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The Impact of Long-Term Meditation on Attentional Engagement

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Mag. René E. Seiger

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Betreuer:	Prof. Grega Repovš, PhD

Nothing whatsoever should be grasped at or clung to as being "I" or "mine".

– Buddhadasa Bhikkhu –

Contents

1 Introduction

Meditation can be seen as a mental training, which supports the cultivation of well-being, awareness and other beneficial properties by improving cognitive traits, like attention and emotion [1]. In line with the postulate of neuroplasticity [2], long-term mental training may influence the mind and the body in a sustainable manner, subsequently leading to observable changes in the brain. The scientific study of meditation dates already back to the 1950s, whereby, the lack of statistical evidence or scientific rigor in many of the early studies accounts for the quite modest contributions of neuroscientific research on the topic of meditation [3]. Although recent studies have attempted to reveal putative effects in a more methodical manner, proper evidence of whether brain activity is altered systematically due to long-term meditation is still missing [4]. Some studies, however, suggest that long-term meditation influences the brain in the form of altered neurophysiological processes [3]. Types of meditation are rather diverse and even subjects from the same school of thought can significantly differ in practice. Therefore, it is indispensable to be specific about the type of meditation under investigation. In this regard, a distinction between two major styles has been proven to be useful for scientific investigations: The first style is known as focused attention meditation (FA), where all attention is focused on a specific object. The other style, referred to as, open monitoring meditation (OM), involves a non-reactive monitoring of the actual experience from moment to moment. Different neuroscientific methods have been used in the investigation of meditation and it has therefore been revealed that neuroelectrical measurements (EEG) are a quite decent method for exploring the possible influences of meditation on the brain. In this respect, Cahn and Polich [5] showed that during one form of OM-meditation, called Vipassana, decreased automated reactivity and evaluative processing of task irrelevant attention-demanding stimuli occurred in contrast to the control state. More precisely, their results demonstrated that the P3a amplitude, which is a subcomponent of the P300 brain potential, was reduced when a distractor tone was presented during meditation and that the reduction of this amplitude was strongest in participants, who practised more hours of daily meditation. These findings support the hypothesis that long-term meditation can alter neurophysiological processes and that this mental training can induce plastic changes in the brain. In regard to the structure of this thesis, the hypotheses will be initially summarised, followed by an overview of the concept of meditation as well as the neuroscientific study of this mental training. Methods used for meditation research will be mentioned and the contribution of the P300 brain potential will be discussed in detail. Subsequently, used methods and results of this study will be presented and discussed, whereby a final conclusion will summarise gained insights.

2 Aim

The aim of this study was to assess the state and trait effects of long-term meditation practice. Cahn and Polich [5] demonstrated that the P3a amplitude, which is claimed to be an index for attentional engagement, was reduced in meditators during open monitoring meditation in contrast to the control condition, where a mind-wandering state was imposed. It is hypothesised that more concentrative forms of mental training, like focused attention meditation, may facilitate a narrowing of the attentional focus in such a way that stronger alterations in ERP amplitudes can be expected. This is possibly due to the fact that focused attention meditation removes the attentional systems further away from the immediate surroundings [4]. Therefore, participants in this study were encouraged to perform focused attention and open monitoring meditation to account for P3a amplitude differences between both types of meditation and two control conditions, where no meditative state was to be reached. In addition, a control group was asked to perform the same tasks, to account for trait effects.

3 Hypotheses

In order to assess state and trait effects of long-term meditation, the following hypotheses were tested. These neurophysiological changes are expected during distractor tone presentation:

1) It has been shown that meditation state can decrease the amplitude of neurophysiological processes that subserve attentional engagement elicited by distracting stimuli [5]. In this regard, P3a amplitude decreases during both types of meditation, relative to the control conditions, are expected. This implicates that during meditation, distracting stimuli are perceived differently, compared to a non-meditative state.

2) It is hypothesised that during more concentrative forms of meditation, attentional systems are even further away from the immediate surroundings [4]. Therefore, decreases in the P3a amplitude will be more pronounced during focused attention meditation.

3) It is expected that control subjects with no prior meditation experience will perceive presented stimuli as more distracting, in a way that automated reactivity to distracting stimuli will be increased compared to long-term meditators. Hence, larger P3a amplitudes during all conditions, compared to the meditators, are expected.

4 Background

4.1 Defining meditation

Meditation has a long history and various forms have been practised in several cultures worldwide for many centuries as a means of cultivating a state of well-being as well as for religious purposes [6]. The term itself refers to a wide range of practices, which significantly differ from one another in relation to varying characteristics. Practices as diverse as the ritual dances of some African tribes, the spiritual exercises of the desert fathers and the tantric practices of Tibetan adepts can all be seen as forms of meditation [7] and it is this fact, which underpins this thesis. The term is also often employed in a quite imprecise sense, such that its descriptive power is greatly decreased. This can be compared to using the word "sport" to refer to all kind of sports, as if they were all essentially the same [8]. Being not specific about the meditation type under investigation entails several pitfalls and is a mature issue while investigating meditation in a neuroscientific manner. Despite this variation in even related Buddhist practices it is possible to identify some core features, shared across meditation types. These are important for putting eastern traditions into a scientific framework. Every practice can be seen as a distinct technique, which induces a certain state or several states during practice. These states can have mental or physical effects and are phenomenally observable to the meditator and thus reportable. It is also thought that by inducing this state repeatedly, the effects on the mind and the body are sustainable. In other words, the repetition of a certain practice enables the meditator to enhance desirable traits and inhibit those, which are undesirable. Of further belief is that it becomes easier to induce a certain state for an experienced practitioner compared to a novice, meaning that inducement of the intended state improves over time [8].

A usual meditation practice is often performed daily with the duration ranging between 15 minutes to several hours. The posture of the body varies slightly, depending on the performed practice. Generally, the body should be kept in an upright position, whereby the spine should be kept straight and the rest of the body should be in a balanced condition, meaning neither too tense nor too relaxed. Most practices are performed in a sitting manner, whereby also standing or moving practices exist. Depending on the practice, eyes can be either open or closed. In addition to daily practice, so-called retreats offer a guided intensive practice, often held in complete silence. These retreats can last from a few days to even several months [6].

Due to the diversity and peculiar characteristics of each tradition, a concise generic definition of meditation has not been established and also does not account for the manifold characteristics of each tradition. Nevertheless, in considering all the different varieties, meditation can be conceptualised as an emotional and attentional regulatory training that focus on improving attention, awareness and emotion in order to bring mental processes under greater voluntary control and thereby foster general well-being, emotional balance, mental development and specific mental capacities [3, 4, 9]. This broad definition fits quite well and emphasises the importance of attention, emotion and awareness, which are the fundamental bases of almost every meditative training. These trained cognitive properties are prerequisites for other positive achievements that arise during and from meditation practice. There are many positive outcomes of all the different practices. Next to the facilitation of a deeper insight into the mind and the world [6], the development of compassion, love, joy, patience, emotional balance and well-being are just some of the essential aspects of meditative training [3, 9]. It is part of the meditation philosophy that all these positive properties should not just be reached during meditation, but should ultimately become part of the personality as a trait of character. Next to the cultivation of these positive aspects, negative properties, such as emotions, fear and anger should cease [10]. As it is stated, the training of attention and awareness can especially be seen as the fruitful basis for all positive outcomes a meditative training entails. It seems that by improving these faculties, the mind becomes more concentrated and calmer, leading to the cultivation of all these positive aspects.

The opposite state of being aware or concentrated can be referred to as a specific mode of thinking termed mind-wandering. In this state, people are not fully focused or aware of what is going on in their immediate surroundings and are occupied with inner thoughts, fantasies and feelings not related to the task at hand [11]. Studies suggest that mind-wandering occurs during daily routine to an extent of almost 50% during waking life. Gained empirical results revealed that mind-wandering may be a cause for unhappiness. One study showed that people tend to be unhappier when their minds are wandering [12]. This may be the case because being not in the "here and now" can lead to negative feelings as one tries to grasp something, which is not even there, and thoughts become entangled. One major point in many philosophical and religious traditions is that happiness is to be found by living in the moment [12]. Being in the past or in the future with thoughts can lead to worries, fear or anger. Meditation tackles this problem at the root. The target of this mental training is to stop the mind from wandering by means of gaining control of the drifting attention. Therefore, regulation of attention in different ways can be applied in order to be more focused and prevent the mind from wandering in a sustained manner, which is also a prerequisite for happiness.

4.2 Diversity of meditation practices

As mentioned above, many different meditation types exist. Besides their peculiarities, the manipulation of attention can be seen as a key theme throughout all kinds of practices. This following overview is intended to give concise insight into some of the common meditation practices.

Zen meditation

There are two major forms within the tradition of Zen meditation, namely Rinzai and Soto Zen. In both types, the initial focusing of attention one's breath is a key element in reaching a first level of concentration. After such a state has been attained, an advanced level of meditation should be reached. In the Rinzai Zen tradition, practitioners have to concentrate on so-called koans, which are riddles and not solvable with pure knowledge or thinking. Instead, koans should help the meditator to gain access to pure awareness of the present moment. Koans are given to Zen students by their teachers and vary according to one's level of practice, experience and personality. The student is then instructed to meditate until the riddle is solved. Finally, the solution is presented to the teacher and a new koan is given.

The other form of Zen meditation, Soto Zen, is related to mindfulness and open awareness meditation. Here, practitioners should observe their thoughts and emotions as they arise in their minds without having any attachment. Meditators should not cling to them, but should be purely aware of the sitting process. Distracting thoughts should be given up when they arise and attention must be brought back to the present moment [6].

Vipassana meditation

During Vipassana meditation, practitioners start to observe their breath around the area of their nostrils, which should help to stop the mind from wandering. Subsequently, the mind becomes calm and a state of sustained, focused attention can be achieved. When the mind starts to wander, meditators are instructed to bring attention back to the sensation of breathing. As the meditation session proceeds, attention becomes more and more focused. When a certain level of attention is reached, practitioners must mentally scan each part of the body and feel the sensation in each of these respective body parts. Attention is to move from the head down to the toes and then back up again in reverse manner. The aim is to keep attention moving with equanimity through each part of the body. No feelings of aversions or cravings of specific sensations should be developed. This type of meditation can be seen as a good example in which focused attention and open monitoring meditation are both contained and combined [6].

Mantra meditation

Mantra meditation is a very popular and widespread form of mental training, present in many meditation traditions. Many types of mantras exist and can be comprised of a religious or mystical sound, a word or a poem. During mantra meditation, practitioners are instructed to recite this mantra, either aloud or mentally. During this process, all attention is focused on the recitation or on the meaning of the mantra. Body vibrations, which a mantra induces, are believed to calm the mind and body, without any other intense concentrative efforts. Some of these practices also involve mantra repetition with or without awareness of the breath. If phases of mind-wandering occur, attention has to be brought back to the mantra [6].

Loving-kindness meditation

The goal of compassion or loving-kindness meditation is the generation of compassion towards oneself and all living beings and is a common practice in Tibetan Buddhism. The state is described as an unrestricted readiness and availability to help living beings. A session begins with the visualization of a respected, a beloved and a neutral person. This should evoke feelings of compassion for each person. The focus should then broaden to all living beings in everyday life. It is believed that the cultivation of compassion creates a general sense of well-being and prevents the rise of feelings of anger or irritation [6, 8, 13].

Transcendental meditation

The aim of transcendental meditation is to calm and transcend the ongoing stream of internal mental dialogue. Similar to the mantra meditation type, the repetition of a mantra plays a key role in transcendental meditation and is intended to help quiet the ongoing stream of thought. The meaning of the mantra itself is not important, instead, the sound, which occurs during reciting, takes the place of significance. All attention should be absorbed by the sound in an easy and automatic manner. The sound occupies all awareness during the meditative practice. This state should be maintained without any concentrative effort. Finally, the development of a witnessing, thought-free, "transcendental-awareness" is emphasised. This sensation induced by the sound of the chanted mantra should finally lead to a deep relaxation and a state of "pure consciousness" [4, 14].

4.3 Two major styles of meditation

A common key element, which can be found throughout different meditation practices, is the regulation and the manipulation of attention. Depending on how attention is regulated, practices can be classified into two major subgroups, namely, focused attention and open monitoring meditation, which are roughly related to Samatha and Vipassana, respectively [3]. These two styles are explicitly designed to improve specific cognitive processes [3, 15] and are sometimes combined either within one single session or function as specific parts of an entire meditation practice. They can be found in several meditation traditions such as Vipassana, Zen and Tibetan Buddhism. Further, it is not easy to classify a certain meditative practice as purely focused attention or as open monitoring meditation because the two styles often overlap in their approach towards similar goals. Generally, the first type requires a narrowing of the attentional focus, whereas during the second type, a state of open perceptivity has to be maintained [4].

Focused attention meditation

Focused attention meditation can be seen as a form of concentration practice. Here, all attention is focused in a sustainable manner on a specific object. The object on which the attention is focused can vary, but common themes include focussing on a sound, an image or a bodily sensation. When the mind becomes distracted and starts to wander – a normal process for novice meditators – attention has to be brought back onto the initial object of choice. This can be accomplished by detecting the wandering mind, disengaging attention of distracting thoughts and redirecting attention back onto the prior object. During the practice of this type of meditation, it becomes easier over time to sustain a high level of attention, which should lead to an effortless sustainment of attention after several years of practice. This specific practice develops certain skills, essential for attention. The monitoring faculty perceives distractors, but remains focused on a specific object without destabilisation and if distraction occurs, disengaging from a distractor without any further involvement will be facilitated. Finally, the ability to redirect focus onto the initial object is achieved [3].

Open monitoring meditation

The second type of meditation is also referred to as mindfulness meditation [4]. Open monitoring meditation shares various core features with focused attention meditation, especially the initial use of the focused attention technique to calm the mind in order to reduce distractions. When a certain state of concentration is reached, the practitioner has to gradually reduce the focus placed on the explicit object and then emphasise open monitoring meditation [3, 15]. During this kind of meditation, no explicit focus on an object or an activity should be achieved. This form of meditation is characterised by a non-reactive and non-judgmental monitoring of the content of the actual experience from moment to moment, including perceptions, sensations, cognitions and affects [3]. That means, whatever appears in consciousness will be observed, but without any attachment. The aim is to cultivate a state of reflexive awareness. This is a state in which the mind becomes aware of its own processes. Essentially, the aim is to become reflectively aware of the nature of emotional and cognitive patterns [14]. Mindfulness is often described as a state, where the practitioner is fully present and alive in the moment [16].

4.4 History of scientific research on meditation

The history of scientific research on meditation dates back to the middle of the 20th century. In these early attempts, different groups – especially from India, the United States, Japan and South Asia – have been observed. These practitioners under investigation came from different meditation schools, like Yoga, Transcendental Meditation, Zen and Tibetan Buddhism [8]. The first studies were conducted in Asia in the 1950s with advanced yogic practitioners from India [17] and later with advanced Zen meditators from Japan [18]. Several studies were performed during the following decades, whereby in the late 1990s, a widespread interest in the neuroscientific study of meditation arose. This entailed the exploration of a broad range of meditation practices. Not only were advanced adepts measured, but also novices and patients. Academic research institutions started to express an interest in the research of meditation and meditative practices like Yoga and Mindfulness-Based Stress Reduction (MBSR) were introduced into the medical environment. This led to a rising interest from clinicians in the influence of meditation on the brain and the body in general. [8]. Despite this long history, no clear generic consensus about the underlying neurophysiological changes from meditation practice have yet emerged [4]. Nevertheless, more than over 2,000 scientific studies containing the term meditation have been published and several meditation-responsive variables that range across psychological, physiological and chemical parameters have been identified [6]. The overall aim of this research endeavour is to understand how mental training affects and influences the brain, the body and overall health [9].

Today, the scientific study of meditation is a vivid field of research and interest continues to rise, which is not merely a coincidence. Recent developments in cognitive science led to the viewpoint that first-person experience and consciousness are essential entities, indispensable for an integrated scientific investigation of the mind. Due to the fact that meditation entails the fostering of altered mental states, it can play a valuable role and help to gain new insights. This already mentioned opinion of the importance of first-person experience known as introspection did not arise from nowhere, but was kept under wraps and only reanimated during the last decades.

At the end the 19th century, experimental psychologist, William James, and philosopher, Edmund Husserl, emphasised the importance of subjectivity and introspection while studying subjective mental phenomena. For James, one of the founding fathers of American psychology, the purpose of psychology was to study mental events as experienced in the first person perspective and to examine how mental states are related to objects, brain states and the environment. For him, introspection meant to look into one's own mind and to report what is discovered, namely, different states of consciousness [19]. Later, in the early 20th century, with the rise of behaviourism, subjective and private experiences were strictly rejected following the explanation that no objective observations can be made. The mind was only studied by investigating behavioural responses to certain presented stimuli. All mental phenomena were only investigated by their observable consequences in the world. With the appearance of the cybernetic movement in the middle of the 20th century and the birth of cognitive science, the brain was now conceived as an information-processing unit and computers were used as models for the mind. Overall, the agenda of psychology at that time was to objectify the mind as much as possible. It was conceived as a behavioural performance, a physiological response, or with the occurrence of cybernetics and cognitive science, as a non-conscious information processing system [20]. This cognitivist paradigm was prevalent in cognitive science up until two decades ago. The study of consciousness became a red rag and the method of introspection was vehemently rejected and not believed to be a proper tool for the investigation of the mind. There were, however, some exceptions, like Gestalt psychologists and phenomenological philosophers such as Merleau-Ponty, who tried to attempt more subjective approaches to the mind. As is such, this reductionistic view of cognition and the "taboo of subjectivity" had a severe effect on cognitive science and influenced the study of the mind in a sustainable manner [6, 21]. However, in the last two decades, reconsideration of the value and importance of first-person experience in cognitive science has been introduced by Damasio [22] and Varela, Thompson and Rosch [23] in the proposal of the embodied approach. This encouraged the reconsideration of first-person experience in cognition. It states that first-person experience is a crucial element for the investigation and the understanding of the mind. Further, in recent years, various cognitive scientists postulated the opinion that there is no complete science of the mind without taking subjectivity and consciousness into account. With this renaissance of the first-person approach, scientists claimed that it is essential to make systematic use of introspective first-person reports about subjective experience [24]. With this in mind, in 1996, Varela introduced the concept of "Neurophenomenology", which tries to combine subjective experience with neurophysiological evidence [25]. This idea was crucial in taking meditation into account for scientific investigations.

4.5 Meditation and the neurophenomenological approach

The approach of neurophenomenology stresses the importance of combining quantitative third-person measures of neural activity with first-person data gathered from phenomenologically well trained subjects [25, 26]. Due to the combination of these two realms of observation, this research programme aims to shed full light on the mind via a quantification of physiological processes relevant to consciousness [3]. The use of introspective reports detailed first-person data are thought to be a crucial and indispensable element for the understanding of the neural correlates of mental phenomena. The endeavour of neurophenomenology claims that subjects are able to generate and describe specific and stable experiential or phenomenal categories. This gained data can help to detect and to interpret certain neural processes, linked to concrete phenomenological experiences.

How this neurophenomenological approach can be employed has been shown in a study by Lutz et. al. in 2002. In this experiment, a quite easy visual protocol was used in combination with naive subjects. On the first day of the experiment, participants were trained to become aware of the fluctuations of their cognitive experience from trial to trial, as defined by their attentive state, spontaneous thought processes and the strategy used to carry out the task. During the visual task, electrical brain activity was recorded and self reports of cognitive context were reported. After the recordings were taken, trials were clustered according to the gained-first person data. For each of these clusters, characteristic patterns of synchrony over frontal electrodes were found, which was then correlated with the stability of attention and task preparation. Researchers found a correlation between synchrony patterns and ongoing experienced conscious states. This illustrates paradigmatically how information on inner phenomenological experience can guide the study of brain dynamics [27].

Although first-person reports are a valuable source and a central element of the neurophenomenological approach, people vary drastically in their ability to observe and report mental states, leading to biased or inaccurate introspective reports. However, it is assumed that these abilities can be enhanced and improved through mental training, where attentional and emotional processes are observed and regulated. Therefore, long-term meditators are a reliable source and can further help to refine this research strategy [28]. Precise and rigorous first-person methods, such as meditation, can help in this case to obtain very reliable high-quality reports of inner experience, which should also help to improve the neurophenomenological approach. It is thought that these practitioners are able to generate more stable and reproducible mental states than untrained individuals, since Buddhist meditative practitioners are skilled in cognitive and emotional training, like the cultivation of a sustained, attentive awareness of the context of ongoing experiences [20, 26]. Further, practised person are better in describing these states more accurately and provide more refined phenomenological reports compared to other subjects. These trained introspective skills from versed subjects can help to gain more reliable results while mapping the two realms of introspection and neuroscience, which is in line with the neurophenomenological approach. Moreover, it is hypothesised that the correlations between phenomenological reports and simultaneously measured brain activity is stronger for long-term meditators due to their skill in reporting precisely the content and processes of their mind [3]. The use of Buddhist meditative techniques for the development of rigourous first-person phenomenological methods is related to the introduction of the enactive approach to cognition and neurophenomenology. In general, Buddhist practices play a central role for enactivism, which was proposed in 1991 by Varela, Thompson and Rosch [23]. Following this conception, cognition can be seen as a process, emerging from the dynamic interactions between the brain, body and environment. Phenomenological descriptions should be incorporated in this approach to deliver a description of experience in relation to its intersystemic complexity. Mindfulness meditation seems to be an especially adequate tool for the analysis of experience following this paradigm. Neurophenomenology means that phenomenological accounts, like human experience and scientific accounts of cognitive processes, can benefit from each other and bring new insights to the study of the mind. Buddhists can help as a result of their contemplative mental training and critical phenomenological and philosophical analysis of the mind. Neurophenomenology depends on subjects with contemplative and phenomenological expertise. Their expertise could play an active and creative role in the neuroscientific study of consciousness [20]. The meditative process underlying most Buddhist meditation traditions of developing insight (vipassana) by calming the mind (samatha) via practicing mindfulness can be seen as an ideal framework for the analysis of experience. This process allows the mind to be present to itself. Such a method of mindfulness, where mental refinements take place, is important because it emphasises the maintaining of a continued mental stance of non-abstracted awareness. One becomes aware of actual experiences, finally leading the mind to control its hasty nature. The meditator tries to return to the present experienced moment, which leads to a taming of the mind's restlessness and finally leads to a state of pure awareness. For Varela, Thompson and Rosch, the Buddhist concept of mindfulness meditation delivers an ideal pragmatic discipline for an adequate observation of the ongoing mental processes in one's mind. It takes a look at experience as it occurs and neglects the abstract attitude. Mindfulness brings one closer to the actual ordinary experience rather than further from it. They are arguing for a change in the nature of reflection from an abstract, disembodied activity towards an embodied (mindful), open-ended reflection, where reflection is a form of experience itself. During this open-ended form of reflection, the chain of habitual thought patterns and preconceptions are cut. The importance of taking mindfulness meditation into account is its disciplined experiental analysis by reaching a de-abstracted or pre-theoretical mode of experience. Simultaneously, experiental awareness is enhanced due to the suspension of habitual mental acts of interpretative abstraction. Finally, the focus of attention should lie on the experience of the unfolding content of the lived experience itself [23].

4.6 Meditation and the neuroscience of consciousness

The approach of neurophenomenology provides important and crucial data for the study of consciousness. Further, long-term meditators are preferred subjects for this endeavour. This "first-person expertise", which is provided by these subjects to identify neural counterparts of subjective experience, might even be able to shed light on the neural correlates of consciousness. Due to long-term mental training over several years, experienced meditators are able to induce a wide variety of altered states of consciousness and it is claimed that meditation can reveal and will contribute to the general understanding of its neural basis. There are without doubt several other areas, where the integration of experienced meditators can be made fruitful. Lutz and colleagues claimed that there are three specific areas for the neuroscience of consciousness, where experienced meditators can provide their expertise, namely (a) in the identifying of the physical substrate of subjectivity or the self, (b) in identifying and understanding the physical principles underlying the emergence of coherent conscious states from unconscious brain processes (c) and the functional role of the spontaneous brain baseline [8].

<u>Studying the substrate of subjectivity</u>

Every study involving consciousness needs to define the actual entity, exhibiting this conscious experience, namely the self. An important point in bringing Buddhist practices and the neuroscience of consciousness together is the interest in understanding the nature of the self, whereby in both approaches, a certain distinction can be made between a minimal subjective sense of ipseity and a narrative or autobiographical self. In taking this distinction for granted, the former can be seen as a reflexive self-awareness and can further be defined as the minimal subjective sense of "I-ness" on which the narrative self is based on. Conversely, the narrative or autobiographical self comprises the anticipation of the future or the recollection of the past and occurs with its explicit content, or object of experience. In phenomenological terms, experiences can be seen as either transitive or intransitive modes of consciousness, whereby transitivity means that the experience refers to its intentional object

[29]. At the same time, the experience also exhibits an intransitive aspect, where the experience is reflexively manifested to itself. The intransitive aspect of a conscious experience is passive in a sense that it is involuntary and spontaneous. It occurs simultaneously with the awareness of the object meaning that no act of reflection or introspection is required [30].

Both transitive as well as intransitive aspect of consciousness can be part of the neuroscientific investigation of experience. The question is how the brain produces the manifold mental images in conscious experience and how it produces the self in the act of knowing. Experienced meditators may help in the investigation of these two types of phenomena. Hence, the best approach is to start with the easiest form of a conscious state capable of being reduced to ipseity. One strategy would be to tell meditators to induce a state in which ipseity is emphasised and the narrative self is switched off. In this state, just the basic tacit sense of reflexive self-awareness would be intact, leading to the neural correlates of bare subjectivity and selfhood [8]. Meaning that in an experiment, containing a practical method where the narrative self and this more basic sense of reflexive self-awareness can be distinguished phenomenologically, meditators would be the most appropriate subjects for distinguishing between these two types of consciousness.

A study conducted by Farb in the year 2007 attempted to show how to account for these two distinct forms of self-awareness. They compared the neural activity of subjects, who participated in an eight week mindfulness meditation training with subjects, who had no such training. Two tasks were designed, with one evoking a narrative-based self-focus and the other an experientially-based self-focus. Results suggests that these two distinct kinds of self-awareness that are habitually integrated, but can be dissociated through the training of attention exhibit fundamental neural dissociation. There is both a higher order of self-reference, characterised by neural processes, which account for an awareness of a self extending across time and a more basic momentary self-reference, characterised by neural changes representing the awareness of the psychological moment [31].

Studying the substrate of consciousness

It is hypothesised that only a selection of specific neurons in the brain gives rise to a conscious experience in a single moment of time [8]. If a stimulus is phenomenally reportable, it is thought to be a result of translocal, large-scale mechanisms that integrate local functions and processes. In this regard, studies suggest that neural activity crucial for consciousness can be seen as a transient and continual orchestration of scattered mosaics of functionally specialised brain regions [8, 32, 33]. This hypothesis was substantiated by the application of a so-called binocular rivalry paradigm. Subjects are presented with two competing dissimilar images, each for one eye. Due to the alternating switching of perception, the observer reports the experiencing of only one picture at a time, whereby the dominant picture alternates every few seconds. It has been shown that this paradigm is one of the most important experimental paradigms for the investigation of the neural correlates of visual experience because even though the presented stimuli stay constant, the conscious content alternates. Therefore, it is possible to observe the cerebral activity caused by the dominant image and some seconds later also the neural activity, which occurs when the very same image is no longer phenomenologically accessible in consciousness [33].

In this respect, a study published in 2005 showed that meditation practice can alter perceptual rivalry. Carter and colleagues showed that highly advanced Tibetan Buddhist meditators are able to decrease the "perceptual switching" rate drastically in a state of "single pointed" meditation. Curiously, some meditators were able to maintain the stability of one single percept throughout the entire meditation session of five minutes. Researchers pointed out that these results were in contrast to the 1,000 meditation-naive subjects tested prior to the meditators. This indicates that meditation may alter perceptual capacities [34].

Besides these results gained via the binocular rivalry paradigm, meditators exhibit additional beneficial properties, relevant to the study of consciousness. Due to the fact that long-term meditators are trained to examine, modulate and report their experience, these subjects may provide a valuable heuristic for the study of large-scale synchronous brain activity underlying conscious activity in the brain. It is hypothesised that they are able to produce, constantly reproduce and to describe particular mental states more accurately than untrained subjects. Furthermore, they show strong experimental control over subjective states, the stability of their states is greater and they are able to deliver precise descriptions of their own experiences. All these versed properties of introspective skills could support the experimenter in better controlling, identifying and interpreting the large-scale integrative processes in combination with the subjective experience [8].

Meditation and physiological baselines

The aim of every meditation practice is to induce specific kinds of changes. These changes can be seen as long-lasting alterations in the experience of the practitioner and vary in their appearance according to the type of practice and also to the time, dedicated for such mental training across one's life span. These developments, mediated by meditation can now be seen as a change or alteration of a physiological baseline. A baseline change is perceived as an indicator of a physiological change in the form of a state or a trait effect. The characterisation of baselines before, during and after meditation is thought to be a legit way to observe the putative physiological effect on the body. Hence, long-term meditation changes the way the world is experienced and perceived, as indicated by the shift of a certain baseline. As a trait effect, meditation should have a long-lasting influence on the baseline of the meditator, even when the practitioner is not in a state of meditation. A certain state should be cultivated, which becomes finally a trait of character. As is such, specific qualities or features should be cultivated and endure over time. These gained properties through mental training should then be relatively independent of changes in the environment, meaning that these achieved qualities become lasting traits. Different types of practice are responsible for different types of baseline changes. Essentially, an open presence form of meditation, were increased awareness should be cultivated, leads to an altered baseline of awareness, which also applies to other types of meditation, like compassion or mindfulness meditation. The former type of meditation is thought to weaken egocentric traits, leading to a change in the emotional baseline, whereas the practice of mindfulness meditation, where the experience of the present moment is emphasised, has an influence on the attentional baseline in the form of, for example, lessening distractors or daydream-like thoughts [8].

4.7 State versus trait effects

The neuroscientific study of meditation is based upon the premise that different conscious states are accompanied by different neurophysiological states and that meditation practice results in short-term as well as long-term effects. The aim of almost every meditation practice is to achieve altered mental states and traits. Essentially, putative effects should not only occur during the meditative session but should finally lead to observable long-lasting effects.

State effects are short-term changes, induced during the meditation state and refer to altered sensory, cognitive self-referential awareness, which includes a deep sense of calm peacefulness, leading to a cease of the ongoing inner mental dialogue. Furthermore, it is reported that phases of perceptual clarity and conscious awareness merging with the object of meditation along with all arising thoughts and feelings are just observed as an arising phenomenon instead of occupying the full attention of the person. In some cases so-called peak-experiences are reported, which are characterized by blissful absorption in the current moment.

Trait effects are long-term changes due to extensive practice of meditation. These changes mature with the grade of experience and are even observable when the mind is not actively engaged in meditation. Trait changes entail a deepened sense of calmness, an increased sense of comfort and a sense of heightened awareness [4]. It is thought that the study of state changes is relevant to the research on consciousness due to the possibility of exploring the effects of meditation itself on the brain. Studying the trait effects of meditation, however, helps to shed light on the beneficial effects on health and general well-being, which is of interest while introducing meditation practice in clinical applications [6]. Every neuroscientific study of meditation has to be aware of this distinction between state and trait effects and the study design has to be devised accordingly. Lutz and colleagues [13] designed a study where both effects could be observed. In this experiment, high-amplitude gamma-band oscillations and phase-synchrony in long term practitioners during meditation were observed. These EEG-patterns differed from those of controls, especially over lateral frontoparietal electrodes. In addition, the ratio of gamma-band activity (25-42 Hz) to slow oscillatory activity (4-13 Hz) was initially higher in the resting baseline before meditation for long-term meditators than for the controls over medial frontoparietal electrodes (Trait-effect). This difference increased sharply during meditation over most of the scalp electrodes and remained higher than the initial baseline in the post-meditation baseline (State-effect). Hereby, results of the data showed that meditation involves temporal integrative mechanisms, resulting in short-term and long-term neural changes.

4.8 Event-related potentials

4.8.1 Continuous EEG

ERPs are measured by using EEG. The first continuous EEG-measurement of a human brain was taken by Hans Berger in 1924. He reported the occurrence of several different brain rhythms and published his results in 1929. Berger showed that closing the eyes decreased the sensory input and increased alpha activity, especially over the occipital scalp. Furthermore, he characterised wave patterns, including alpha and beta waves, and coined the term "electroencephalogram" [35]. After these initial observations, oscillatory patterns, have been studied and characterised as well as mapped to certain mental states, such as sleep, the waking state, vigilance or to mental pathologies, such as epilepsy. Since the 1950s, electrophysiological measures of the brain were the most popular procedure into studying the influence of meditation on the brain. The electroencephalography method is a non-invasive technique that measures the electrical potentials on the scalp. Electrodes detect mostly post-synaptic activity of neurons in the neocortex. When a bigger population of neurons oscillates at the same frequency with a common phase, their local electric fields add up and produce a burst of oscillatory power [36]. This signal is then measured by an electrode, amplified and recorded. The EEG is known for its high temporal resolution in the range of milliseconds. This allows the investigation of the fine temporal dynamic of neural processes. In general, EEG signals are divided into different frequency bands (delta < 4Hz, theta 4-8Hz, alpha 8-12 Hz, beta 12-30 Hz and gamma > 30 Hz). The synchronization or desynchronization within these different frequency ranges allows one to characterize different mental states. Synchronization means that numerous populations of neurons fire their action potentials at the same time with a precision within the millisecond range. Short-range and long-range synchronization exist. The former indicating that synchronization over a small local network has occured, whereas the latter refers to a synchronization of different population of neurons, which are farther apart from one another [8].

4.8.2 Historical considerations

Event-related potentials (ERPs) are neural responses, elicited by a specific cognitive, sensory or motor event [37]. In other words, an ERP can be defined as an electrophysiological reaction of the brain to a certain type of stimulus[1]. ERPs stand in contrast to continuous EEG measurements, where brain wave patterns are under observation and the oscillations of neural populations over time are of interest. In the beginning of ERP research, all these obtained potentials were called evoked potentials (EPs), which indicates only the processing of the physical stimulus without the involvement of higher cognitive functions. The term ERP was initially introduced by Vaughan in the late 1970s [38], as he supported the hypothesis that the term "evoked potentials" is not accurate for all observed potentials. He came up with this more general expression to account for all the psychological events responsible for certain potentials. Today, this term is widely used in the neuroscientific community, whereby ERPs come in several variations and significantly differ from each other regarding their modality. In contrast to the conventional continuous EEG measurements, ERPs are time-locked and only observed over a short period of time. Only the immediate reaction of the brain to the presented stimulus is under observation. The occurrence of an ERP is quite short and is within the millisecond range. By averaging all the obtained EEG signals it is possible to extract these distinct electrical potentials from the brain associated with specific events [37]. Standard ERP techniques have been developed as early as the 1960s and due to the rise of cognitive neuroscience and the decline of computer prices in the 1980s, ERP measurements have become popular on a larger scale; although, the history of this technique dates as far back as the first third of the 20th century. Initial ERP recordings of humans were taken during the 1930s and published a few years later [39]. This research was done long before computers were available to record these signals. Nevertheless, researchers were already able to detect ERPs. During the 1950s, researchers focused predominantly on sensory issues, whereby occasionally the effects of top-down factors on sensory responses were under investigation [37]. A modern era of the observation of event-related potentials began in 1964. The first observed cognitive ERP component was the so-called contingent negative variation (CNV). In one of the first studies, researchers demonstrated that there are consis-

[1]These stimuli, which evoke ERPs can be presented to different senses. Hence, ERP responses can be either auditory, visual or olfactory.

tent patterns to the amplitude of electric responses, which can be obtained from the large background noise, occuring in EEG recordings [40]. In this study conducted by Walter et. al. in 1964, subjects were confronted with two types of stimuli. The first one was a warning signal in the form of a click followed half a second or one second later by a target stimulus. When there was no task imposed, researchers measured the expected sensory ERP responses elicited from each of these two stimuli. Following, researchers prompted their subjects to press a button upon target detection. This imposed task led to a large negative voltage over frontal electrode sites between the period of the warning click presentation and the target signal. This negative voltage in the form of a CNV turned out to be not just a sensory response; instead, it was assumed that it indicated the cognitive preparation of the subject for the upcoming target signal and that negative activity can be related to a cognitive process, such as expectancy. This new finding led to increased research focusing on cognitive ERP components. The next major step was the discovery of the famous P3 component by Sutton et. al. [41]. In this groundbreaking paper, researchers showed that when subjects were uninformed about the nature of the upcoming stimulus[2], a large positive P3 component could be observed, with a peak around 300ms subsequent to the stimulus presentation. Also demonstrated was that the amplitude of the component was much smaller when the nature of the stimulus was predictable. These discoveries led to a boom in ERP research over the following 15 years, where attempts were made to identify various other cognitive ERP components. At the same time, firm methods for recording and analysing ERPs were developed. During this period, research was mostly occupied with the discovery and the understanding of these ERP components rather than addressing questions of broad scientific interest as related to this method. This was beyond doubt necessary, however, during the late 1970s and early 1980s, the ERP technique gained a bad reputation amongst cognitive psychologists and neuroscientists, due to this confined orientation of ERP research. Nonetheless, this orientation changed after several years and ERP researchers started to address questions of broad scientific interest, leading to an improved reputation, which became even more popular in the mid 1980s. Even during the introduction of high spatial resolution techniques – PET and fMRI – into the neurosciences, ERP research was still a popular method. Due to the high temporal resolution of the ERP technique, it became an important complement to PET and fMRI, which are not able to hold pace on the temporal scale [37].

[2]Subjects did not know if upcoming stimulus will be a visual or an auditory one.

4.8.3 Neural bases of ERPs

Two main types of electrical activity are associated with neurons, namely action potentials and postsynaptic potentials. Action potentials are signals in the form of voltage spikes that travel down the axon. They are generated at a region next to the cell body, called the axon hillock. If a neuron becomes depolarized – meaning that the voltage level reaches a certain threshold – an action potential is generated and travels straight down the axon to the synapse, where the release of neurotransmitters into the synaptic cleft is initiated. These neurotransmitters bind at the receptors of the postsynaptic neurons, which leads either to the opening or the closing of ion channels. This process is responsible for the changes in postsynaptic potentials, resulting in the entire potential along the membrane to be altered. With surface electrodes used in the EEG, it is not applicable to measure action potentials due to their timing and the physical arrangement of axons. Instead, postsynaptic potentials are easier to measure because they are confined to a certain space at the dendrites and the cell body. These potentials summate and can be measured over a greater distance at the scalp. How ERPs exactly emerge is not yet fully understood. However, it is hypothesised that when an excitatory neurotransmitter binds at the dendrites of a postsynaptic pyramidal cell, current flows into the cell, which leads to a net negativity on the outside of this cell in the region of the apical dendrites. In addition, current also flows outside to other parts of the neuron, like the cell body or the basal dendrites, meaning that this area of the extracellular space becomes positive. Due to the negativity at the apical dendrites and the positivity at the cell body and basal dendrites, a small dipole[3] occurs. It is not possible to detect one single dipole via a scalp electrode; instead, millions of neurons have to fire in a compound, resulting in the summation of their dipoles and thus, enabling the measurement of the resulting voltage with the scalp electrode. As a prerequisite, they have to fire almost simultaneously and the dipoles of the single neurons must be spatially aligned, otherwise dipoles cancel each other out. The same applies for the neurotransmitters. If one neuron receives an excitatory neurotransmitter and the other one an inhibitory neurotransmitter, cancellation occurs. In the ideal case, neurons have the same orientation and receive the same input. In this scenario, dipoles summate and the resulting voltage is measurable at the scalp. Pyramidal cells are aligned in a perpendicular way to the surface of the cortex, making it quite easy to measure their summed dipoles. The summation of many individual dipoles is equivalent to a single dipole, by averaging the orientation of the thousand of individual dipoles. This averaged single dipole is also called an ECD, which stands for equivalent current dipole. Single dipoles, which are more than 90 degrees from each other, will cancel out to some ex-

[3]A dipole is a pair of positive and negative electrical charges, which are separated by a small distance.

tent, whereby an entire cancellation occurs at 180 degrees. At times, the cortex has many folds, like in the case of the cerebellar cortex. Here, cells are aligned perfectly and also oriented perpendicular to the surface of the cortex. However, it is almost impossible to record cerebellar activity from the scalp. The surface is so extremely folded that dipoles will almost always be cancelled out by oppositely oriented dipoles [37].

4.8.4 ERP characteristics

An ERP waveform consists of several components comprised of positive or negative voltage deflections observed at a distinct point in time. ERP components have certain labels, such as P1 and N1, which indicate the polarity of the amplitude and the position within the waveform after stimulus onset. P1, for example, stands for the first positive and N1 for the first negative peak of the overall signal. At times, the number after the polarity (P/N) indicates the latency in milliseconds instead of the position. Therefore, N100 reflects a negative component with a maximum peak 100 ms after stimulus onset. This latency is quite coarse and can vary in each experiment. One has to be careful regarding these designations because they are not firmly linked to certain underlying brain activity. Meaning, sensory components from different modalities (visual/auditory/olfactory), which exhibit the same labels, are not related in any functional manner. P1 elicited by an auditory stimulus is not the same as a visually evoked P1 component. They only exhibit the same polarity and order within the respective waveform, but have no functional correlation; whereby, some late components, such as P3, are more or less modality-independent, but can have modality-specific subcomponents. Beyond that, even when a single modality is given, a certain ERP component may be different from one experiment to another [37]. Due to the nature of the conducted experiment within this thesis, the emphasis lies on auditory evoked (event-related) potentials.

Figure 1 shows the variety of brain potentials that can be observed after auditory stimulus presentation. In general, there is a basic discrimination between two major kinds of potentials. While evoked potentials (EPs) reflect an automatic processing of the presented stimulus during repetitive sensory stimulus presentation, event-related potentials (ERPs) are only measured when cognitive task processing is involved [4]. These different responses are further divided into subcategories regarding their latencies. The brainstem response occurs in the first 10 ms and comprises the early-latency EPs, which reflect initial sensory processing. These so-called BAEPs[4] consist of seven positive waves I-VII with small amplitudes, which are recorded from the scalp after click presentation and arise from various

[4]Brainstem Auditory Evoked Potentials

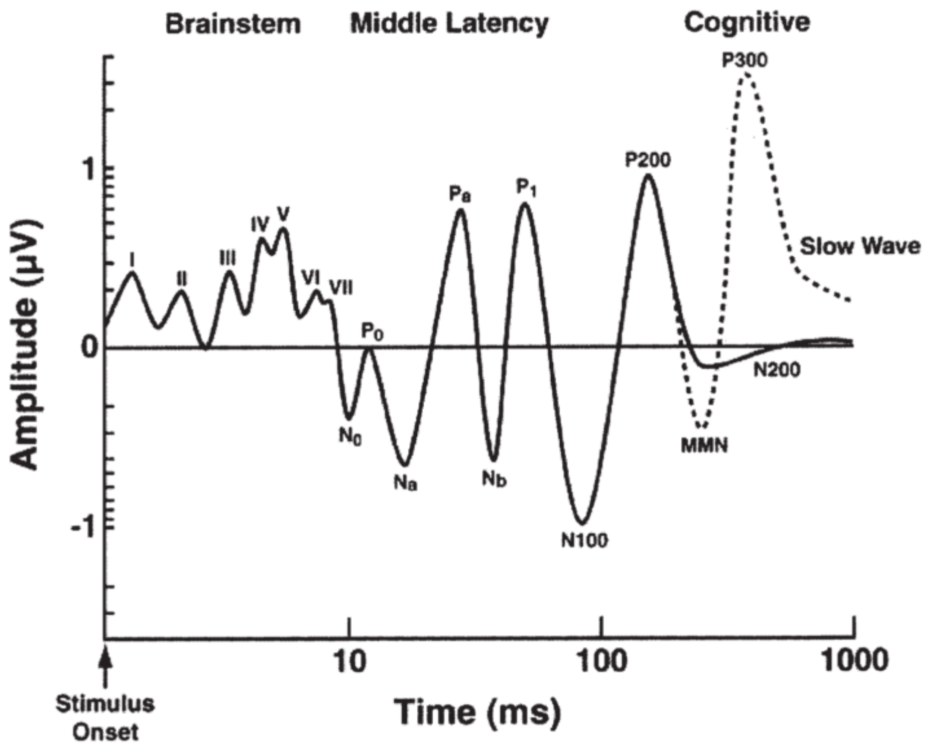

Figure 1: This picture shows evoked (EPs) as well as event-related potentials (ERPs) after auditory stimulus presentation. Potentials are divided in brainstem, middle latency and cognitive components and are characterised by their amplitude and latency. For illustrative purposes logarithmic scales for amplitude and latency are used. Copyright Cahn and Polich 2006.

stages along the brain stems auditory pathways. BAEPs are used to study the functional integrity of the central auditory pathways and are applied in clinical settings. These potentials are followed by the middle-latency EPs, which can be observed between 10 and about 80 ms after the acoustic signal presentation, and reflect initial cortical auditory processing [4]. They are termed N0, P0, Na, Pa and Nb, whereby Na and Pa deflections are studied most often. They are also preliminary used in a clinical context. They are applied, for example, in the assessing of the hearing threshold in infants and children or for the identification of dysfunction in central auditory pathways [42]. Finally, slow or late EPs can occur from 50 ms onwards after stimulus presentation. These potentials can be divided into exogenous and endogenous components. Exogenous components, such as P1, N100 and P200, depend strongly on the properties of the external stimulus. They exhibit the highest amplitude over the vertex, but are generally widely distributed over frontal and central electrode sites and are thought to index primary auditory cortex activation. The most prominent component is the N100 potential, which already shows a sensitivity to attention [43]. These kinds of EPs are followed by endogenous components, such as the MMN[5] and the P300, which are more related to internal cognitive processes. The MMN is observed when subjects are presented a repetitive train of stimuli of the same type interspersed with infrequent mismatching stimuli. For example, when tones with a frequency of 500 Hz are presented constantly and suddenly a 1000 Hz tone appears a negative-going wave, which peaks between 160 and 220 ms can be observed. There are several other components, sensitive to mismatches. However, the difference to this mismatch negativity is that it is also observed when no task is imposed. It is thought that the MMN is related to automatic processes, that compare the incoming stimuli to a sensory memory trace of already presented stimuli [37].

4.8.5 The P300 component

The discovery of the P300 component spurred increasing interest in the use of ERP methods for the investigation of the neural underpinnings of cognition [44]. It has been shown that presented stimuli, when ignored by the subject, lead to a smaller amplitude or even lack of P300 response. Hence, it was assumed that active attention towards the target stimulus[6] is an essential premise for eliciting a prominent P300 potential. However, certain aspects remained unclear and researchers especially struggled with the fact that subjects exhibited a P300 signal even when they were instructed to completely ignore the target tone. This led to the assumption that the P300 is actually not a unitary phenomenon as it was initially postulated. The proof of such a hypothesis was first rendered by Squires and colleagues in 1975 [45]. They compared P300 signals, where active attention was paid to the stimuli, with conditions where subjects paid no attention at all. It turned out that these two P300 potentials differed in latency and scalp topography, leading to the insight that the P300 component consists of two distinct psycho-physiological entities. More specifically, it has been shown that when subjects were told to ignore the less frequent or rare tones, a positive-going potential, which occurred between 220 and 280 ms could be observed. This component was termed P3a in contrast to the positive-going potential that occurred at 310-380 ms, when subjects attended to the infrequent tones, which was termed P3b. They discovered a frontally maximal P3a component and a maximal P3b component on parietal brain sites. Both components were observed during the presentation of unpredictable and infrequent auditory stimuli, whereby the P3b component was only present when stimuli were task relevant [45, 46]. This led to a distinction between the P3a and the P3b component. The P3a is a positive-

[5] Mismatch negativity

[6] The P300 component is obtained by the application of a stimulus discrimination task, where the subject has to detect infrequent target tones in a series of frequent standard tones.

going scalp recorded brain potential with a maximum amplitude over frontal/central electrode sites and a latency between 220-280 ms [46]. It could even be observed when stimuli were ignored and when no attention was paid to the task. The P3a component is associated with brain activity related to the engagement of attention and the processing of novelty. It can be observed during orienting and involuntary shifts to changes in the environment [47]. Overall, it is hypothesised that P3a is an index for frontal neural activity with an anterior/central scalp distribution produced by stimulus-driven attention mechanisms. On the other hand, P3b indicates temporal-parietal activity associated with attention and seems to be related to memory processing. When the the stimulus is a rare non-target, the waveform has characteristics associated with the P3a, and if the stimulus is recognised as a target, a P3b is elicited. P3a peaks occur 75-100 ms prior to P3b and unlike the latter, P3a habituates with repeated presentations [44].

4.8.6 The oddball paradigm

In most of the studies, the P300 event-related potential is obtained by a stimulus discrimination task, which can be obtained across modalities [48]. In a so-called oddball paradigm, two types of stimuli are presented randomly with different probabilities of their occurrence. For example, target tones occur to an extent of 20%, whereas frequent non-targets show up 80% of the time. The task of the subject is to discriminate and identify the infrequent target from the frequent standard stimulus. This target stimulus detection can either happen by a button press or by mentally counting. The P300 component elicited by this kind of target stimulus detection exhibits a large, positive-going amplitude with a maximum over parietal electrode sites and with a peak latency that reflects the P3b component. It is thought that this brain potential reflects attentional resource allocation when working memory is engaged. In addition to the traditional oddball paradigm, a three-stimulus oddball paradigm can be applied. The setting in this paradigm is slightly modified in such a way that infrequent non-target stimuli are added to the sequence of target and standard stimuli. When these novel infrequent non-target stimuli are included in the stream of more typical target and standard stimuli, an altered P300 component can be observed, with a peak amplitude especially over frontal/central brain sites. This type of component, which is elicited when these rare non-target stimuli are presented, is also called the novelty P300 or P3a in contrast to the P3b, elicited by target stimulus presentation [44].

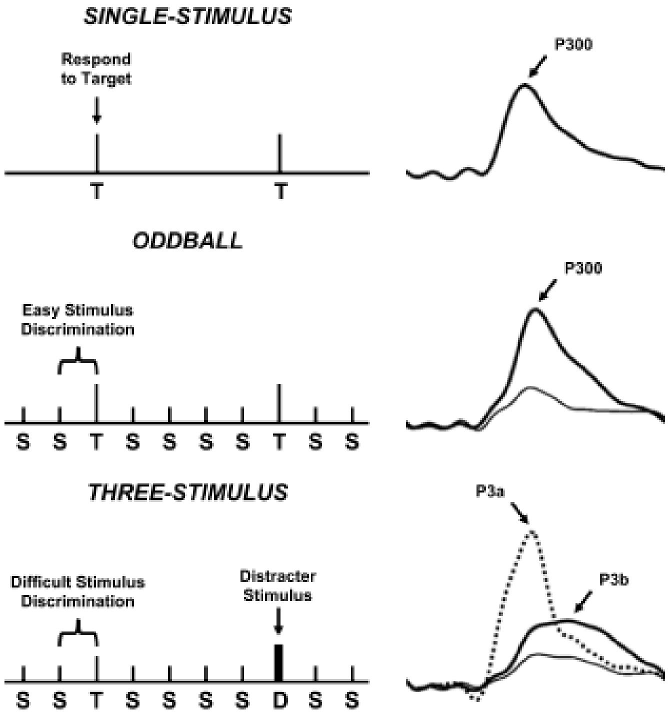

Figure 2: This figure illustrates the elicited ERPs (on the right) from a single-stimulus (top), an oddball (middle) and a three-stimulus oddball (bottom) paradigm. During the single-stimulus task only one infrequent target (T) is presented to the subject in the absence of any other stimuli. In the oddball task frequent standard stimuli (S) and infrequent target (T) stimuli are randomly presented. In the three-stimulus oddball task, an infrequent compelling distractor (D) is added to the sequence of standard and target tones, whereby the distractor elicits a P3a and the the target a P3b. In all three tasks, the subject was instructed to respond exclusively to the target stimulus. Copyright Polich 2007.

4.8.7 Theoretical aspects concerning the P300 signal

Habituation

Habituation and target discrimination are two main factors, which can influence the characteristic of the P3a amplitude. One difference between the P3a and P3b component is the fact that only the former habituates when the stimulus is repeated over several trials [49]. This habituation, where a certain stimulus no longer generates a response after several presentations, can be seen as an indicator that memory encoding for an event has occurred. Every time a novel stimulus is experienced, it is compared to already existing neural representations. When there is no deviation between the stimuli, then the neural representations are the same and this leads to habituation. This phenomenon is also explained by the "context-updating theory" [44]. When a presented stimulus enters the processing system, a memory comparison takes place and an evaluation occurs. It is detected whether or not the actual presented stimulus is the same as the previous presented stimulus. Essentially, when an oddball paradigm is applied, the processing system evaluates if the presented stimulus is a standard or target tone. If the stimulus is the same (e.g. target - target) the current mental schema of the stimulus context is maintained. In this case, only sensory evoked potentials like the N100, P200 and N200, are elicited. If the actual stimulus is different than the previous presented one, attentional resources are allocated to the target and the neural representation of the stimulus environment is changed or updated. In this case, a P3b potential will be generated in addition to the sensory evoked potentials.

Target discrimination

An additional factor with a strong influence, especially on the P3a amplitude, is target discrimination. Although the P3a amplitude is elicited by non-target distracting stimuli, the mode of the target stimulus also affects the P3a response. It is hypothesised that the P3a is altered regarding the individual ability of a person to distinguish the target from the standard stimuli. When the subject has no problems with discrimination, meaning the discrimination is easy, distractor stimuli produce a P300 smaller than the target P3b, which is largest over parietal sites. If the target discrimination is difficult, a larger P3a response occurs during distractor stimulus presentation [47]. Results suggest that when the perceptual discrimination between the target and the standard stimulus is difficult, an increased frontal/central amplitude for the infrequent non-target (P3a) and a parietal maximum for the target stimulus (P3b) is observed. This led to the idea that this distinction between P300 subcomponents occurs because of the stimulus context. Stimulus content and relative perceptual distinctiveness among stimuli affect the target as well as the non-target P300 amplitude, because each component is generated by different and distinct neural structures [46].

Other influences

Whether task conditions are demanding also influences the P300 component. If, for example, task conditions are undemanding, the P300 amplitude is hypothesized to index attentional resources in such a way that the amplitude is quite large and the peak latency relatively short. Therefore, if a task requires greater amounts of attentional resources, a smaller P300 amplitude with a longer latency will be observed because resources for processing are already used for task performance [49]. Oddball paradigms can be either active or passive. During an active paradigm, subjects have to, for example, count the target stimuli, whereas during a passive paradigm, no task is imposed. Passive stimulus processing produces a smaller P300 amplitude in contrast to the active task. This is the case because non-task related events engage attentional resources, leading to a reduction of the amplitude. The rapid amplitude reduction of the P3a during exposure to repeated trials of novel stimuli reflects the hypothesis that the P3a is the electrophysiological representation of the orienting response [50]. In this respect, a 3-stimulus oddball paradigm was conducted in which subjects listened to a condition, where the deviant stimuli were constant and to a condition, where stimuli were always novel. This led to the observation that the largest P3a occurred during the presentation of the deviant stimuli that were novel [51]. Although a great amount is known about what manipulations have which effect on the P300 amplitude and latency, not much is actually known about what neural or cognitive process the P3 wave reflects. However, it is known that the wave is sensitive to target probability. Hence, when target probability becomes smaller, the amplitude also becomes larger. This is not the only effect regarding this issue. When many non-targets were presented before the actual target stimulus presentation, the amplitude was also larger [37]. Although researchers have shown that P3a and P3b are two distinct phenomena, the amplitude and latency of P3a can be affected by factors that also modulate the P3b. These factors can be stimulus probability, stimulus evaluation difficulty, natural state variables, like circadian cycles, and environmentally induced state variables, such as drugs and exercise [52].

4.8.8 Meditation and ERP studies

The earliest EEG studies related to stimulus presentation suggested that meditation may induces "de-automization", in a way that each presented stimulus is perceived as fresh while engaged in forms of open monitoring meditation [18, 53]. This "de-automization" is related to alpha blocking,[7] where a decrease in ongoing alpha power (8–12 Hz) can be observed after the stimulus has been presented [4]. In this respect, experts of concentrative Yogic practices did not demonstrate alpha blocking to auditory clicks or aversive stimuli [54, 55]. Studies also showed that alpha power was less disrupted during meditation, when loud aversive stimuli were presented [56]. These results may indicate that long-term meditators exhibit changed neural attentional networks in a way that the brain is less activated by stimulation and less reactive to stimulus driven processing during meditation [5]. Many neuroscientific studies tried to assess the influences of different kinds of meditation by observing alterations in certain ERP components along the entire spectrum by applying different click paradigms. The earliest potentials to be observed after auditory stimulus presentation, are the brainstem potentials, which reflect initial sensory processing. Although it is thought that these potentials are not involved in attentional mechanisms, results showed that component number V latencies were affected by TM-Siddhi meditation, where special mantras where used to sensitise the auditory system [57, 58]. A study on middle latency potentials showed that meditators were able to produce a decrease in the Nb component after a phase of mantra meditation relative to the preceding resting period [59]. In addition, decreases in Na and Pa amplitudes could be observed during Qigong[8] meditation [61]. Decreases in Na peak latencies have also been reported during Raja yoga meditation [62], whereby it is hypothesised that this component is generated at the midbrain-thalamic level and that meditation may affect these early thalamic circuitries [4]. Studies also tried to assess alterations in long latency auditory potentials. Decreased P1, N1, P2 and N2 latencies have been observed for TM meditators compared to a control group, while auditory tones were presented [63]. TM and yoga meditators exhibited an increased N100 amplitude over the first 30 stimulus presentations in contrast to non-meditators [64]. During Qigong meditation P200 amplitude decreases have been observed during meditation compared to the pre- and post meditation phase. This could be an inicator that later auditory long-latency potentials may be sensitive to meditation state [61]. Auditory and visual P300 studies also showed differences between meditators and non-meditators regarding amplitude and latency changes. Some studies showed that meditators exhibited altered amplitudes and shorter latencies after stimulus presenta-

[7] Alpha blocking is normally observed after closed eyes are reopened.

[8] During Qigong meditation, the practitioner has to become aware of the Qi or subtle energy in the body. This Qi should be consciously manipulated by means of intentionality, physical postures and movements [60].

tion in ERP tasks compared to non-meditators. During a passive auditory paradigm, TM meditators showed shorter P300 latencies. The latencies were even shorter for long-term meditators compared to novices [65]. In line with these findings, an early study showed shorter response times as well as increased N1, P2 and P3b amplitudes to visual stimuli in experienced yoga meditators after a period of meditation. These results suggest increased attentional control and CNS quiescence [66]. Subsequent studies for auditory stimuli were conducted, whereby no systematic effects of different types of meditation were obtained. However, post-hoc analyses for TM and yoga meditators revealed increased N1 component amplitudes towards the beginning of the stimulus train [64]. Several studies with TM meditation subjects showed that an increase in the length of meditation practice was associated with a decrease in P3b latencies [65, 67]. A study conducted by Srinivasa and Baijal suggests changes in automatic preattentive processing due to concentration meditation. Auditory tones were presented to meditators and a control group. The results revealed an increase in mismatch negativity (MMN) amplitudes immediately after and before meditation. This indicates enhanced sensitivity of the perceptual system of the meditators, even before attention could be allocated to a cognitive task [68]. Further, these decreased latencies of the P3b amplitude were only observed after meditation and not after periods of rest [69]. In a clinical setting it has been demonstrated that depressed and dysthymic patients showed an improved clinical status and increased P3b amplitudes by the application of an auditory oddball paradigm after a period of concentrative meditation practice [70]. Another study confirmed these results and also showed increased P3b amplitudes after a session of concentrative meditation [71]. By applying an attentional blink paradigm, it was demonstrated that meditators showed decreased visual P3b amplitudes to the T1 stimulus and an increase in T2 target detection after an intensive Vipassana retreat. These results suggest that Vipassana meditation may support more efficient attentional processing [72]. In this respect, Cahn and Polich showed that by applying an auditory three-stimulus oddball paradigm, that especially the P3a amplitude was decreased during Vipassana meditation while the distractor tone was presented. In addition, decreases for N1 and P2 amplitudes could be observed during distractor tone presentation. These results suggest that the meditation state decreases the amplitude of neurophysiologic processes that subserve attentional engagement [5]. An early study showed increased CNV amplitudes during TM meditation [73], which not only indicate state-effects of meditation on the CNV, but also trait effects were reported [74]. It is thought that the CNV component is affected by meditation practice related to alteration in attentional resource allocation [4]. These results suggest that ERPs and especially the P300 component are modulated due to meditation training. However, further systematic research is needed to reveal the putative effects of mental training on neurophysiological processes.

4.8.9 Complementary research methods

Due to technical progress improved neuroscientific methods have been established, which are subsequently used for the research on meditation. It turned out that PET[9], SPECT[10] and fMRI[11] are especially useful methods in studying the impact of meditation on the brain. During a PET scan, radioactively labelled chemicals are injected into the bloodstream and the resulting emissions can then be measured and localised. With this data, two- or three-dimensional pictures can be compiled, showing the distribution of the chemicals throughout the brain or body. Dependent on the used tracer, either blood flow, oxygen and glucose metabolism or neurotransmitter concentration in the working brain can be displayed. For example, blood flow and oxygen and glucose metabolism indicate the amount of brain activity in specific regions. SPECT is quite similar to PET, but exhibits some disadvantages and is not able to produce pictures with high spatial resolution. For MRI, no injection of a radioactive tracer substance is needed. Magnetic fields and radio waves are used to produce high-quality images of different kinds of brain structures with a high degree of anatomical detail. Using fMRI enables the production of functional images of the brain. This technique utilises the magnetic properties of the blood in terms of measuring the blood flow in the brain as it changes in real time. Changes in brain activity can be measured while subjects perform different tasks or are exposed to certain stimuli. An image of brain activity can be taken almost every second, whereas PET takes much longer to image brain function. Furthermore, fMRI reveals precisely when certain brain regions become active and how long they remain in this active state. It is also possible to make clear whether brain activity occurs simultaneously or sequentially in different brain regions while the participant performs a certain task. High-quality pictures are possible and it is much easier to identify which areas of the brain are being activated in contrast to PET. However, with PET, researchers are able to identify which neurochemicals are involved in functional brain alterations [8].

Summary of results gained from continuous EEG and Neuroimaging studies

Numerous outcomes for meditation studies exist, which applied continuous EEG and neuroimgaging methods. To conduct an exhaustive discussion of all would go far beyond the scope this study. To this point, it is best to refer to Cahn and Polich [4] and to Raffone and Srinivasan [14], who gave an extensive overview on a majority of the conducted studies of the last decades. In taking together the essential obtained results from different continuous EEG and neuroimaging studies, the following conclusions can be drawn: Continuous EEG

[9]Positron emission tomography
[10]Single photon emission computed tomography
[11]Functional magnetic resonance imaging

studies showed that the alpha and theta bands are especially affected by meditation as a state effect. In general, EEG measurements showed an alpha and theta activation, related to the proficiency of meditation practice. The increases of alpha power were observed during meditation as compared to the control condition, whereby these alpha power increases are associated with relaxation. In addition, decreased frequencies have been observed at least in the alpha band. Further, an overall frequency slowing, alteration of coherence and gamma effects were observed. Neuroimaging studies also start to deliver results on the influence of meditation on the brain in the form of localization studies. It was shown that frontal and prefrontal areas were activated, which could be an index for the increased attentional demand of meditative tasks and also alterations in self-experience. Especially the anterior cingulated cortex and dorsolateral prefrontal areas were activated. Combined studies showed increased alpha power related to decreased blood flow in inferior frontal, cingulate, superior temporal and occipital cortices. Besides these frequently observed results, certain other outcomes have been obtained and deliver to some point quite contrary results. This is due to the fact that meditation types are very diverse and techniques differ from each other significantly [4].

4.9 Present study

Several conducted EEG studies have already pointed out that specific ERP components are modulated by or during meditation training, corresponding to trait and state effects, respectively. In fact, little is known about the underlying function of each component, whereby several results suggest that the P3a potential is an index for attentional engagement processes [44]. It was shown that this component was reduced during Vipassana meditation compared to the control condition and that this reduction was strongest in participants with more hours of daily meditation practice [5]. These results suggest reduced attentional engagement to distracting and unexpected stimuli as a state effect, which is in line with the aim of Vipassana meditation. The present study tested this hypothesis and also investigated if these alterations in the P3a amplitude are even more pronounced during focused attention meditation. Due to the fact that this kind of meditation promotes a narrowing of the attentional focus, the attentional systems may be even further away from the immediate sensory surrounding, leading to even more decreased P3a components during distractor tone presentation compared to the non-meditation state [3, 5]. In addition to the assessment of these state effects in the form of altered neurophysiological processes during open monitoring and focused attention meditation in long-term meditators compared to the control conditions, also trait effects have been observed. This was accomplished by the inclusion of control subjects, with no meditation experience. A comparison has been made between the long-term meditators and the control subjects across all conditions. Next to the two meditation conditions and the active listening task, subjects were asked to induce a "mind-wandering state", where the mind should wander freely. During this condition participants had to think about past and future events without any emotional engagement. This state was induced to have meaningful contrast to the meditation condition. In addition to the P3a amplitude measurements, differences in P3b amplitudes and latency changes have been investigated.

5 Methods

5.1 Participants

Overall, 31 subjects were invited to participate in this study. Due to difficulties during the EEG-recordings three meditators and one control subject had to be excluded from the experiment. In the end 14 (f=6/m=8) meditators (age M=37.7, SD=12.1, 24–58 years) and 13 (f=6/m=7) healthy control subjects (age M=25.6, SD=4.7, 19–37 years) with no prior meditation experience were assessed. All subjects reported normal hearing and an absence of neurological and psychiatric disorders. Meditators were recruited from different local meditation circles and differed in their type of practice and expertise. On average a meditation frequency of 5 times per week (SD=2.4) with a length of 37 minutes (SD=17.5) per session was stated by the meditators. The overall level of meditation experience amongst participants was diverse. Total hours of practice across life span were stated with 1133 hours (SD=1696, min=60, max=5179) on average. Subjects came from different meditation backgrounds, but were asked prior to the recruitment about their ability to perform focused attention as well as open monitoring meditation. Before the experiment, subjects were asked to fill in a questionnaire with their personal data and details about their meditation practice.

5.2 Recording conditions

The experiment was conducted in a sound proof and electrically shielded room. Subjects were asked to sit still to avoid as much movement related EEG artefacts as possible. They had to sit in an upright position in a chair with eyes half open and mouth closed. Participants were instructed to look at a fixation point on a screen and to listen to the tones, which were presented over a speaker system placed in front of them. Data was collected by a 128-channel Brain products EEG amplifier with an ActiCap using Brain Vision Recorder (Brain Products, Germany), sampling frequency: 500 Hz, low cutoff: 0.016 Hz, high cutoff: 250 Hz. Electrodes were fixed on a cap and arranged according to the extended 10/5 system with 6 electrodes removed and put on the face and neck to account for eye movements and appropriate average reference calculation. Each electrode was placed on the head by the administration of a small amount of hypercloride gel using a syringe to keep impedance below the level of 5 kOhm. In addition, pulse was measured with a pulse oximeter connected to the index finger and subjects had a nasal cannula inserted into both nostrils to measure breathing frequency and amplitude.

5.3 Paradigm

In this study a passive auditory three-stimulus oddball paradigm was applied to elicit the desired ERP responses. All stimuli were presented randomly and consisted of a frequent standard tone (80%), an oddball tone (10%) and a distractor tone (10%) in the form of white noise. The stimuli were presented using a personal computer running E-Prime software package. Former studies showed that especially the distractor tone presentation led to a prominent P3a response [5, 48], which is hypothesised to be an index for frontal neural activity produced by stimulus-driven attention mechanisms [44]. All stimuli were presented over a speaker system, placed next to the computer screen. Throughout the different conditions of the experiment, the oddball paradigm was not presented continuously. Oddball periods (2.8 min) were interspersed with phases of silence (2.2 min). No behavioural response task was integrated to allow the subjects to fully engage in the respective condition. Although no active task was imposed, the repetitive standard tone entails a state of brain expectation that the stimuli will continue. The oddball tone triggers automated processes of change evaluation, whereas the inclusion of the white noise distractor tone engages additional frontal cognitive functions [5, 44].

5.4 Procedure and Protocol

Both meditators and control subjects underwent the same procedure. The overall net recording session without the breaks in between lasted 1 hour and 20 minutes. The protocol consisted of the following six conditions with a duration of either 10 or 20 minutes[12]:

(1) Active listening (10 min)
(2) Mind-wandering (10 min)
(3) Focused attention meditation (20 min)
(4) Open monitoring meditation (20 min)
(5) Mind-wandering (10 min)
(6) Active listening (10 min)

During condition (1), subjects were instructed to listen carefully to the sounds that appeared during this 10-minute task. They were told that some of the sounds would appear frequently and some of them less frequently, following the oddball paradigm. The aim of task (2) was

[12] During the conditions with a duration of 10 minutes, phases of silence and oddball periods occurred two times each in the following manner: 1. silence (2.2 min) - 2. oddball (2.8 min) - 3. silence (2.2 min) - 4. oddball (2.2 min). During the two meditation parts with a duration of 20 minutes each, the entire cycle (1-4) was repeated once.

to induce a mind-wandering state with high ecological validity. Participants were required to think neutral thoughts regarding themselves in form of recollection of past or imaging of future events. If they recognised the appearance of emotional thoughts, attention was to be brought back to neutral thoughts. During conditions (3) and (4), participants had to perform focused attention and open monitoring meditation. Each of the two meditation parts lasted for 20 minutes. Due to the fact that control subjects had no meditation experience, they were asked to mimic a meditation-like state. During the focused attention meditation part (3), subjects were asked to sustain selective attention moment by moment by focusing on the respiration. The quality of attention had to be monitored constantly. If attention drifted away from the sensation of respiration - during phases of mind-wandering, for example – it had to be brought back to breathing. Following the 20 minute phase of focused attention meditation, open monitoring meditation had to be performed, which for control subjects meant that they were instructed to gradually reduce the focus on the breathing and to remain only in a monitoring state. They had to be attentive moment by moment to anything that occurred in experience, but without focusing on any explicit object. This could include a mental scanning the sensations from body parts from the head to the toes without stopping. Conditions (5) and (6) were the same as (1) and (2), but active listening and mind-wandering occurred in reverse order. Prior to the EEG-recordings, subjects were instructed on the entire protocol, whereby a concrete briefing before every condition was held. This ensured that subjects were able to perform the requested task properly. At the end of each condition, participants had to answer questions concerning their internal experiences[13]. Each condition started with the pressing of a button when the subject felt properly prepared for the upcoming task.

[13] All questionnaires for each condition and for the type of subject can be found in the appendix section.

5.5 ERP analysis

Before ERP analysis, raw EEG data of every subject was preprocessed to eliminate recording artefcacts. The EEGLAB software package for Matlab was used together with customised Matlab scripts. EEG data was initially filtered with a 0.1 Hz high-pass filter and the continuous EEG data was then epoched by taking sequences of every channel signal starting from 300 ms pre to 1.5 s post stimulus presentation. The resulting 1344 epochs for each subject were additionally prepared for later use of the ERPLAB toolbox to perform the ERP analysis. Epochs were sorted into ERPLAB related bins. Due to the structure of the experiment, 24 bins were created overall. After epoching recordings were visually inspected, epochs containing gross artefacts were rejected. Different statistical indices relating to the level of noise in individual channels were calculated, which enabled the rejection and later interpolation of channels exhibiting a high level of noise. Overall, 1 to 18 (on average 5) of 122 channels were rejected. Bad epochs were then detected by the calculation of statistical indices, such as variance, and were automatically excluded from further analysis[14] (between 10 and 69, on average 35 epochs were marked as bad and excluded from further analysis). The EEG-signal was re-referenced to the average of all channels. By using AMICA, the signal was decomposed in a set of independent components (IC), whose topographies were then visually inspected and only those deemed to reflect the P3a and P3b activity were included in further analysis (between 14 and 43, on average 28 IC components were retained for further analysis). For visualisation purposes the signal was filtered with a 60 Hz low-pass filter, whereas analysis of mean amplitude and fractional latency were conducted on unfiltered data. P3a and P3b virtual sum channels were computed to obtain a measure of average activity elicited by the distractor and the oddball tone. The following channels were used for the computation of the summary signal for P3a: Pz, CPP1h, CPP2h, CPz, CP1, CP2, CCP1h, CCP2h, CCP4h, CCP5h, Cz, C1, C2, FCC1h, FCC2h, FCz and for P3b: Pz, P1, P2, CPP1h, CPP2h, PPO1h, PPO2h, POz, CPz. The P3a mean amplitude was calculated by taking the mean values between 150 and 400 ms after distractor presentation, whereas for the P3b, a time window between 150 ms and 600 ms after oddball presentation was used to estimate the mean amplitude. Fractional latencies were estimated by computing the timepoint at which the area under the curve reached 50% of the area under the curve across the entire time window of interest. All the statistical analyses and plots were carried out for midline electrodes Fz, FCz, Cz, CPz, Pz. A mixed-design analysis of variance model was used to test for differences between meditators and controls and for differences within these two groups. All calculations and plots were done with the R software package [75].

[14] e.g. if the variability within the epoch exceeded 3 standard deviations when compared with variability across all epochs

6 Results

6.1 Self-reports

6.1.1 Meditation backgrounds

Most subjects were experienced mantra-meditators, whereby others stated experience in Yoga, Vipassana or Zen meditation. Although subjects came from different meditation backgrounds, each of them stated the ability to induce a state of focused attention or open monitoring meditation, which was relevant for the study. Prior to the beginning of the recordings, participants were asked several questions regarding their practice. Mantra meditators explained that they usually induce relaxation and focus on and repeat or chant a mantra mentally. If mind-wandering occurs, attention has to be brought back to the mantra. After a certain level of concentration is reached, an open monitoring state will be induced. Vipassana meditators declared that they typically first concentrate on breathing. They focus on an area below the nose and pay attention to the feeling of when the air is coming in and out. After a certain level is reached, every part of the body from head to toe is scanned and feelings in the body are observed. One subject stated the she is also doing metta[15] meditation, by sending out positive energy after each meditation session. Zen meditators reported that their practice starts with focusing on the breaths, which are counted. When the mind starts to wander, it has to be brought back to the initial object. First, feelings and thoughts are present, but fade while engaging in a deeper sense of concentration (samadhi). Yoga practitioners reported that relaxation is induced in the beginning and that the focus lies on the breathing. This focused state can also lead to a state of pure observing, depending on the mood. After the meditation is finished, focus lies on the body and the room and OM is chanted. Although the backgrounds of the meditators differed, the aims and outcomes of these practices overlap to a certain extent. Subjects expect practise to lead to improved concentration and a general calming of ongoing thought processes. Deeper insight into the nature and also the self should be gained, leading to more balanced thoughts and emotions. Further, spiritual growth and God were mentioned, whereby gaining a state of peace and overall well-being where also some prominent aims.

6.1.2 Depth and stability of meditation states

To account for the phenomenological experience, self-report scales were filled in by the meditators after each experimental condition. The values of the scale 0–10 indicated the depth and stability during the meditative state as well as during the control conditions. High val-

[15] In this form of meditation loving-kindness has to be established towards all living beings.

ues for focused attention and open monitoring meditation and low values for the control conditions were expected. Results revealed a mean meditative depth of 6.90, SD=2.33 for focused attention and 6.60, SD=2.37 for open monitoring meditation. The control conditions yielded the following results: active listening 1 3.10, SD=2.08, active listening 2 3.00, SD=2.94, mind-wandering 1 2.60, SD=2.95 and mind-wandering 2 3.10, SD=2.77. The difference between the reported depth and stability during the meditation parts compared to the control conditions was significant $F(1,10)= 15.46$, $p<0.05$.

6.1.3 Levels of tiredness

Meditation as well as control subjects had to state their level of tiredness after each experimental condition. Scale 0–10 indicated the level of tiredness, with 10 signifying very tired. Meditators stated an overall level of tiredness of 2.98, SD=2.50, whereas control subjects exhibited a slightly higher mean value of 4.04, SD=2.93. However, these group differences were not significant ($p=0.77$).

6.2 Event-related potentials

6.2.1 Grand averages of ERPs

As shown in the following two figures below, each type of stimulus (distractor, standard and oddball) exhibited its own characteristic waveform. Grand averages of controls and meditators for stimulus type, experimental condition and midline electrode are shown. The red and blue background frames indicate time windows relevant for mean amplitude and fractional latency estimations for distractor and oddball stimulus, respectively. Line colours represent

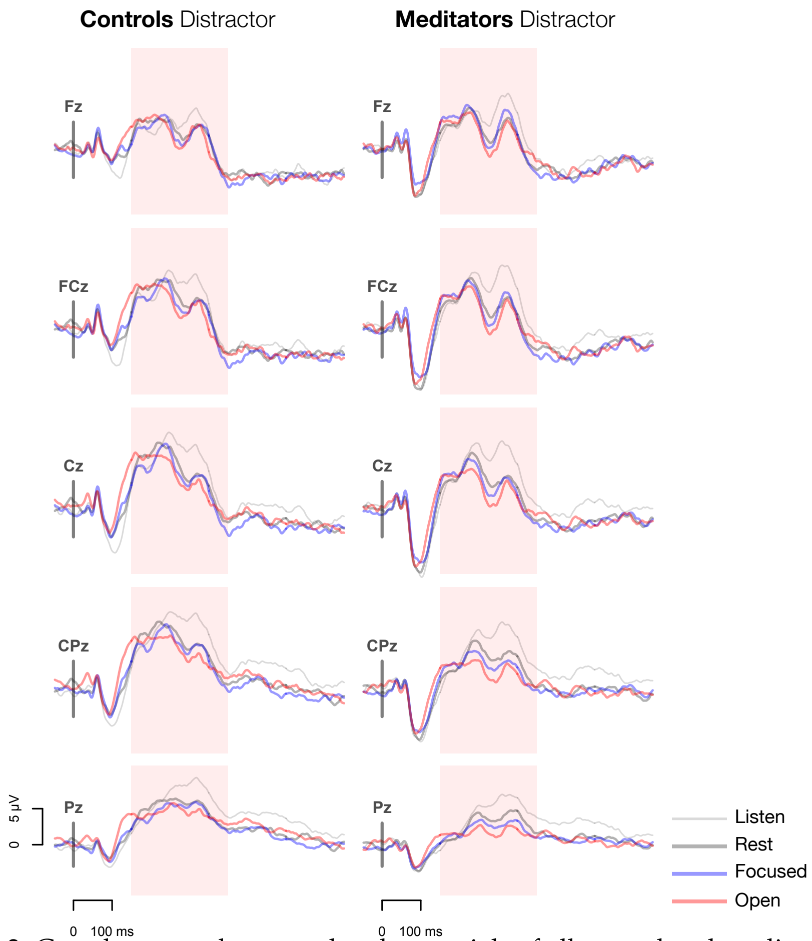

Figure 3: Grand averaged event-related potentials of all control and meditation subjects after distractor tone presentation for each experimental condition (active listening, mind-wandering, focused and open monitoring meditation) across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Red background indicates time window 150–400 ms used for estimation of mean amplitude and fractional latency for distractor stimuli.

the four experimental conditions. Figure 3 illustrates ERPs elicited by distractor tone presentation, whereas Figure 4 depicts ERPs elicited by standard and oddball tones. In general, the signal was strongest and most pronounced at frontal electrode sites and attenuated at posterior locations. As expected, standard tone presentation led to no P300 response. More precisely, next to the early potentials, only the N100 and P200 components could be observed. In addition, no difference between experimental conditions for standard tone presentation could be detected. On the contrary, distractor and oddball tones showed characteristic P3a and P3b amplitudes that differed across experimental conditions. Both for the distractor and the oddball tone, highest amplitudes occurred during the active listening condition, in which subjects were asked to pay active attention to the presented tones. This was true for meditators as well as for the control subjects. During oddball tone presentation, however, these

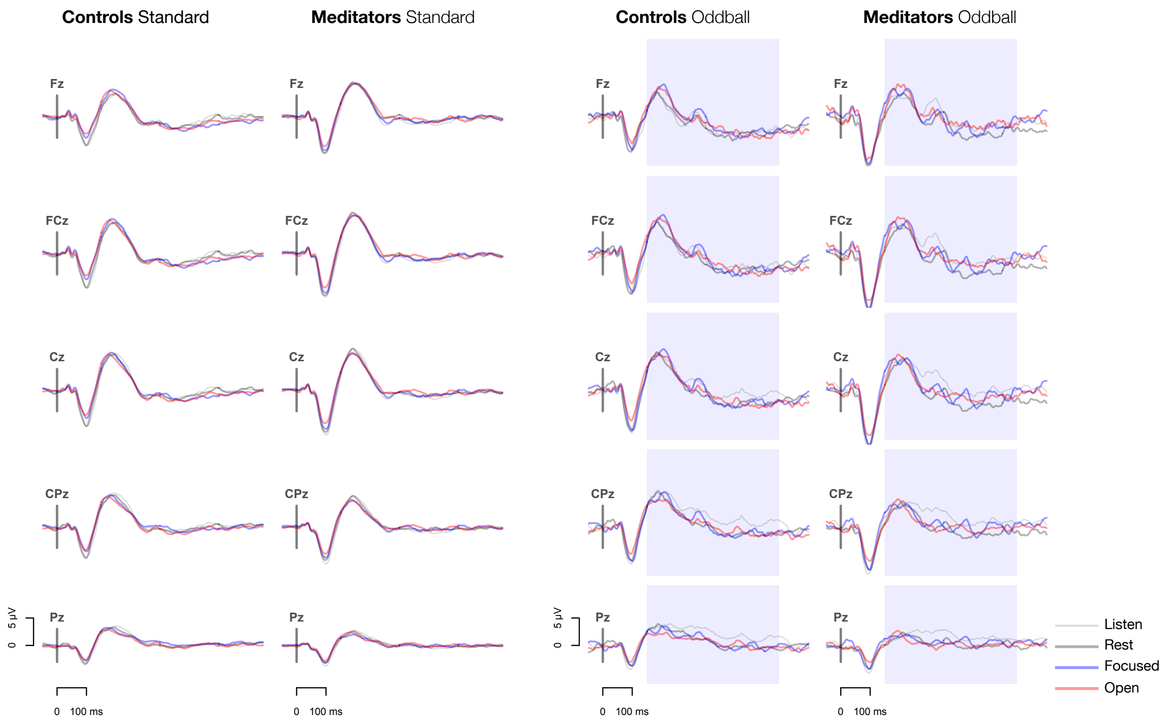

Figure 4: Grand averaged event-related potentials of all control and meditation subjects after standard (left) and oddball tone presentation (right) for each experimental condition (active listening, mind-wandering, focused and open monitoring meditation) across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Blue background indicates time window 150–600 ms used for estimation of mean amplitude and fractional latency for oddball stimuli.

elevated values during the active listening condition, were not observed on frontal electrode sites for control subjects. Furthermore, it seemed that the conditions of mind-wandering, focused attention and open monitoring meditation led to no apparent differences. Although, during the distractor tone presentation, a reduction of the two meditation states compared to mind-wandering could be observed for meditators on posterior electrode sites. These decreases were more pronounced for open monitoring meditation.

Figure 5 shows the differences in grand averaged event-related potentials for controls and meditators during both types of meditation. Thinner lines represent ERPs elicited during FA meditation and thicker indicate those during OM meditation for each type of stimulus. In this depiction it is even easier to observe that the different stimuli led to distinct types of waveforms. As expected, the amplitude during distractor tone presentation was much higher than during the presentation of the oddball stimulus. Again, one can see that open monitoring meditation led to slightly decreased amplitudes compared to focused attention meditation at most electrode sites for meditators. This effect is hard to observe during oddball tone presentation, however, it seemed that for control subjects, amplitudes for open monitoring were decreased at all midline electrode sites.

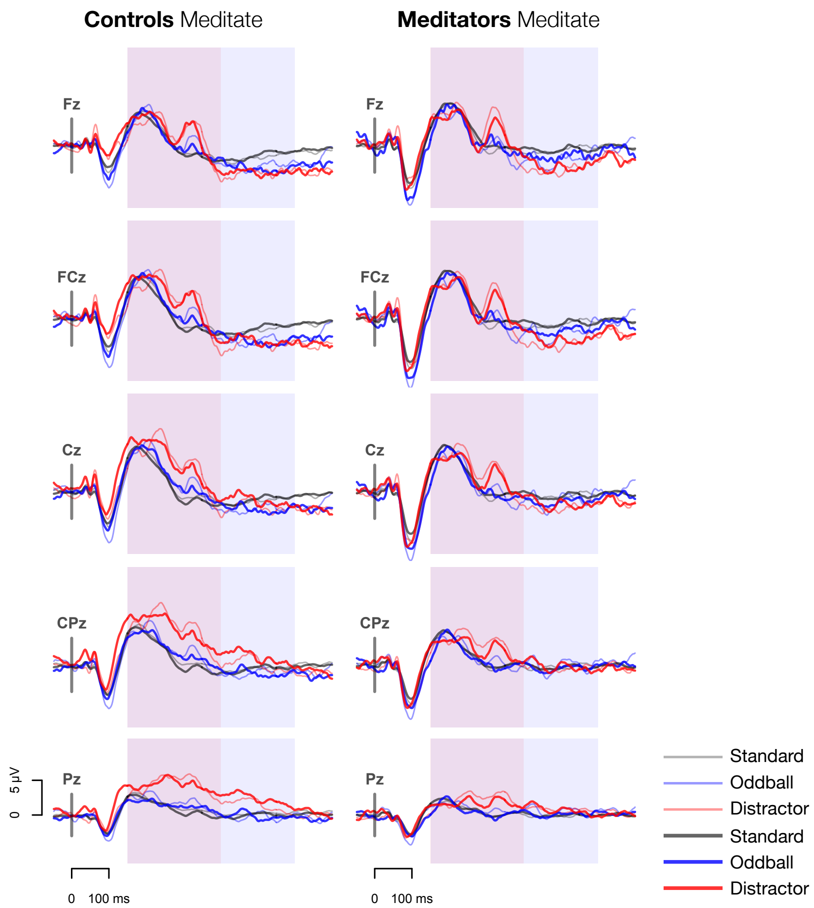

Figure 5: Grand averaged event-related potentials of all control and meditation subjects for focused attention (thin lines) compared to open monitoring meditation (thick lines) for each presented stimulus (standard, oddball and distractor) across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Red and blue backgrounds indicate time windows 150–400; 150–600 ms used for estimation of mean amplitude and fractional latency.

Figure 6 illustrates the comparison of both control conditions; mind-wandering 1 vs. mind-wandering 2 and active listening 1 vs. active listening 2 before and after the meditation block. This comparison was conducted to assess putative influences of the interspersed meditation block on both control conditions. During distractor tone presentation, the amplitude for mind-wandering 2 was reduced, especially over posterior electrodes, for both meditators and controls. This was not observed for oddball stimuli. For the active listening section, however, decreases due to meditation under distractor tone presentation were only observed for meditators over all electrodes. For controls, this effect was only observed at Pz. Oddball stimuli led to no differences between active listening 1 compared to active listening 2 in meditators. For controls, differences at posterior electrodes can be observed.

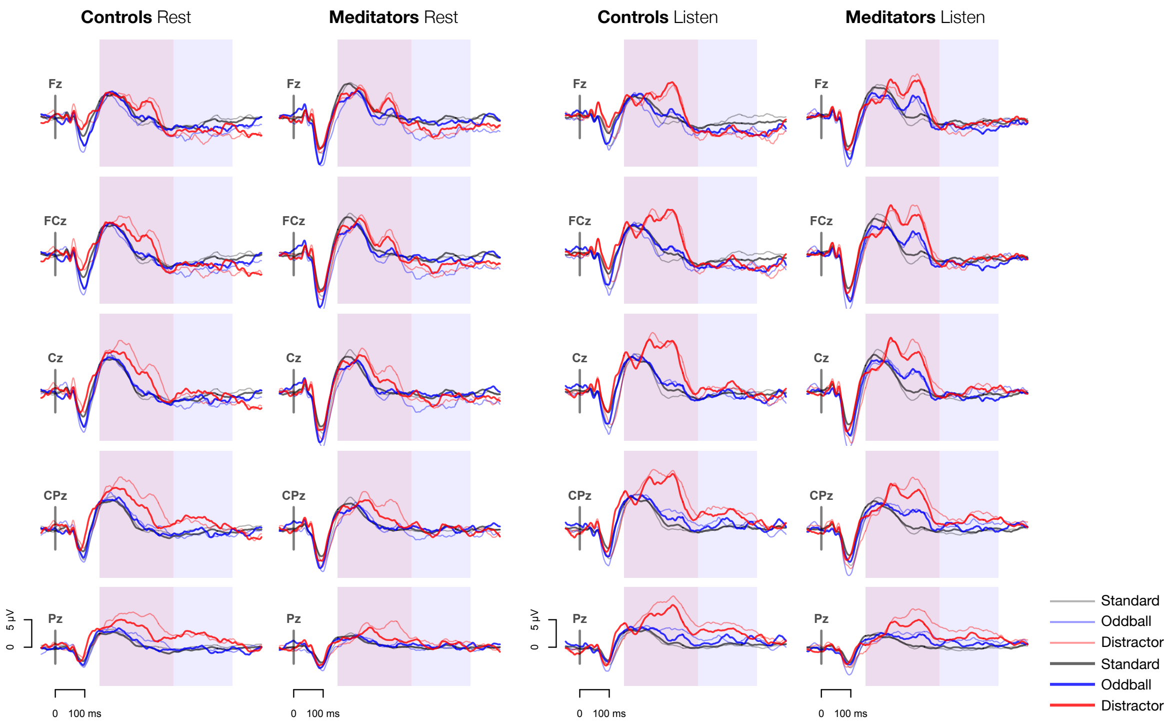

Figure 6: On the left, grand averaged event-related potentials of all control and meditation subjects for mind-wandering 1 (thin lines) compared to mind-wandering 2 for each presented stimulus (standard, oddball and distractor) across the midline electrodes (Fz, FCz, Cz, CPz and Pz) are shown. Red and blue backgrounds indicate time windows 150–400; 150–600 ms used for estimation of mean amplitude and fractional latency. The picture on the right shows the same, only for active listening 1 (thin lines) compared to active listening 2 (thick lines).

6.2.2 P3a / P3b amplitudes

P3a amplitude

The following depictions, accompanied by statistical analyses, illustrate P3a mean amplitudes elicited by distractor stimulus presentation. Differences between the meditation and control conditions, the two types of meditation and the control conditions before and after the meditation block were examined.

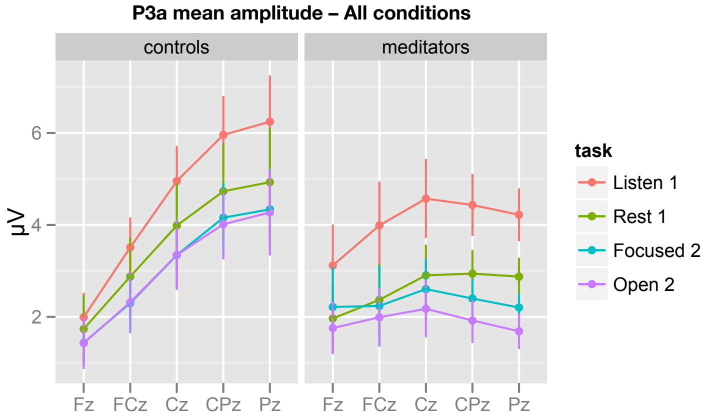

Figure 7: P3a mean amplitude comparison of control and meditation conditions elicited by distractor stimulus for controls and meditators across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Mean amplitudes were computed on the time window 150–400 ms. Error bars indicate standard error of the mean.

Figure 7 illustrates mean amplitude differences between the two types of meditation and the two control conditions. A mixed-design analysis of variance model with the between factor group (controls, meditators) and the within factors condition (active listening 1, mind-wandering 1, focused attention 2, open monitoring 2) and electrode site (Fz, FCz, Cz, CPz, Pz) revealed a significant difference for the main factor condition (task) $F(3,84)= 8.40$, $p<0.001$. In examining the graph, one can see that the amplitude of active listening differs from the other conditions in the form of higher amplitudes over all five midline electrodes. However, differences between the other condition were not observed, as already suggested by the ERP plots in the former chapter. Further, group by electrode site interaction $F(4,112)= 6.73$, $p<0.001$ indicated a difference between the groups over certain midline electrodes. This effect was observed for central and posterior midline channels. Group by condition interaction revealed no significant differences $F(3,84)= 0.31$, $p=0.821$.

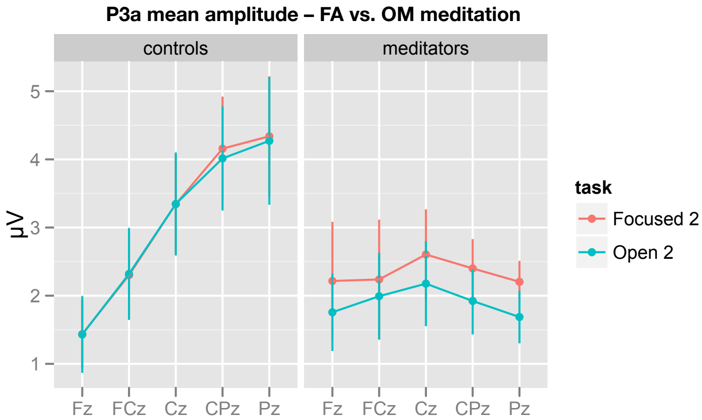

Figure 8: P3a mean amplitude comparison of focused attention and open monitoring meditation elicited by distractor stimulus for controls and meditators across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Mean amplitudes were computed on the time window 150–400 ms. Error bars indicate standard error of the mean.

In Figure 8 differences between the two types of meditation are depicted. Conducted mixed-design ANOVA with between factor group (controls, meditators) and within factors condition (focused attention 2, open monitoring 2) and electrode site (Fz, FCz, Cz, CPz, Pz) revealed no difference between the two conditions $F(1,28)= 0.51$, $p=0.480$. Although, meditators and controls differed across electrode sites, indicated by a group by electrode site interaction $F(4,112)= 7.25$, $p<0.001$. Differences among groups were greatest for posterior electrodes.

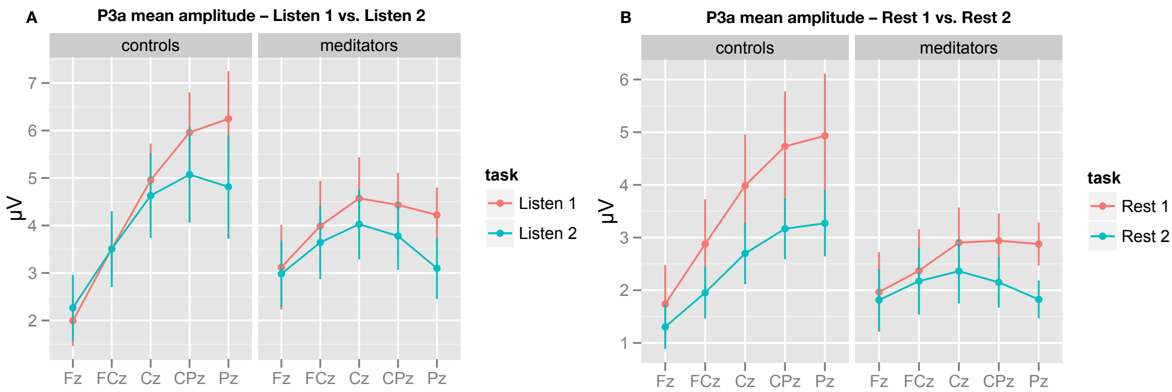

Figure 9: P3a mean amplitude comparison of active listening 1 vs. active listening 2 (Panel A) and mind-wandering 1 vs. mind-wandering 2 (Panel B) elicited by distractor stimulus for controls and meditators across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Mean amplitudes were computed on the time window 150–400 ms. Error bars indicate standard error of the mean.

Figure 9 illustrates differences between the two active listening and the two mind-wandering conditions, respectively. The aim of this comparison was to investigate possible influences of the meditation block on either active listening or mind-wandering. For the active listening condition (Figure 9A), a mixed-design ANOVA with between factor group and within factors condition (active listening 1, active listening 2)[16] and electrode site showed no significant differences between controls or meditators for these two conditions $F(1,28)= 1.44$, $p=0.239$. However, groups differed by electrode site, indicated by a group–electrode site interaction $F(4,112)= 6.46$, $p<0.001$. Further, condition by electrode site interaction was statistically significant $F(4,112)= 5.08$, $p<0.001$. Again, differences were greatest for posterior electrodes. For mind-wandering (Figure 9B), a significant difference between condition 1 and 2 $F(1,28)= 4.37$, $p=0.045$ was observed. Condition by electrode site interaction $F(4,112)= 5.71$, $p<0.001$ again revealed differences amongst channel location, with the greatest differences over posterior electrodes. Group by electrode site interaction was also significant $F(4,112)= 5.09$, $p<0.001$.

P3b amplitude

Figure 10 illustrates comparisons of P3b mean amplitudes elicited by oddball stimulus presentation. Differences between the meditation and control conditions, the two types of meditation and the control conditions before and after the meditation block were examined. Figure 10A displays mean amplitude differences across active listening, mind-wandering and the two types of meditation. Mixed-design analysis of variance model with the between factor group (controls, meditators) and the within factors condition (active listening 1, mind-wandering 1, focused attention 2, open monitoring 2) and electrode site (Fz, FCz, Cz, CPz, Pz) exhibited significant differences between conditions $F(3,84)= 3.95$, $p=0.011$. This indicates an increased amplitude for the active listening condition, especially over posterior channels in contrast to the other conditions. The interaction between condition and electrode site was reliable $F(12,336)= 5.53$, $p<0.001$. No group or condition differences were observed for the two types of meditation during oddball stimulus presentation (Figure 10B). ANOVA with the between factor group and the within factors condition (active listening 1, active listening 2) and electrode site revealed a significant group by electrode site interaction $F(4,112)= 3.36$, $p=0.012$ as well as a significant interaction between condition and electrode site $F(4,112)= 3.33$, $p=0.013$ for the comparison of the two active listening conditions (Figure 10C). In Figure 10D, differences between the two mind-wandering states are depicted. ANOVA with the between factor group and the within factors condition (mind-wandering 1, mind-wandering 2) and electrode site indicated a significant main effect for the two conditions $F(1,28)= 6.96$, $p=0.013$. Further, an interaction between condition and electrode site was

[16] ANOVA for mind-wandering (Figure 9B) of within factor condition included the levels mind-wandering 1, mind-wandering 2

observed F(4,112)= 7.65, p<0.001. Interestingly, amplitude was lower for condition mind-wandering 1 along all midline electrodes for meditators.

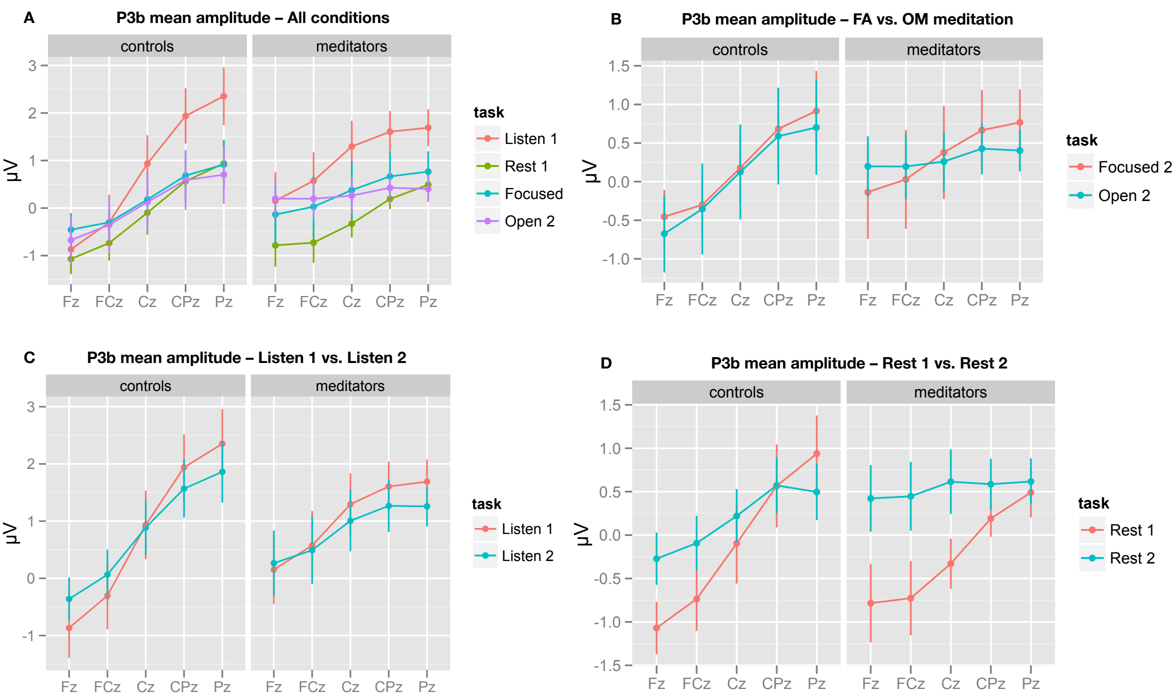

Figure 10: P3b mean amplitude comparisons of different conditions elicited by oddball stimulus for meditators and controls across the midline electrodes (Fz, FCz, Cz, CPz and Pz). Panel A illustrates comparison of conditions active listening 1, mind-wandering 1, focused attention 2 and open monitoring 2. Panel B shows a comparison of the two types of meditation. Panel C and D illustrate differences between active listening 1 vs. active listening 2 and mind-wandering 1 vs. mind-wandering 2, respectively. Mean amplitudes were computed on the time window 150–600 ms. Error bars indicate standard error of the mean.

6.2.3 P3a / P3b latencies

P3a latency

As described in the method section, fractional latencies were computed on the summary channels. Analysis of P3a latencies revealed some interesting outcomes. Figure 11 shows fractional latencies for different conditions. Mixed-design analysis of variance model with the between factor group (controls, meditators) and the within factor condition (active listening 1, mind-wandering 1, focused attention 2, open monitoring 2) indicated a significant difference between the conditions F(3,84)= 11.83, p<0.001 with highest latencies for active listening, whereby no group differences were observed F(1,28)= 1.00, p=0.326 (Figure 11A). ANOVA with the between factor group and the within factor condition (focused attention 2, open monitoring 2), showed a significant group by condition interaction F(1,28)= 5.50, p=0.026 for the comparison between the two types of meditation (Figure 11B). Here, the transition from focused attention to open monitoring meditation led to a slight increase of latency for meditators, whereas latency decreases for control subjects could be observed. While comparing latencies for active listening before and after the meditation block – depicted in Figure 11C – ANOVA with the between factor group and the within factor condition (active listening 1, active listening 2) revealed a significant group by condition interaction F(1,27)= 4.36, p=0.046. There was a strong decrease in latency for meditators after the meditation section, whereas latencies of control subjects increased. This group by condition interaction was not observed for the two mind-wandering states, depicted in Figure 11D. Although condition differences, in the form of latency decreases after the meditation part, were significant F(1,27)= 10.75, p=0.002, ANOVA with the between factor group and the within factor condition (mind-wandering 1, mind-wandering 2) yielded no group by condition interaction F(1,27)= 0.29, p=0.589.

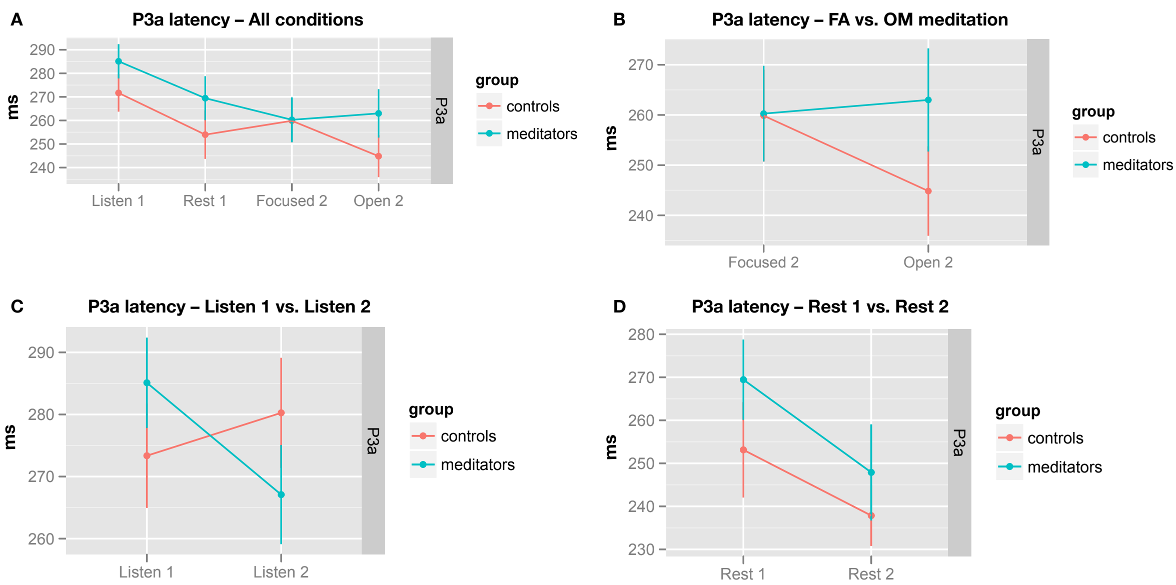

Figure 11: Fractional P3a latency comparisons of meditators and controls for different conditions. Panel A illustrates comparison of conditions active listening 1, mind-wandering 1, focused attention 2 and open monitoring 2. Panel B shows a comparison of the two types of meditation. Panel C and D illustrate differences between active listening 1 vs. active listening 2 and mind-wandering 1 vs. mind-wandering 2, respectively. Error bars indicate standard error of the mean.

P3b latency

Figure 12 illustrates P3b latencies. Like for the P3a latencies, ANOVA with the between factor group (controls, meditators) and the within factor condition (active listening 1, mind-wandering 1, focused attention 2, open monitoring 2) exhibited a difference between the four conditions in P3b latency F(3,84)= 3.44, p=0.020 (Figure 12A). Again, highest latency values were reported for the active listening condition. Although latency was decreased in controls compared to the meditators during active listening, mind-wandering and also focused attention meditation, group by condition interaction was not significant F(3,84)= 0.54, p=0.658. Further analysis of P3b latencies revealed no significant differences among groups or conditions.

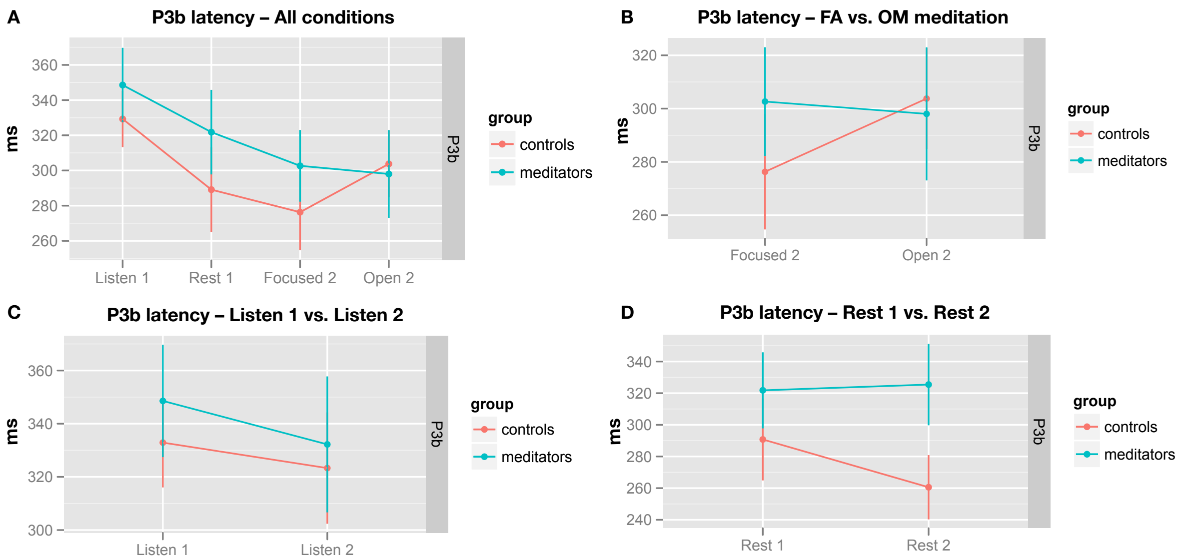

Figure 12: Fractional P3b latency comparisons of meditators and controls for different conditions. Panel A illustrates comparison of conditions active listening 1, mind-wandering 1, focused attention 2 and open monitoring 2. Panel B shows a comparison of the two types of meditation. Panel C and D illustrate differences between active listening 1 vs. active listening 2 and mind-wandering 1 vs. mind-wandering 2, respectively. Error bars indicate standard error of the mean.

7 Discussion

7.1 P3a amplitude

It was hypothesised that the two different types of meditation would lead to reduced P3a amplitudes during distractor tone presentation in meditators compared to the control conditions, with a reduction more prominent during focused attention meditation. Results proved these hypotheses to be partially true. In fact, there was a significant difference between active listening compared to all other conditions. However, a difference between the two types of meditation and mind-wandering was not observed. Although it seemed that the amplitude during the mind-wandering condition was higher compared to the meditation states at all electrode sites except for Fz, results were not statistically significant. A comparison between the two meditation states actually revealed stronger amplitude decreases for open monitoring compared to focused attention meditation. This reduction was observed for all midline electrodes – again, results were not statistically significant. An explanation for these results may be that active listening was the only condition were subjects paid active attention to the tones, which led to higher amplitudes over all midline electrodes. During the other conditions, tones were more or less perceived in a passive manner, as if it was required. Not observed differences between the other conditions may be due to the fact that mind-wandering and the two meditation states were quite similar in phenomenological terms. This is in line with the reports of several subjects stating difficulties in reaching a certain depth during the desired meditative state. In addition, some participants indicated that the meditation states and the state, where the mind should wander freely, were perceived almost as similar. The comparison between meditators and controls showed no significant group by task interaction, meaning no differences were observed by comparing both groups during each condition. This indicates that even when meditators were engaged in a meditative state and controls mimicked the same state, for example, it seemed that no group was affected differentially by the inducement of this certain state. Subsequently, this was true for all conditions. However, trait effects were observed in the form of overall decreased mean amplitudes during all conditions for meditators compared to the controls, over central and posterior midline electrodes, which corroborates the last hypothesis, postulated at the beginning of this thesis. Although no state differences were observed, these results in turn suggest that there is an effect of meditation on the brain due to long-term mental training in the form of general decreased P3a amplitudes regardless of the performed task. In addition, influences of the meditation block were analysed by comparing both control conditions before and after meditation. Both groups showed tendentially reduced P3a mean amplitudes after the meditation part, but results were only significant for the mind-wandering conditions. This implies that stimuli were perceived differently after a 20 minutes phase of meditation, which is reflected by decreased P3a amplitudes in the second task.

7.2 Other findings

In contrast to the P3a potential, which is thought to be an index for attentional engagement and elicited by distractor stimuli, the P3b component is related to memory processing and resource allocation, elicited by oddball (target) stimuli [44]. Meaning, if tasks are demanding increased P3b amplitudes are observed [37]. As set out above, studies so far have shown contrary results concerning meditation state and trait effects and the P3b amplitude. On the one hand, increased P3b amplitudes have been reported due to meditation [66, 70, 71], on the other hand, a study using the attentional blink paradigm in conjunction with Vipassana meditation showed decreased P3b amplitudes due to meditation [72]. It is important to note that all these studies used active paradigms, where subjects had to detect the target stimulus. Due to the fact that a passive paradigm – with no task imposed – was applied in this study, one has to be careful in interpreting gained results concerning P3b amplitude. Generally, in contrast to the P3a amplitude, no trait effects in the form of lower amplitudes for meditators compared to controls at posterior electrode sites were observed. By comparison of the different conditions, it seemed that active listening differed in contrast to all other conditions in appearance of higher mean amplitude values. In addition, amplitudes were most decreased during mind-wandering over frontal electrode sites for meditators.

As for the P3b amplitude, gained results for latencies have to be treated with caution as no task was imposed in this paradigm. In general, it is thought that increased latencies correspond to delayed perceptual processes as well as difficulties in stimulus categorisation, however, no firm conclusions can be drawn about latency differences between conditions or groups without relying on a long chain of assumptions and inferences [37]. One previous study observed shorter P300 latencies for long-term TM meditators by using a similar passive auditory paradigm [65]. These results were not confirmed in this study. By looking at gained results for P3a and P3b latencies, it was shown that for both components, significantly higher latency values were observed for the active listening condition compared to all other conditions. No differences were observed for meditators during the comparison of both types of meditation, however, controls showed significantly shorter latencies during open monitoring meditation. Further, P3a latencies were decreased after the meditation block during mind-wandering 2 in both groups. The comparison between active listening 1 and active listening 2, however, revealed shorter latencies only for meditators after meditation. At the same time, latency increases were observed for the control group. This may indicates that the period of meditation influenced groups in different ways, when active attention was paid to the tones.

7.3 Limitations

One crucial question is how reliable and appropriate ERP potentials are in assessing the influence of meditation on the brain. As already pointed out, many components exist, but what neurophysiological processes they actually reflect and by what cognitive functions they may be influenced is not yet fully understood and still a topic of discussion in ERP research. This applies especially to the used P300 potential in this study with its two characteristic subcomponents: P3a and P3b. Regarding this, the application of the used passive three-stimulus auditory oddball paradigm should also be seen critically and further research is needed to elucidate the concrete influences and effects of every type of stimulus. Another point was the limitation of time, which was spent to introduce subjects to the concrete tasks of the experiment. Participants only received instruction right before the experiment, with no prior training sessions. To gain more stable and reliable states for the meditation as well as for the control conditions during the experiment, preceding training sessions would have been appropriate to allow subjects to become familiar with the concrete setting of the experiment. This approach may have led to more distinct states between meditation and control conditions and to more reliable values of the phenomenological reports. By taking a look at the participants, meditators differed in their meditation backgrounds strongly. One can assume that these different practices over the life span influence cognitive processes like attention in different ways. Although subjects were told to induce a state of focused attention and open monitoring meditation, some of the participants expressed problems in gaining depth in each of the two states. To prevent such issues, further studies have to include subjects explicitly familiar with one of these two styles of meditation in their studies, which may lead finally to observable state effects, between the two types of meditation and also in contrast to the control condition. Due to the fact that it was not easy to obtain enough experienced meditators, the two groups differed in their mean age significantly. Studies showed that this can influence certain characteristics of the P300 potential in type of increased latencies [76] and decreased amplitudes, especially over posterior electrode sites in age [77]. Next to the issue of age, experience differed also amongst meditation subjects. Some reported meditation experience of 20 years and over more than several thousand hours of practice. Whereas others exhibited only about 100 hours of overall meditation experience across the life span. Although averaged levels of tiredness were not stated as high, particular individuals expressed high levels of drowsiness during certain sessions. This partial high level of tiredness due to a lack of sleep may also influences results. One aim of the study was also to look at whether the meditation block influences the components during the two control conditions. Differences were expected in the second control states compared to the pre-meditation ones. Results suggested differences, but one has to be aware of possible habituation effects, meaning that subsequent stimulus presentation may lead to weaker response after numerous presented stimuli. Finally, the used strategy for preprocessing and data analysis can of course have also influenced gained results. In general, several approaches concerning this issue exist and all of them exhibit benefits and drawbacks, with the overall aim to extract the relevant information out of the large amount of background noise. As illustrated, statistical values were computed rejecting bad channels and epochs, although individual components were rejected or kept manually, which can also have influenced gained results.

7.4 Conclusions

State and trait effects of long-term meditation practice were assessed, by observing changes in the P300 brain potential. Especially, alterations in the P3a potential were expected, as this component is known for its association with the engagement of attention. Overall, no state effects in the form of lower P3a amplitudes during open monitoring and focused attention meditation compared to the mind-wandering condition were observed. However, a comparison to the active listening state revealed lower amplitudes for both types of meditation, but also for mind-wandering. Further, the comparison between the two types of meditation yielded no significant differences. These results suggest that the inducement of a meditative state does not affect attentional systems in the form of altered P3a amplitudes. Although significant differences compared to the active listening condition were observed, these findings may indicate that active attention towards the tones leads in general to higher amplitudes compared to passive conditions, where no active attention is paid to the tones. Whereby, it does not matter if this state is related to meditation or to a mind-wandering state, where subjects have to think about neutral past or future events. Although no state effects were experimentally verified, it seemed that long-term mental training can lead to sustainable trait changes. In this regard, the comparison between the meditators and the control group revealed significantly lower P3a amplitudes during all conditions for meditators over central and posterior midline electrode sites. These results suggest that long-term meditation influences the brain in a way that unexpected and distracting auditory stimuli are processed differently, indicating less automated reactivity of the brain as a trait effect. This was already demonstrated by Cahn and Polich for state effects [5], however, this study showed that this can also be observed in the form of trait changes. As a consequence, gained results imply that meditation, practised over a long period of time, may induce neuroplasticity, in the form of altered brain processes.

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A Appendix

A.1 Questionnaires

Dear Participant!

Thank you very much for your participation. Before we can start with the study, we need some information about you and your meditation practice. Please take your time and answer the following questions:

1) **Surname:** ______________________ **First Name:** ______________________

2) **Gender:** ☐ m ☐ f (please tick)

3) **Date of birth:** ____ ____ ________ (DD MM YYYY)

4) **Phone:** ___________________________ 5) **Mail:** ___________________________

6) **Date of testing:** ____ ____ ________ (DD MM YYYY)

7) **Highest completed education:** (please tick)

1. Primary school not completed ☐
2. Primary school ☐
3. Secondary / professional school ☐
4. Higher professional school ☐
5. University ☐
6. Masters, Doctorate ☐

8) **Please tick and explain:** **YES / NO**

1. Can you sit still on a chair for 1,5 hours? ☐ ☐
   If you choose "NO", please explain the details:

   ____

   ____

2. Can you breathe effortlessly through the nose ☐ ☐
   while having your mouth closed?
   If you choose "NO", please explain the details:

   ____

   ____

(1/3)

YES / NO

3. Is your hearing in some way impaired? ☐ ☐
   If "YES", please explain the details:

---

4. Have you ever visited a doctor of went to the hospital due to a pulmonary or heart disease? ☐ ☐
   If "YES", please explain the details:

---

5. Have you ever been taking medications that affect your brain? ☐ ☐
   If "YES", please explain the details:

---

6. Have you ever been in a hospital due to a neurological or muscular disease? ☐ ☐
   If "YES", please explain the details:

---

7. Have you ever suffered from any psychiatric disease? ☐ ☐
   If "YES", please explain the details:

---

8. Do you take any drugs or drink alcohol? ☐ ☐
   Please, explain:

(2/3)

9) Have you ever practiced meditation and/or activity similar to meditation? How intensely?

This includes all types of meditation, yoga, pilates, professional/extreme sport, tai chi, other marshal arts, different relaxation techniques and other religious and non-religious practices that cultivate attention to one's thoughts and bodily sensations. Leave the field empty if you never practiced something like this.

Please describe each activity separately. Please state 1) the type of activity; 2) the institution, school or book; 3) the duration (from year – to year) 4) the average number of hours per week

(3/3)

1) How do you feel today?
Please tick; multiple choice possible

☐ tired ☐ excited ☐ neutral ☐ happy ☐ tense ☐ nervous ☐ sad

☐ other: ____________________

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainable difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

____

____

____

____

____

____

6) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

____

____

____

____

____

____

(1/1)

Please describe how you felt during the task and how you performed the task

1) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

____

____

____

____

____

____

5) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

____

____

____

____

____

____

(1/1)

FOCUSED ATTENTION ON BREATHING

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

____

____

____

____

____

____

6) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

____

____

____

____

____

____

(1/4)

7) How did you feel during this task?

8) Did you experience anything special during focusing on breathing that you would like to mention or stress?

(2/4)

OPEN MONITORING

1) **Mark from [0-10] if you reached some kind of meditative state:**
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) **How tired or sleepy were you during the task?**
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) **How aware of the sounds you were during the task?**
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) **What percentage of time were you able to maintain the desired mental state?**
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) **How difficult was it for you to maintain the desired mental state?**
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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6) ***Which*** **bodily sensations** ***were you aware of during the task*****?**
Please state what percentage of time you were aware of these sensations.

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(3/4)

7) How did you feel during this task?

8) Did you experience anything special during open monitoring that you would like to mention or stress?

(4/4)

Please describe how you felt during the task and how you performed the task

1) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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5) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

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(1/1)

1) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainable difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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5) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

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6) How did you experience the auditory and other stimuli before and after the “long task” (focusing on breathing + open monitoring)?
Was your perception more stable after the “long task”? Did you experience the stimuli differently? How?

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(1/1)

Dear Meditator!

Thank you very much for your participation. Before we can start with the study, we need some information about you and your meditation practice. Please take your time and answer the following questions:

1) **Surname:** ______________________ **First Name:** ______________________

2) **Gender:** ☐ m ☐ f (please tick)

3) **Date of birth:** ____ ____ ________ (DD MM YYYY)

4) **Phone:** ___________________________ 5) **Mail:** ____________________________

6) **Date of testing:** ____ ____ ________ (DD MM YYYY)

7) **Highest completed education:** (please tick)

1. Primary school not completed ☐
2. Primary school ☐
3. Secondary / professional school ☐
4. Higher professional school ☐
5. University ☐
6. Masters, Doctorate ☐

8) **Which of the abilities listed below do you possess** (please tick) **YES / NO**

1. Ability to perform focused attention meditation ☐ ☐
2. Ability to perform open monitoring meditation ☐ ☐
3. Ability to meditate sitting on a chair ☐ ☐
4. Ability to meditate with eyes half open and mouth closed ☐ ☐

9) **Please tick and explain:** (please tick) **YES / NO**

9a) Can you breathe effortlessly through the nose while having your mouth closed? ☐ ☐
If you choose "NO", please explain the details:

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(1/6)

YES / NO

9b) Is your hearing in some way impaired? ☐ ☐
If "YES", please explain the details:

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9c) Have you ever visited a doctor of went to the hospital due to a pulmonary or heart disease? ☐ ☐
If "YES", please explain the details:

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9d) Have you ever been taking medications that affect your brain? ☐ ☐
If "YES", please explain the details:

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9e) Have you ever been in a hospital due to a neurological or muscular disease? (Especially sensory or motor disorder related to respiration or hearing) ☐ ☐
If "YES", please explain the details:

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9f) Have you ever suffered from any psychiatric disease? ☐ ☐
If "YES", please explain the details:

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9g) Do you take any drugs or drink alcohol? ☐ ☐
Please, explain:

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(2/6)

10) Please, describe in your own words how you meditate:

10a) Describe your usual meditative process from the beginning till the end:

10b) Explain, do you go through different stages during your meditation?

10c) What is the purpose of your meditation?

11) Have you always practiced one meditative technique or has the technique been changing during your meditative career? Please, explain:

11a) If you practiced more than one type of meditation, please describe each one separately. State all types of meditation and the names of organizations / schools / books that taught you how to meditate:

12) Has your meditative experience been changing during your career? Please describe:

13) Do you always meditate in the same way or you use different techniques in your meditative sessions when you meditate these days?

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13a) Is the structure of your meditative session always the same? If not, please explain:

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14) Is your usual way of meditating closer to focused attention (FA) or open monitoring meditation (OM*)?*

Scale [0–10] 0=FA; 5=both; 10=OM

(FA) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | (OM) (please tick)

15) Please state your level of experience:

0 = No Experience; 10 = Very experienced

Focused Attention	0	1	2	3	4	5	6	7	8	9	10	(please tick)
Open Monitoring	0	1	2	3	4	5	6	7	8	9	10	(please tick)

16) How many times per week do you meditate?

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17) What is the average length of one meditative session?

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18) When during the day do you usually meditate?

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19) If there were breaks in between your meditation career, please state their length and how long you have been meditating again since your last break:

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19a) Why did you make a break?

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20) Please state how many hours have you meditated in your whole life:

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21) Besides the already described meditative techniques, have you ever practiced any other type of meditation and/or activity similar to meditation? How intensely?

This includes all types of meditation, yoga, pilates, professional/extreme sport, tai chi, other marshal arts, different relaxation techniques and other religious and non-religious practices that cultivate attention to one's thoughts and bodily sensations.
If there was more than one such activity, please describe each one separately. Please state 1) the of activity; 2) the institution, school or book; 3) the duration (from year – to year) 4) the average number of hours per week

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Thank you

(6/6)

1) How do you feel today?
Please tick; multiple choice possible

☐ tired ☐ excited ☐ neutral ☐ happy ☐ tense ☐ nervous ☐ sad

☐ other:____________________

2) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5.) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

6) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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7.) Which bodily sensations were you aware of during the task?
Please state what percentage of time you were aware of these sensations.

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(1/1)

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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6) *Which* bodily sensations *were you aware of during the task*?
Please state what percentage of time you were aware of these sensations.

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(1/1)

FOCUSED ATTENTION ON BREATHING

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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6) Which bodily sensations were you aware of during the task?
Please state what percentage of time you were aware of these sensations.

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7) Did you experience anything special during the meditation that you would like to mention or stress?

OPEN MONITORING

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

6) Which bodily sensations were you aware of during the task?
Please state what percentage of time you were aware of these sensations.

(3/4)

7) Did you experience anything special during the meditation that you would like to mention or stress?

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

6) Which bodily sensations were you aware of during the task?
Please state what percentage of time you were aware of these sensations.

(1/1)

1) Mark from [0-10] if you reached some kind of meditative state:
0 means no meditative state at all, 10 means deepest meditative state ever reached

0	1	2	3	4	5	6	7	8	9	10

(please tick)

2) How tired or sleepy were you during the task?
0 = completely awake and refreshed 10 = maximally tired and sleepy

0	1	2	3	4	5	6	7	8	9	10

(please tick)

3) How aware of the sounds you were during the task?
0 = not aware at all 10 = maximal awareness

0	1	2	3	4	5	6	7	8	9	10

(please tick)

4) What percentage of time were you able to maintain the desired mental state?
0 = zero 10 = all the time

0	1	2	3	4	5	6	7	8	9	10

(please tick)

5) How difficult was it for you to maintain the desired mental state?
0 = utterly easy, 10 = unattainably difficult

0	1	2	3	4	5	6	7	8	9	10

(please tick)

If it was difficult, please state why:

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6) Which bodily sensations were you aware of during the task?
Please state what percentage of time you were aware of these sensations.

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(1/2)

7.) How did you experience the stimuli before and after meditation during non-meditative tasks (1, 2, 5, 6)?

Was your perception more stable after the meditation? Did you experience the stimuli differently? How?

(2/2)

FOCUSED ATTENTION

1) How would you describe your meditation experience today?
Was it in any way different from the way you usually experience it? Would you say that you succeeded? Was it easy or hard for you to reach the requested state? Did you experience any difficulties reaching the desired state?

2) How long did it take to reach the requested state?

3) If you would have to describe your meditation as a process, which phases did you go through?

4) Please describe the deepest state you reached today during meditation with focusing on breathing in your own words:

5) When you successfully reached the state of "focused attention", how stable was this state? Could you describe the intensity of the state (as compared to your previous experience)?

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6) Did you experience anything out of the ordinary during meditation?
E.g. out of body experiences, dream-like states, extra-sensory perception etc.?

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OPEN MONITORING

1) How would you describe your meditation experience today?
Was it in any way different from the way you usually experience it? Would you say that you succeeded? Was it easy or hard for you to reach the requested state? Did you experience any difficulties reaching the desired state?

2) How long did it take to reach the requested state?

3) If you would have to describe your meditation as a process, which phases did you go through?

4) Please describe the deepest state you reached today during "open monitoring" meditation in your own words:

(3/4)

5) When you successfully reached the state of "open monitoring", how stable was this state? Could you describe the intensity of the state (as compared to your previous experience)?

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6) Did you experience anything out of the ordinary during meditation?
E.g. out of body experiences, dream-like states, extra-sensory perception etc.?

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Thank you!

A.2 Abstract / Zusammenfassung

Abstract
Meditation can be seen as a mental training, which supports the cultivation of well-being, awareness and other beneficial properties by improving cognitive traits, like attention and emotion. It is hypothesised that this long-term mental training may influence the mind and the body in a sustainable manner, subsequently leading to observable changes in the brain. A former study showed that the P3a brain potential – which is thought to be an index for attentional engagement – was decreased during a form of open monitoring meditation compared to a mind-wandering state in long-term meditators during distractor tone presentation. It is hypothesised that a more concentrative practice, like focused attention meditation, may facilitate a narrowing of the attentional focus in such a way that even stronger alterations in this P3a event-related potential amplitude can be expected. Therefore, meditators in this thesis were encouraged to perform focused attention and open monitoring meditation to account for P3a amplitude differences between both types of meditation and the two control conditions (active listening, mind-wandering), where no meditative state was to be reached. In addition, a control group was asked to perform the same tasks, to account for trait effects. A three-stimulus auditory oddball paradigm was presented to the participants to gain reliable ERP responses. Overall, no state effects in the form of lower P3a amplitudes during open monitoring and focused attention meditation compared to the mind-wandering condition were observed. However, a comparison to the active listening state revealed lower amplitudes for both types of meditation, but also for mind-wandering. Further, the comparison between the two types of meditation yielded no significant differences. These results suggest that the inducement of a meditative state does not affect attentional systems in the form of altered P3a amplitudes. Although no state effects were experimentally verified, it seemed that long-term mental training can lead to sustainable trait changes. In this regard, the comparison between the meditators and the control group revealed significantly lower P3a amplitudes during all conditions for meditators over central and posterior midline electrode sites. These results suggest that long-term meditation influences the brain in a way that unexpected and distracting auditory stimuli are processed differently, indicating less automated reactivity of the brain as a trait effect. As a consequence, gained results imply that meditation, practised over a long period of time, may induce neuroplasticity, in the form of altered brain processes.

Zusammenfassung
Meditation kann als mentales Training aufgefasst werden, welches positive Eigenschaften wie allgemeines Wohlbefinden und Aufmerksamkeit fördert. Darüber hinaus kann es zu einer generellen Schulung kognitiver Fähigkeiten und zur Stärkung emotionaler Prozesse beitragen. Es wird vermutet, dass Meditation – über einen längeren Zeitraum praktiziert – Geist und Körper nachhaltig beeinflusst und möglicherweise mit Veränderungen im Gehirn in Zusammenhang steht. Eine Studie, in der Probanden ablenkende auditorische Reize präsentiert wurden, zeigte, dass Achtsamkeitsmeditation zu einer Reduktion des P3a Potentials führt, wobei dieses ereigniskorrelierte Potential ein Index dafür ist, wie viel Aufmerksamkeit einem präsentierten Reiz beigemessen wird. Es wird vermutet, dass Konzentrationsmeditation zu einer noch drastischeren Reduktion der P3a Amplitude führt, da während dieser Art der Praxis der Meditierende verstärkt fokussiert ist und daher Störgeräusche weniger stark wahrgenommen werden. In dieser Masterarbeit wurden nun Meditierende

dazu angehalten beide Arten der Meditation – Achtsamkeitsmeditation wie auch Konzentrationsmeditation – durchzuführen. Zwei zusätzliche Kontrollzustände (aktives Zuhören, "Tagträumen") dienten außerdem dazu die Unterschiede zwischen Meditation und Nicht-Meditation zu untersuchen. Zusätzlich wurde eine Kontrollgruppe in die Studie miteinbezogen, um neben dem Einfluss des Meditationszustandes auch mögliche Auswirkungen von Meditation, die über Jahre hinweg praktiziert wurde, zu beobachten. Ein sogenanntes auditorisches Oddball-Paradigma wurde verwendet, um die ereigniskorrellierten Potentiale zu evozieren. Die Ergebnisse zeigten keine P3a Amplitudenunterschiede zwischen den beiden Arten der Meditation und dem Kontrollzustand des "Tagträumens". Verglichen mit dem Kontrollzustand, in dem aktive Aufmerksamkeit den Tönen gegenüber aufgebracht werden sollte, wurden jedoch verminderte Amplituden für beide Arten der Meditation festgestellt. Dies traf jedoch auch auf den anderen Kontrollzustand zu. Der Vergleich beider Meditationsarten erbrachte keinerlei signifikante Unterschiede. Diese Resultate weisen darauf hin, dass die Induktion eines Meditationszustandes keine Unterschiede zu einem Nicht-Meditationszustand aufweist. Im Gegensatz dazu wurde gezeigt, dass Meditation möglicherweise zu nachhaltigen neurophysiologischen Veränderungen beitragen kann. Der Vergleich zwischen den Meditierenden und der Kontrollgruppe zeigte eine verminderte P3a Amplitude über den gesamten Versuchsaufbau – für beide Arten der Meditation und beide Kontrollzustände – für die zentralen und hinteren Elektroden. Diese Ergebnisse weisen darauf hin, dass erfahrene Meditierende allgemein weniger durch Störgeräusche abgelenkt werden und dass Meditation möglicherweise zu Veränderungen bestimmter Hirnprozesse, die mit Aufmerksamkeit in Verbindung stehen, führen kann.

A.3 Curriculum Vitae

PERSONAL DATA	
Name:	Rene E. Seiger
Birth:	30. August 1982
EDUCATION	
October 2010 – February 2013	**University of Vienna / Ljubljana** Cognitive Science (Master's degree)
October 2004 – June 2010	**University of Vienna** Philosophy (Diplomstudium)
March 2003 – January 2004	**Vienna University of Technology** Electrical Engineering
September 1997 – June 2002	**HTL Donaustadt** Computer Engineering
RESEARCH EXPERIENCE	
March 2012 – February 2013	**Mind & Brain Lab (Ljubljana)** Assessing influences of meditation on the brain via EEG measurements
October 2011 – February 2012	**Department of Neurology (Ljubljana)** Assisting at EEG studies
February 2011 – July 2011	**Center for Brain Research (Vienna)** Research on the distribution and composition of $GABA_A$-receptor subunits
PROFESSIONAL	
April 2010 – April 2011	**Altstoff Recycling Austria AG** Controlling
October 2008 – September 2009	**SE Orbitaltechnique and Weldingsystems** Engineering
May 2006 – October 2008	**Electrovac** Quality management
January 2004 – October 2004	**Siemens** Analysis of electronic applications