will return to the implications of this experiment later in the text.

So far, we discussed some factors that enhance neuroplasticity (circle A in Figure 1). We will now turn to meditation, with the specific intention of investigating whether some common features exist between different meditation techniques (circle B in Figure 1).

3 What is meditation?

Researchers within the field of meditation in general and the neuroscience of meditation in particular are faced with the challenging issue of operationalizing their object of investigation. The word "meditation" is used to refer to a wide range of practices, ranging from traditional religious activities such as prayer, to more contemporary, secular practices, such as relaxation techniques. In many research articles, the technique in question is merely referred to as "meditation" with little or no specification.

When attempting to operationalize meditation, we encounter a dilemma pertaining to terminology. In traditional descriptions of meditations, esoteric descriptions and labels abound, with no apparent scientifically accepted equivalents. The book "The Varieties of Meditative Experiences" by Daniel Goleman (Goleman, 1988) represents one of the first attempts of a western scientist to describe Buddhist meditation practices. He writes:

> Strange terms and concepts assailed me: "samadhi", "jhana", "turiya", "nirvana", and a host of others used by these teachers to explain theirs spiritual paths. Each path seemed to be in essence the same as every other path, but each had its own way of explaining how to travel it and what major landmarks to expect (p. xvii).

Goleman attempts to make order out of the chaos through categorizing the different techniques he encountered into two styles of meditation that he calls "concentration meditation" and "insight meditation". A similar categorization is still used by many researchers today, now commonly referred to as "focused attention" (FA) and "open monitoring" (OM) meditation (Lutz, Slagter, Dunne, & Davidson, 2008). The categorization is developed mainly to encompass Buddhist contemplative techniques, including Zen, Vipassana and Tibetan Buddhism, and their secular derivatives, such as Mindfulness Based Stress Reduction (MBSR). Most meditation techniques can be placed somewhere along a continuum of these two categories. Moreover, many meditators will practice techniques from both of the styles interchangeably (Davidson & Goleman, 1977), making it challenging to discern the causal relationship between practice and effect. Still, this categorization into two styles is widely used in meditation research. The two styles have shown to correlate with different activation patterns in the brain and performance on attentional tasks. Therefore, it will be referred to throughout this text.

The first style, FA meditation, entails focusing sustained attention on a chosen object, for example the sensations of the breath. Central to this style is the ongoing monitoring of attention, which might wander towards arising distractions. The meditator then notices that attention has shifted, and brings it back to the intended object. It is thought that through practice, the monitoring of attention and ability to sustain focus will become increasingly effortless. The second style, OM meditation, is characterized by monitoring the content of consciousness from moment to moment. OM meditation is thought to increase an awareness of features of the mind that are otherwise implicit (Lutz, et al., 2008). Although not easily classified, it has been suggested that mindfulness practices, Zen, and Vipassana are located towards the OM pole, and forms of yogic meditation and Samatha meditation (focusing on the breath) towards the FA pole. Transcendental meditation and Acem meditation fit somewhat within FA styles, because of the repetition of a mantra. However, both forms lay an emphasis on developing a broad awareness with an absence of concentrative effort, drawing it closer to OM styles (Cahn & Polich, 2006).

The attempt to classify meditation techniques into the styles of FA and OM is useful because it enables researchers to notice similarities and differences between the large number of meditation techniques based on a common parameter, namely the use of attention. At the same time, the approach has some important limitations. Firstly, some of the terms used to describe the two categories are neither clearly defined nor easily accessible to research. It may be argued that in order to replicate and generalize results from meditation research, it would be preferable to use terms that are commonly accepted and defined within a scientific framework. At the same time, it can be argued that in exchanging the terms used in traditional descriptions with strictly western scientific concepts might involve a risk. During this translation, important spiritual, cultural and emotional aspects of meditation practice might be lost (Walsh & Shapiro, 2006).

A somewhat different approach to understanding what meditation is, comes from researchers who compare and analyze known meditation techniques in order to extract common features that have to be present in order to call something meditation. This approach originates mainly from researchers within the field of meditation for health purposes (Cardoso, de Souza, Camano, & Leite, 2004; Ospina et al., 2007). Cardoso and colleagues note that, while techniques referred to as "meditation" is increasingly implemented in treatments for a variety of health disorders, vague definitions of the term hinders the possibility of evaluating the effects scientifically. The authors suggest that in order to be characterized as meditation, the technique should include the following factors: (1) the use of a specific technique, (2) muscle relaxation in some moment of the process, (3) "logic relaxation"; (4) it must necessarily be a self-induced state, and (5) use of "self-focus skill" (coined "anchor"). By "logic relaxation", the authors refer to a non-judgment state of not intending to analyze, explain, or judge the content of consciousness. The use of "self-focus skill" points to the use of attention in a specific way, either through what they call a "positive anchor", a specific object of focus, or a "negative anchor", referring to an absence of such an object (the "anchor" is to not be caught up in any object in particular). Comparing to Lutz and colleagues' categories, techniques with a positive anchor might be categorized as FA meditation, while techniques with a negative anchor probably would be characterized as OM meditation. The proposal by Cardoso and colleagues holds an advantage over FA and OM in that it includes a wider variety of features of meditation than merely the focus of attention. It might, however, be criticized for a certain reductionism, in that it excludes all aspects of spiritual or cultural value. A similar review by Ospina and colleagues agrees on the factors proposed by Cardoso, but adds that although not essential, meditation practice may also (1) involve an altered state/mode of consciousness, mystic experiences, enlightenment or suspension of logical thought processes, (2) may be embedded in a religious/spiritual/philosophical context, and (3) involve an experience of mental silence (Ospina, et al., 2007).

Clearly, the question of "what is meditation" is not easily answered. Perhaps the best answer to the question comes from the Indian philosopher Jiddu Krishnamurti: "meditation is the very inquiry into what meditation is" (Krishnamurti, 1991, p. 192). For the purposes here, however, there seems to be some common features to many forms of meditation, as summarized by the mentioned articles (Cardoso, et al., 2004; Ospina, et al., 2007). Furthermore, with regard to the use of attention, meditation practices might be broadly categorized according to whether the scope of attention is broad, such as in open monitoring meditation (OM), or narrow, such as in focused attention meditation (FA).

3.1 Methodological issues in meditation research

Besides the discussed difficulty in agreeing on a common understanding of what meditation is, there are a number of other issues one has to take into account when trying to make sense of the field of meditation research, in particular the neuroscience of meditation. Firstly, many of the early studies on the effects of meditation on the brain lacked statistical power, did not include control populations, studied a wide range of meditative states that were not clearly specified, and did not report the degree of expertise in the practitioners (Lutz, et al., 2008).

The measuring of brain activity during meditative practice is based on the premises that meditation induces distinct states of consciousness, and that different conscious states are accompanied by different patterns of neurophysiological activity. A *"state"* refers to the altered sensory, cognitive, and self-referential awareness that can arise during meditation practice (Cahn & Polich, 2006). Furthermore, measuring brain activity outside of meditation practice is based on the possibility of *trait* effects, referring to lasting changes in these dimensions. Separating state and trait effects are difficult because of the synergistic association between the two. For example, in experienced meditators, an observed state of meditation might in fact be a deeper reflection of the trait, and a state of non-meditative rest might involve meta-cognition similar to that occurring during meditation.

The developing field of neurophenomenology emphasizes the need to correlate first-person reports of internal experience with neurophysiological activations, in order to clarify the relationship between states and traits of consciousness and brain activity (Varela, 1996). A central problem in this approach is the obvious difficulty in reporting subjective states in an "objective" way. In Buddhist traditions, methods have been developed for refining attention in order to observe the contents of the mind with clarity and stability (B. A. Wallace, 1999), and it has been suggested that experienced meditators exhibit relative superiority in describing their subjective experiences in detail (Lutz, et al., 2008). However, these claims have not been tested scientifically. Therefore, in most available studies, it is not clear what particular states or traits of consciousness the observed brain activation patterns are actually reflecting. However, one might still extract important information from these studies by comparing the activations observed to already established knowledge about the functions of the brain areas in question. If, for example, areas involved in allocation of attentional resources are activated during meditation, one might suppose the meditation state draws upon attentional resources (e.g. Manna et al., 2010).

Another central issue is the possibility of measurement influencing the meditation. Most meditation forms are executed in silent surroundings, often sitting in a particular position. Loud noises from the scanning equipment or other features of the test situation might influence the meditative state. In one study investigating the effects of a form of Kundalini yoga, the participants listened to a tape of loud fMRI clicking previous to the scanning sessions to promote meditative focus during this potential distraction (Lazar et al., 2000). However, in most studies such measures are not undertaken.

In sum, a range of methodological issues poses challenges to the field of meditation research. While many of these issues are addressed in newer studies, caution is warranted when interpreting the presently available evidence. In the following, we will begin the work of investigating whether there are some features of meditation that overlap with the factors we have seen to enhance neuroplasticity.

4 Does meditation enhance neuroplasticity?

The first research question of this thesis is whether meditation enhances neuroplasticity, thereby making the brain more flexible and malleable. Revisiting Figure 1, the question is whether there exists an overlap at all between factors that enhance neuroplasticity (circle A) and features of meditation (circle B).

Summing up what we have found so far, we have seen that we can place a number of factors within circle A. We have seen that *enriched environments* and *exercise* contribute to enhance neuroplasticity. At the molecular level, *neurotrophins* are implemented in generation and protection of nerve cells. Furthermore, at the psychological level, *stress* might negatively affect plasticity, and *attention* enhances plasticity in the areas that represent the object being attended to.

As we have seen, trying to determine what to include in Circle B as features of meditation is a challenge because meditation practices vary greatly in their techniques and purpose. However, it has been proposed that certain factors need to be present in order for something to be called meditation (e.g. Cardoso, et al., 2004; Ospina, et al., 2007). Some proposed factors are that it involves a *specific technique*, include elements of *physical and mental relaxation*, involves *self-induced states*, and employ a *self-focus skill*, also called an "anchor" towards which attention is to be directed. Other researchers have laid a primary focus on this last factor, and argue that meditation techniques can be classified into the two styles of open monitoring (OM) and focused attention (FA) based on how *attention* is directed (e.g. Lutz, et al., 2008).

In comparing the factors that enhance (or decrease, as in the case of stress) neuroplasticity and the features of meditation, we see that two factors stand out as common ground between the two. Firstly, because stress has negative effects on neuroplasticity, meditation might relieve stress through the features of physical and mental *relaxation*. Furthermore, since *attention* is involved in enhancing neuroplasticity, and most meditation techniques lay an emphasis on the use of attention, meditation might enhance plasticity through the employment of attention is specific ways. In the following, we will explore these hypotheses further.

5 Does meditation enhance neuroplasticity through relaxation?

In examining whether meditation enhances neuroplasticity through relaxation, it might be fruitful to begin by looking at the counterpart of relaxation, namely stress.

5.1 Stress and the brain

It has proved difficult to agree upon a common definition of stress, and research on stress often confounds multiple concepts, such as "anxiety", "threat", and "demand" (Burton & Hinton, 2010). The differences in terminology make it difficult to navigate the landscape of stress research. Still, there is some consensus in the literature that awareness that one is not coping with something personally important (a perceived stressor), often results in the psychological state of stress (Burton & Hinton, 2010). In this thesis, the word stress will be used to describe this psychological state with its physiological correlates, not the stressor itself.

While it has been reported that transient mild stress can enhance learning and memory (Luine, Martinez, Villegas, Magarinos, & McEwen, 1996), severe or chronic stress has a number of adverse consequences on the nervous system and body as a whole (for an overview, see Golberger & Breznitz, 1993). In an experiment done with rats subjected to chronic stress, it was shown that stress caused neuronal atrophy in medial prefrontal cortex, an area known to regulate shifts in behavioral responses to changing environmental demands. Furthermore, these structural changes was reflected in bias towards habitual and maladaptive responses, rather than exhibiting flexibility in the situation (Dias-Ferreira et al., 2009).

Stress involves an activation of the sympathetic nervous system, a response first coined by Walter Cannon in 1929 as the “fight-or-flight response” (Cannon, 1929). This response prepares the body for action and increases chance of survival in dangerous situations, but can be detrimental to the body and nervous system if kept active over longer periods. The stress response is multi-faceted and involves cardiovascular, respiratory, gastrointestinal, and endocrine changes. One result of chronic stress is secretion of a range of hormones, among them cortisol. Cortisol is secreted by the adrenal gland, suppresses the immune system, and accelerates fat, protein and carbohydrate metabolism (Tsigos & Chrousos, 2002).

There is growing evidence of a link between stress and neuroplasticity. A study by Shors and colleagues indicates that stress has adverse consequences for LTP in the hippocampus (Shors, Seib, Levine, & Thompson, 1989). Rats were divided into two groups, where one group was administered a shock from which they could escape, while in the latter group, the shock was inescapable. The latter group was thought to undergo the most stress. After one week of this training, the experimenters found that the rats in the stress group had significantly impaired LTP in hippocampus compared to the group that could escape. The authors interpreted this as evidence that controllability, and thus, stress levels, affects neuroplasticity at a neuronal level. Since this study, there has been increased understanding of the effects of stress on the mechanisms of neuroplasticity (for a review, see McEwen, 1999). In rodents, not only is it demonstrated that many different types of stress reduce neurogenesis in the hippocampus

(Dranovsky & Hen, 2006), but it can also lead to atrophy in these areas (reviewed in Duman, 2004; Sapolsky, 2000).

5.2 Meditation and the relaxation response

"The relaxation response" is a term coined by Herbert Benson in the early 70s, thought to be the counterpart of the fight-or-flight response. Benson started by studying practitioners of Transcendental Meditation (TM), and from his observations, he described the relaxation response as "the set of integrated physiologic changes that occur when a person; assumes a relaxed posture with eyes closed within a quiet environment, engages in a repetitive mental activity and, passively ignores intrusive distracting thoughts" (R. K. Wallace & Benson, 1972). Alterations in physiological functions during the relaxation response are marked by a reduction in sympathetic activation. This includes decreases in oxygen consumption, heart rate, respiratory rate, and arterial blood lactate, and a slight increase in skeletal muscle blood flow (Benson, 1983).

As we saw earlier, most meditation forms have in common that they include an element of physical and mental relaxation (Cardoso, et al., 2004; Ospina, et al., 2007). Evidence for a relationship between meditation and stress-reduction comes from studies measuring levels of autonomic nervous functioning in the body before, under, and after meditation. In one study examining the effects of Acem meditation, changes in heart rate and blood pressure in experienced male meditators during one hour of meditation were compared to matched control participants instructed to rest as comfortably as possible for the same amount of time. Results showed that the heart rate of the meditators declined significantly more than in controls, indicating an additional relaxation effect of this type of meditation compared to rest (Solberg et al., 2004).

Several meditation-based programs have been designed specifically to help people reduce stress levels. One of the most prominent is Kabat-Zinns Mindfulness Based Stress Reduction-program (MBSR). MBSR is a structured 8-week program of meditation derived from Buddhist mindfulness traditions, designed to enhance awareness of moment-to-moment experience of mental and bodily states. This "non-judgmental awareness" is in turn thought to relieve stress (Kabat-Zinn, 1993). A meta-analysis on the psychological benefits of MBSR summarized the findings of about 20 research projects (Grossman, Niemann, Schmidt, &

Walach, 2004). About 34 studies were excluded due to lack of scientific rigor. Accepted studies covered a wide range of subjects from both clinical and non-clinical populations. The analysis showed that both controlled and uncontrolled studies yielded similar effect sizes of about 0.5 ($P < .0001$) on physical and psychological functioning, indicating that "mindfulness training might enhance general features of coping with distress and disability in everyday life, as well as under more extraordinary conditions of serious disorder or stress" (Grossman, et al., 2004, p. 39). They caution, however, that the long-term effects are still unclear, because few follow-up studies have yet been performed. Moreover, there were several methodological shortcomings in the included studies worth mentioning. Among them were questions about therapist's competence, training, and adherence to the program, as well as a lack of rigor in describing the details of the intervention. Similar methodological concerns are voiced in a former meta-analysis, which yielded comparable results (Baer, 2003).

Furthermore, it has not been clear that the beneficial effects of MBSR come specifically from stress reduction. A new study, however, lends support to this interpretation (Hölzel et al., 2009). The researchers conducted a longitudinal MRI study to investigate whether changes in perceived stress was correlated with gray matter density in amygdala following MBSR. The amygdala is a brain structure known to be highly active during stress responses (LeDoux, 2000). The researchers found that the intervention significantly reduced the participants' perceived stress. Moreover, reductions in perceived stress correlated positively with decreases of gray matter density in certain areas of the amygdala. These findings are complex and will not be discussed in detail here, but the researchers interpret the finding as indications that mindfulness-based meditation reduces activation of amygdala, which is then followed by structural changes in this region.

5.3 Preliminary conclusions

From the research reviewed so far, we see that stress and meditation might affect the body and brain in two diametrically different ways; while stress increases sympathetic activity and prepares the body for fight or flight, meditation has relaxing effects on the nervous system, decreases sympathetic activity and allows for restoration of resources. Meditation might therefore counteract the detrimental effects of chronic stress, thereby enhancing neuroplasticity. However, in order to know whether meditation has a strong effect on neuroplasticity through relaxation, we need to know more about whether the stress-reducing effects of meditation are long lasting.

Furthermore, meditation might not be unique in promoting neuroplasticity through relaxation. It is probable that any method that reduces chronic stress might have similar, beneficial effects. A crucial difference between meditation and other sources of relaxation, is that meditation involves sustained attention, thereby cultivating a balance between hypoarousal and alertness (Lutz, et al., 2007). Next, we turn to the issue of attention.

6 Does meditation enhance neuroplasticity through attention?

As discussed earlier, schools of meditation differ in their purpose and practice, but they have in common the importance laid on the direction of attention (Davidson & Goleman, 1977). Meditation has been described as “practices that self-regulate the body and mind, thereby affecting mental events by engaging a specific attentional set” (Cahn & Polich, 2006, p. 180). This attentional set can be broad, as in meditation practices involving open monitoring, or narrow, as in meditation involving varieties of focused attention.

If meditation is to enhance neuroplasticity through attention, the first criterion that needs to be met is that meditation has to affect or improve attention in some way. We can imagine two possible effects. One is that meditation affects neuroplasticity through the deployment of attention in a specific way under meditation (which we can call a state effect). The other is that meditation increases attentional abilities that last also outside of meditation (which we can call a trait effect). This question will have consequences for the possible uses of meditation. In a school setting, as suggested in the introduction, it might be beneficial to use meditation as part of an attention-training program. In this case, the goal would be to achieve a trait effect of improved attention generalizable to activities outside of meditation. We will therefore examine whether meditation practice may lead to enhanced attentional performance while meditating, as well as outside of meditation. Thereafter, we will examine the role of attention in neuroplasticity.

6.1 Does meditation improve attention?

> *And the faculty of voluntarily bringing back a wandering attention, over and over again, is the very root of judgment, character, and will. No one is* compos sui *if he have it not. An education which should improve this faculty would be the education par excellence.*
>
> *William James (1890, p. 424)*

Attention, just like meditation, is a word with many meanings. Researchers have found it problematic to pinpoint what attention actually is, as well as to separate it from the related concepts of awareness, consciousness, and attentiveness. Posner and Rothbart states that "attention serves as a basic set of mechanisms that underlie our awareness of the world and the voluntary regulation of our thoughts and feelings" (2007, p. 6). Studies have found that the attention system of the brain consists of a network of areas, anatomically separate from the areas that represent specific inputs. This means that the parts of the brain that are responsible for attention interacts with, but are separate from, other brain areas (Posner & Petersen, 1990). Furthermore, it is common to divide the attention system into subsystems that perform separate but interrelated functions. These functions can be labeled as *alerting*, defined as achieving and maintaining a state of sensitivity to stimuli; *orienting*, defined as the selection of information from sensory inputs; and *executive attention*, defined as monitoring and resolving conflict among thoughts, feelings and responses (Posner & Rothbart, 2007).

Next, we will review evidence concerning the effects of meditation on attention. We can look at this through investigating whether meditation practice changes the networks in the brain that is involved in attention (through neurophysiological studies), as well as measuring attention performance on behavioral tasks.

6.1.1 Evidence from neurophysiological studies

It is likely to assume that the different meditation styles engage the brain in different ways, and that this is reflected in neural correlates as well as in behavioral outcomes. Focused attention meditation involves continuously monitoring the subject of attention, detecting distraction, disengaging attention from the source of distraction, and redirecting and engaging attention to the intended subject (Lutz, et al., 2008). Momentary lapses of attention have been shown to coincide with decreased activation in anterior cingulate and right prefrontal regions, indicating their role in executive control of attention allocation (Posner & Rothbart, 2007; Weissman, Roberts, Visscher, & Woldorff, 2006).

The investigation of brain activity during meditation has resulted in somewhat ambiguous findings. This might be due to methodological issues, such as heterogeneity of the studied meditation techniques and a lack of first-hand reports from the subjects as to what they are actually experiencing. However, with the advent of refined functional imaging (such as PET and fMRI), studies are beginning to locate some neuronal foci for meditation effects. In a review from 2006, it is concluded that different meditation forms generally activate frontal and prefrontal areas such as the anterior cingulate cortex (ACC), the dorsolateral prefrontal cortex (DLPFC) and orbitofrontal cortex (OFC). These areas are known for their involvement in executive function, emotion regulation and attention (Cahn & Polich, 2006).

A recent fMRI study investigated the neural correlates of focused attention meditation in Tibetan meditation experts and novices (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007). During meditation, the participants were instructed to focus on an external visual point. The meditation, compared to the rest condition, was associated with activation in brain regions involved in monitoring (DLPFC), attentional orienting (such as the superior frontal sulcus and intraparietal sulcus) and engaging attention (visual cortex). The activations correlated on the level of expertise of the meditation practitioners, indicating that activity in these neural networks increase with practice. However, activity showed an inverted U-shaped curve depending on level of expertise. While meditators with an average of 19 000 hours of practice showed stronger activations in these areas that novices, meditators with an average of 44 000 hours of practice showed less. The reason behind this shift is unclear, but the inverted u-shape function resembles the activation patterns associated with skill acquisition in other domains as well, such as language (Sakai, 2005). It might also support the development of "effortless concentration" the monks describe as a goal for meditation practice, shifting from a state of effortful "grasping" of the object, to a more trait like state of no explicit focus (Lutz, et al., 2008). Interpreted this way, it seems that FA and OM meditation might become increasingly similar at a high level of practice. Further investigation is needed to clarify this hypothesis.

The first fMRI-study to compare neuronal activity in FA and OM styles of meditation was published this year (Manna, et al., 2010). One group consisted of eight monks highly experienced in both *Samatha* (FA) and *Vipassana* (OM) meditation styles. A control group consisted of eight novice meditators who had practiced each of the two meditation styles 30 minutes every day for 10 days prior to the experiment. The OM meditation instruction consisted of observing experiential content from moment to moment without judgment, while the FA meditation instruction involved sustaining the attention focus on the sensations of the breath, noticing distractions when they arise and gently returning to the breath.

The results from the study are complex, so only some of the main findings will be noted here. During OM meditation compared to rest, the brain activity of the monks resembled the activity of the normal relaxation state, marked only by an increase of activation mainly in areas known for self-referential processing (such as the precuneus). In contrast, open monitoring meditation in novices activated areas known for executive functions and cognitive focus (ACC and right medial prefrontal cortex), as well as affective and cognitive evaluation processes (rostral ACC and lateral OFC). The authors take this to suggest that with practice, open monitoring meditation becomes more of a stable trait of effortless, non-evaluative monitoring.

The brain activity associated with FA meditation in the monks was contrasted sharply to both OM and rest. It was particularly marked by widespread deactivation especially in areas of the left hemisphere, as well as increases in activity of ACC and medial PFC. As mentioned, the ACC and medial PFC are associated with executive control of attention allocation. In the novices, FA meditation deactivated the left posterior cingulate, an area seemingly involved in a “default mode network” that is active during resting states (Fransson & Marrelec, 2008). Furthermore, there appeared no significant differences in activations in the novices when comparing FA to OM meditation.

This study informs us on the neuronal correlates of different ways of directing attention in experts and novices. The results are multifaceted, but point in the direction that meditation experience is associated with increased self-regulation of attentional and emotional processes. Furthermore, while open monitoring might become a stable trait after a certain amount of practice, practice in focused attention meditation is marked by deactivation in a range of brain areas during meditation. Since this is the first study to compare OM and FA meditation directly, further research is needed to replicate and clarify the results.

6.1.2 Evidence from behavioral studies

Is meditation experience associated with superior performance on attentional tasks? Again, it is useful to distinguish between OM and FA meditation. A study of Tibetan Buddhist monks used a binocular rivalry paradigm where two competing images were presented to separate eyes. The results revealed that compared to controls, the monks were able to perceive a stable percept of the images for a longer time period during and after focused attention meditation, but not after open monitoring meditation (Carter et al., 2005). This suggests that training in FA meditation might increase the ability to sustain attention focus on a particular object, whereas open monitoring meditation does not have this same effect.

On the other side, it seems that OM meditation affects the ability to perceive multiple stimuli quickly. An early behavioral study showed that meditators experienced in OM meditation demonstrated superior performance on a test of sustained attention in comparisons with controls, and long-term meditators performed better than short-term meditators (Valentine & Sweet, 1999). Interestingly, OM meditators showed superior performance in comparison with concentrative meditators when the stimulus was unexpected, but there was no difference between the OM and FA meditators when the stimulus was expected. This indicates a more distributed attentional focus in OM meditation.

In line with this, a recent study showed that three months of intensive OM meditation practice significantly reduced the so called “attentional blink”, a term referring to the tendency that after being presented with a target stimuli, attention is momentarily occupied, thereby lowering the likelihood of noticing the second target if this is presented shortly after (Slagter et al., 2007). When presented with the first of two target stimuli amongst a rapid stream of distracters, the meditators exhibited a smaller P3b than the control group. The P3b is a measure of electrical activity in the brain that arises around 300 ms after stimulus onset, which is thought of an index of neural recourse allocation. The reduction in P3b was associated with improved detection of the second target stimuli. These results indicate that OM meditation might reduce the tendency for elaborate processing of stimuli, and thereby increasing overall detection rate. Similarly, in a recent randomized design comparing one group of subjects completing a four week mindfulness meditation program to a relaxation group and a wait list group, the mindfulness group demonstrated superior performance signal detection and sustained attention (Semple, 2010).

Finally, it seems that OM meditation affects these abilities after relatively small amounts of practice; in a study where a group was randomly assigned to five days of meditation training largely based on OM principles, the meditators exhibited greater improvement in conflict monitoring than a control group given relaxation exercises (Tang et al., 2007).

In contrast to these findings, one study found no effects of an eight week program in mindfulness-based stress reduction on tests measuring sustained attention, attention switching, Stroop interference, or detection of objects in consistent or inconsistent scenes (Anderson, Lau, Segal, & Bishop, 2007). However, they found significant increases on measures of emotional well-being and mindfulness, and mindfulness scores were found to correlate with improvement on an object detection task. The authors interpret their findings to indicate that mindfulness meditation might affect awareness of present moment experience more than basic attentional control. These anomalous findings warrant further investigations into the effects of MBSR on attentional performance.

With regard to children, few studies have been conducted. One recent pilot study reported that a 12 week program of Mindfulness-Based Cognitive Therapy for Childen (MBCT-C) significantly reduced attention-related problems in children in the ages of 9-12 (Lee, Semple, Rosa, & Miller, 2008). These results are particularly interesting with regards to the use of meditation in educational settings.

To conclude, both OM and FA meditation is associated with altered activation in neuronal circuitry involved in attention, a sign of functional plasticity in these areas. Furthermore, in most studies conducted so far, meditation experience is associated with superior performance on a range of attentional tests, also after relatively small amounts of meditation practice.

6.2 The role of attention in neuroplasticity

Where attention goes, neural firing occurs. And where neurons fire, new connections can be made. In this manner, learning a new way to pay attention (...) catalyze the integration of new combinations of previously isolated segments of our mental reality.

Daniel Siegel (2006, p. 249)

Within many schools of psychotherapy, an underlying premise has been that in order to change something, the patient has to first become aware of it. This is especially clear in the methods of Sigmund Freud, designed in large part to make conscious the dynamic and hidden forces in the mind, thereby making them subject to change (Cozolino, 2002). Other schools of therapy rely on the same assumption that bringing something into awareness creates a possibility of change, whether it is done through the uncovering of maladaptive thought patterns, exploration of connections between experiences in past and present, the exposure of communication patterns in families, or the like.

Revisiting the research of Recanzone and Merzenich (Recanzone, et al., 1993), we recall that even though all monkeys received both visual and tactile stimuli, functional reorganization only occurred in the cortical maps representing the modality being attended to. Evidence of cortical reorganization in auditory cortex was only evident in the monkeys who were trained to focus on the auditory stimuli, even though both groups received the same stimulation. This implicates a role of attention in facilitating plasticity.

Perhaps even more interesting, mental training alone might be sufficient for facilitating reorganizing of cortical maps. There is ample evidence that mentally simulating a motor action activates overlapping areas in the motor cortex as those activated when actually performing the action (summarized in Grezes & Decety, 2001). In a study investigating the effects of mental imagery on performance and plasticity, subjects were taught a one-handed, five-finger exercise on the piano, where they were to press their fingers down in a specific order while accurately matching a metronome beat (Pascual-Leone et al., 1995). One group was assigned to physically perform the exercise, while another was assigned to mentally simulate the practice. The researchers mapped the cortical areas of the fingers before and after the 5-week practice period with 2 hours of practice each day. Mental training alone led to significant skill learning, but did not result in as much performance improvement as physically exercising the task. However, mental practice led to equivalent changes in motor areas representing the fingers as those occurring in the group with repeated physical practice. This study indicates that paying attention through mental training has effects on the plasticity of the brain.

6.2.1 Neuronal synchrony in attention and meditation

Oscillatory synchrony, or phase synchrony, refers to the mechanism by which a population of neurons fires their action potentials in temporal synchrony with a precision in the millisecond range (Lutz, et al., 2007). The functional significance of neural synchrony is an area of active research. It is assumed that oscillatory neural synchrony is a fundamental mechanism for communication between spatially distributed neurons. Neural synchrony has been proposed as a mechanism to “tag” the spatially distributed neurons that participate in the same process, and thereby enhance the salience of their activity compared to other neurons (Singer, 1999).

Attention and neural synchrony might be closely linked. A group of researchers at the Mind/Brain Institute at John Hopkins University investigated the firing patterns of pairs of neurons in the somatosensory cortex of monkeys trained to switch attention between a visual task and tactile discrimination task (Steinmetz et al., 2000). They found that the degree of synchrony between neurons in this area increased when the monkeys paid attention to the tactile discrimination task, compared to the visual task. These results indicate that attention increases the synchrony in the representation of the location being attended to.

A similar experiment replicates this finding, and sheds light on an area of research that has experienced a surge of interest in the last decade, namely the functional significance of synchronized gamma band activity. In the experiment, they trained macaque monkeys to attend to behaviorally relevant stimuli and ignore distractors (Fries, Reynolds, Rorie, & Desimone, 2001). As in the experiment by Steinmetz and colleagues, the researchers found an increase in synchronized neural activity at the sites in the cortex representing the attended stimuli compared to the distracters. Furthermore, the synchronization occurred specifically in the gamma band. Gamma band activity most likely reflects synchronous firing activity of large ensembles of neurons (Jensen, Kaiser, & Lachaux, 2007). Usually, frequencies of around 40 Hz are referred to as gamma activity, but the range can vary between 20 and 200

Hz across studies (Fell, Axmacher, & Haupt, 2010). Gamma rhythms have received increasing interest because of its association with various cognitive functions in healthy humans (Herrmann, Munk, & Engel, 2004; Kaiser & Lutzenberger, 2003), as well as a possible role in neurological dysfunction and psychiatric illness (Le Van Quyen, Khalilov, & Ben-Ari, 2006). In this thesis, the focus will be laid on the role of gamma band activity as shown to be implicated in attention, plasticity and meditation.

As we have seen, neuroplasticity depends on processes ranging from the molecular level to the level of functional networks. As mentioned earlier, when neurons fire together in a high frequency, the synapses between them become more efficient. The required delay times for effective Hebbian modification of synaptic connections by correlated firing of the pre- and postsynaptic neurons are of the order of less than +/- 10ms (Abbott & Nelson, 2000). Synchronized neural assemblies that fire action potentials in the gamma frequency range do so in a highly time locked manner with a precision of a few milliseconds. This precision is crucial when it comes to activating the target neurons, because the summed input from many neurons firing together has a higher chance of elevating the membrane potential of the target neuron above firing threshold. Synchronized high-frequency EEG rhythms like gamma activity could therefore provide an optimal condition for the establishment of neural assemblies and synaptic plasticity (Fell, et al., 2010).

What does all this have to do with meditation? Firstly, as we have seen, meditation seems to improve attentional abilities, although the evidence is somewhat divergent. Secondly, we have seen a correspondence between attention and synchronized gamma wave activity. Thus, one might suspect that experienced meditators exhibit a higher degree synchronized gamma wave activity. This is exactly what Antoine Lutz and colleagues reported in a study comparing EEG patterns in experienced and novice meditators (Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). One subject group was composed of young students trained for a week in an OM meditative technique, while the second group was comprised of Tibetan Buddhist practitioners with between 15 and 40 years of meditation experience. The control group underwent one week of training where they were to aspire towards a state of non-referential compassion to all sentient beings. The subjects' brain activity was measured by means of EEG before, during, and after meditation.

Two interesting findings appeared. Firstly, the ratio of gamma band activity compared to slow rhythms was higher at baseline before the meditation for the experienced practitioners compared with controls. This effect sustained when controlling for age-effects. Furthermore, the differences at baseline increased sharply during meditation, in fact, the amplitude of synchronized gamma activity was in some of the participants greater than any previously reported non-pathological (non-seizure based) gamma synchrony. The group difference was greatest over frontolateral and posterior electrodes, and the difference continued into post-meditative rest.

6.2.2 How can we understand gamma synchrony in meditators?

The interpretation of these results is not clear at this point in time. Firstly, the functional consequences of sustained gamma oscillations are not yet known. The authors conclude that the observed gamma activity probably reflects the activation of massive distributed neuronal networks. If gamma activity reflects conscious perception or attention, one might speculate that meditation could correspond to increased conscious awareness or broadened attentional scope. It is however difficult to discuss this possibility without falling back on a spiritual language, since there is no obvious scientific term corresponding to “expanded consciousness” or “heightened awareness”. Further insights into this are needed before any conclusions can be drawn.

Secondly, the results collide with other studies reporting slowing of alpha rhythms and increased alpha power during meditation (see Fell, et al., 2010 for a review). This discrepancy might result from earlier studies not analyzing fast rhythms. The authors attempt to explain this fact by pointing out that other studies have focused mainly on meditation with a specific attentional focus, while their current study presumably involved an “object-less”, cultivating a specific state of *being*. An obvious gap in this conclusion is the lack of descriptions from the participants pertaining to what they actually experienced. We can therefore not say with satisfying clarity that the meditation was in fact “object-less”.

Fell and colleagues (2010) attempt a somewhat different approach of the apparent discrepancies of electrophysiological correlates of meditation practice. They propose that there are some steps of meditative development virtually all practitioners go through, regardless of their specific technique. In the first phase of learning how to meditate, there are physical demands as the beginner has to sit in an unfamiliar position and mental strains as the beginner experiences restless attention. The authors suspect only transient alterations of neurophysiologic functioning in this first state. After some training, the next phase is marked by an increasingly internalized attention and an aspect of physical relaxation. This step is thought to be within the reach of every beginner, and the neurophysiologic changes that arise in this state are not markedly different from ordinary non-meditative states. The authors report that an increase in alpha rhythms (8-12 Hz) may mark this state of meditation. The third step is characterized as "the correct performance of the meditation technique" (p. 220), where the first alterations in perception and processing of stimuli occur. This state might correspond with increases in theta activity (3-8 Hz), otherwise known to be involved in hypnosis and transitions from sleep to waking state. When it comes to gamma activity, they believe this type of wave frequency is closely related to an expert level of meditation practice. They go further to discuss the importance of gamma waves in plasticity and the formation of new circuits, as perhaps contributing to the goal of many meditation practices of experiencing new states of consciousness.

An interesting caveat to this section is the work of Mark Jung-Beeman and colleagues on the phenomenon of *insight*. Insight is the process through which people achieve solutions involving conceptional reorganization and distant or atypical relations between problem elements. The insight experience is often sudden and unexpected, resulting in an "aha!" moment (Subramaniam, Kounios, Parrish, & Jung-Beeman, 2009). The main neural correlate of insight self-reports is a burst of gamma-band EEG activity beginning around 0.3 seconds prior to insight solutions occur consciously (Jung-Beeman et al., 2004). Gamma waves may in this case reflect the activation of a new, transient network of neurons being created. A newer study demonstrated a mood-effect on this process, with positive mood facilitating insight-experiences (Subramaniam, et al., 2009). Furthermore, it seems that in order to achieve insight, the mind has to be relaxed, yet focused. The authors could predict who would have an insight experience several seconds before it came, based on the presence of synchronized alpha waves, known to represent a relaxed state of mind. Here we see some similarities between insight experiences and meditation that could be interesting to investigate further. Insight experiences are interesting in the context of neuroplasticity because it can involve quite dramatic rearrangements of previously existing knowledge. Perhaps meditation induces a brain state particularly ripe with the possibility of insight.

7 Implications and questions for future research

The history of science is rich in the examples of the fruitfulness of bringing two sets of techniques, two sets of ideas, developed in separate contexts for the pursuit of new truth, into touch with one another.

J.R. Oppenheimer (1954)[2]

It is clear that the evidence gathered up until this point in time is inadequate to determine whether meditation increases neuroplasticity. We have looked at research demonstrating that certain activation patterns and changes that occur in the brain following different types of meditation, but the central question of whether meditation actually enhances the brain's ability to change, remains unresolved.

We have however, examined indirect evidence pointing in this direction. Firstly, meditation seems to reduce the activity of the sympathetic nervous system, inducing relaxation. Stress-reduction has been shown to have neuroprotective and neurotrophic effects on the brain. Keeping neurons alive and creating new neurons in response to experience is a possible mechanism of enhanced plasticity.

We have also examined evidence pointing to a relationship between meditation, attention and neuroplasticity. In sum, the link might be as follows: Attention is associated with increased synchrony of neuronal firing of the brain areas representing the attended object, especially in the gamma band frequency. Gamma band activity has shown to be implemented in plasticity, specifically in the form of LTP. Meditation might therefore enhance plasticity through the cultivation of attention. The recent discovery that long-term meditators self-induce sustained

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[2] From Oppenheimers book: "Science and the Common understanding" (cited in Walsh & Shapiro, 2006, p. 227).

long-range synchronized gamma activity while meditating, as well as exhibit a higher level of gamma activity outside of meditation, might be taken as further support.

One might wonder whether there exists a relationship between the effects of attention and relaxation. Are the factors independent contributors to the enhancement of neuroplasticity, or are they in some way connected? It might be argued that while attention is a *tool* one employs during meditation, relaxation is an *effect*. Looked at it this way, attention might be the primary feature of meditation that enhances plasticity, while relaxation is a by-product of attention, merely adding to the effect. At the same time, we can imagine ways of using attention that do not promote relaxation. It might also be argued for a reverse relationship; that inducing relaxation through sitting quietly, closing the eyes, and so on is used as a tool in meditation for promoting attention. In addition, we have seen that attention might be best construed both as a tool that is employed during meditation, and an effect, because meditation seems to increase attentional abilities also outside of meditation. Further investigations are needed to clarify the relationship between relaxation and attention. If the two factors are independent, either of them can be employed when constructing interventions, for example in schools. In that case, teaching meditation might not be the most efficient way to go about increasing the students learning potential. If, however, the combination of relaxation and attention has a synergistic effect, perhaps meditation is particularly well suited for this task.

7.1 States or traits?

If we were to assume that meditation enhances neuroplasticity, a next step would be to question whether this enhancement is restricted to a state that is achieved during meditation practice, or where the changes are trait-like in nature, reflecting lasting changes in the meditator also outside of meditation. In other words: Do meditators have a more plastic brain in general, or just when they are meditating?

In Buddhist traditions (and their western secular derivatives), a central tenet of meditation is that it allows the meditator to realize the transient nature of his internal and external reality. A central goal of many meditation practices is to increase awareness of the workings of the mind, thereby allowing for the breaking of mental habits and automatic processes (Goleman, 1988). There seems to exist parallels between these philosophical ideas and the underlying neuroplasticity that such flexibility would demand. To my knowledge, it has not been thoroughly investigated whether meditators exhibit more flexible response patterns or are less driven by mental habit. One study reports that compared to the pre-test, following 20 minutes of transcendental meditation the participants exhibited an increase in the number of atypical responses on a category-production task, and decreases in habitual responses on a Stroop-task (Wenk-Sormaz, 2005). The same changes did not apply for subjects in the two control groups who either rested or learned a mnemonics technique between trial one and two. Lowering of habitual responses have been reported earlier in a study of transcendental meditation with subjects averaging 81 years (Alexander, Langer, Newman, Chandler, & Davies, 1989). However, these studies suffer under a range of methodological weaknesses and need replication with different types of meditation, a higher number of research subjects, and better control of confounding variables. As we saw earlier, it has been reported that meditators had thicker cortices in prefrontal areas of the brain, and performed better on tests of memory and attention, compared to non-meditators in the same age group (Pagnoni & Cekic, 2007). The biggest difference in gray matter volume was found in the putamen, an area central to attention processes and cognitive flexibility (besides its role in motor control and learning). The authors point to both the effects of meditation on autonomic arousal and the conscious regulation of attention as possible factors contributing to the differences. In sum, some research point us in the direction of meditation imposing trait-like effects on neuroplasticity, but more research is undoubtedly needed to clarify this further.

A similar question pertains to dose and effect – how much meditation is needed to achieve beneficial effects? As we have seen, even short-term meditation seems to reduce stress and increase attentional abilities, although these changes may not be lasting. Revisiting the hypothesis of Fell and colleagues (Fell, et al., 2010), we might speculate that short-term meditation is associated with transient, state-dependent changes mostly associated with relaxation, moving gradually towards a trait-like stabilization of attentional control and stress-reduction as the meditator gains expertise. They suggest that synchronized gamma oscillations occur mostly in experienced meditators, indicating that neuroplasticity might increase with meditation practice. This hypothesis is supported by the results of Lutz and colleagues (2004). However, gamma-band has not been monitored during most EEG studies of meditation, therefore further investigation is needed to investigate this hypothesis.

7.2 Practical applications

The research reviewed in this thesis suggests that practices or activities that involve stress-reduction and active employment of attention might enhance neuroplasticity. Meditation is one such practice, and one might imagine others. In the introduction, it was mentioned that the field of therapy might benefit from knowledge about how neuroplasticity is enhanced. In fact, therapy is in some ways similar to meditation – therapy can be a situation where the client in a relaxed and accepting way pays particular attention to his or her thoughts, feelings and bodily sensations, just as in meditation. However, there are some obvious differences. For example, therapy is by many thought to be most beneficial when it involves a certain amount of activation, sometimes even bordering to stress (Cozolino, 2002). In addition, the client's attention is probably not sustained on one particular "anchor" as in meditation, but might instead shift between the client's inner experiences, the conversation, the reactions of the therapist, and so on. Thirdly, meditation can be practiced alone, at home, and every day. As we have seen, relatively short amounts of meditation practice might lead to stress reduction and improvement of attention. Therefore, encouraging client to meditate between therapy sessions might enhance the efficacy of therapy through the enhancement of attentional abilities and stress-reduction. It would be interesting to explore this hypothesis further in research, by comparing groups that receive therapy with and without meditation practice in between sessions.

It has been proposed that attention training can be employed in educational settings to improve learning and self-regulation (Posner & Rothbart, 2005). Some research is appearing with regards to the effects of meditation in children with attentional difficulties, reporting positive outcomes (Harrison, Manocha, & Rubia, 2004; Lee, et al., 2008). With regards to the research discussed in this thesis, one might assume that learning can be enhanced both through the creation of an external environment that promotes relaxation and attention, and through regular meditation practice where the child or youth learns to self-regulate these skills. With regards to the first point, one might wonder what consequences arise from today's grade- and performance-based education system. It might be argued that the competition that arises from grading creates a source of chronic stress in children and youth. Meditation practice could possibly counteract these effects and promote plasticity and learning.

With regards to age-related cognitive decline, meditation practice could be practiced in order to counteract some of the detrimental effects of aging. As we have seen, it has been reported that brain regions associated with attention, interoception and sensory processing were thicker in meditation practitioners than in age-matched controls (Lazar, et al., 2005) and that middle-aged meditators exhibited superior performance on attention related tasks compared to non-meditators (Pagnoni & Cekic, 2007). It is not clear from this research however, whether the meditation practitioners differed from the non-practitioners in other significant ways, for example could subjects who are less prone to cognitive and neural ageing be more inclined to practice meditation. In addition, the question of dose and effects is relevant also here. How much meditation is needed in order to promote plasticity in old age? Can meditation reverse the symptoms of cognitive decline if taught to the elderly, or does one need to start meditation at a certain age for these effects to manifest? These questions clearly need to be addressed in research, but as of now, there is no reason to assume that meditation leads to different effects in the elderly than in younger subjects. Therefore, meditation practice might be applied in health-care for the elderly in order to protect and enhance neuroplasticity.

7.3 Philosophical caveat

We have seen that functional and structural changes in the brain occur in response to a range of experiences, including skill-acquisition, exercise and interaction with stimulating environments. What separates these experiences from meditation is that during meditation the experience is created in one’s own mind. Revisiting Daniel Siegel’s observation that “the mind is using the brain to create itself” (Siegel, 2007), one might be tempted to conclude that meditation research demonstrates a case of “mind over matter”. In fact, a whole industry is being built around this catchy phrase, optimistically encouraging people to create their own reality through changing the workings of their mind (see for example the New York Times bestseller "The Plastic Mind", Begley, 2007).

On the other end of the scale, lies the potential fallacy of reducing everything that occurs in the mind to neurophysiologic processes, thereby leaving no room for the spiritual aspects of the traditions that meditation originally grew out of. What is one to make of the experiences of expanded consciousness reported by meditators? It might be argued that by employing a strict psychophysiological isomorphism one loses the original purpose and meaning behind meditation, and that there might be aspects of the mind that belong to dimensions not easily accessed through the currently available methods of scientific investigation.

The question of the relationship between mind and brain is fascinating, and will most likely always remain an enigma. Nevertheless, through rigorous study of the physiological substrates of meditation and its associated states of consciousness, we might achieve important insights into phenomena that previously have been restricted to the spiritual domain.

8 Conclusions

Although research on the neuroscience of meditation suffers from a range of methodological issues, some tentative conclusions might be drawn from the evidence presented in this thesis. Firstly, meditation might enhance neuroplasticity by inducing relaxation, thereby counteracting some of the detrimental effects stress imposes on the nervous system. Secondly, meditation might enhance neuroplasticity through enhancement of attentional capacities. Attention seems to be an important factor in facilitating experience-induced changes in the brain. Experiences that are paid attention to, may result in more functional and/or structural change than those that go by unattended. In this regard, gamma waves may be an interesting focal point for further studies, as they are associated with attention and may be particularly well suited for inducing synaptic plasticity. Studies indicating that meditators exhibit superior performance on attentional tasks, as well as increased levels of gamma synchrony compared to non-meditators, lend support to the hypothesis of a relationship between meditation, attention, and neuroplasticity.

If increasing numbers of “hard science” studies, such as those reviewed in this thesis, document effects of meditation on biology and behavior, it is likely that meditation will continue on its travel from the spiritual domain into accepted mainstream practices. Many questions remain unanswered, particularly regarding whether meditation induces lasting or transient effects on relaxation and attention, what dosage of meditation might be optimal for enhancing neuroplasticity, and whether different forms of meditation (e.g. open monitoring and focused attention styles) affect neuroplasticity and cognition in different ways. In the future, rigorous studies on the neuroscience of meditation will hopefully clarify these questions further.

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