Stephen Whitmarsh

Nonreactivity and Metacognition in Mindfulness
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Stephen Whitmarsh
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Nonreactivity and Metacognition in Mindfulness

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by

Stephen Whitmarsh

Born on April 27, 1979

in Woerden, the Netherlands
Supervisor:
Prof. dr. H.P. Barendregt

Co-supervisor:
Dr. O. Jensen

Doctoral Thesis Committee:
Prof. dr. K. Roelofs
Prof. dr. J-P. Lachaux (INSERM, Lyon)
Dr. H. van Schie
For all teachers
great and small
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General Introduction

Abstract

In this thesis we set out to investigate the neural and behavioral correlates of mindfulness. The term “mindfulness” has been used in many different ways, however. Mindfulness has been variously defined as a set of cognitive functions, psychological factors, traits, skills or attitudes. A brief but comprehensive overview is therefore necessary. We will organize these different conceptualizations of mindfulness into a preliminary working model that will help parse this overview, while not presuming to be exhaustive or explanatory by itself. As we encounter different aspects of mindfulness it will also serve to provide suggestions for their interrelationships, to which we will return in the general discussion. In our overview we will start by describing how, from its historical roots in Buddhism, mindfulness has found its way into clinical interventions and experimental peer-reviewed papers. We will show that preliminary progress has been made by defining mindfulness and identifying associated psychological concepts. Most of this work has been done within the context of clinical interventions and has focused on outcome measures, without systematically investigating the functional mechanism underlying its salutary effects. Experimental neuroscience, on the other hand, has hypothesized nonreactivity and metacognitive monitoring as unique characteristics that distinguish mindfulness meditation from other meditation practices. Nonreactivity was conceived of as a disposition or ability to respond less automatically to thoughts and feelings, while metacognitive monitoring describes the ability to observe and reflect upon mental content or cognitive processes. These two aspects have received limited attention in experimental studies, preventing the evaluation of the potentially unique contribution of mindfulness to clinical interventions and experimental neuroscience in general. In the second and third chapter of this thesis we investigated the correlation between neural and behavioral measures of nonreactivity with the nonreactivity mindfulness trait. In the fourth and fifth chapter we developed a novel paradigm to study metacognitive monitoring and compared novice and highly experienced mindfulness meditators with controls.
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Mindfulness in Buddhism

Although mindfulness is generally acknowledged to have originated in Buddhist meditative practices, it has become an integral part of today's clinical practice, and a growing body of experimental work has made it a research topic in its own right. More often than not, therefore, the Buddhist origin of mindfulness has become at most a cursory note in the introduction section of scientific and clinical papers. For the purpose of this thesis, we could do the same. However, this would place us in danger of prematurely weaning research on mindfulness from a rich body of ideas, methods, and practical knowledge. Furthermore, its original practice provides a backdrop by which one can evaluate the depth of our own understanding, the potential of its practice and the problems we might face in understanding it.

Meditation (dhyāna) was certainly used to quiet the mind before the time of Šākyamuni1. Relics from the bronze age Indus Valley civilization indicated that they already practiced meditation (Cousins, 1994). Šākyamuni began practicing religious austerities under the guidance of one of the most famous teachers of that time (Ārāḍa Kālāma). After many years of meditation practice and studying with another great meditation teacher (Udraka Rāmaputra), he realized that when he emerged from the trance his mind was still buffeted by everyday problems. Meditation was useful in disciplining the mind, but the freedom he was seeking he believed, also had an aspect of understanding, which could only be realized through wisdom. Determining the exact content of the Šākyamuni's enlightenment poses several major scholarly problems (Cousins (1994), p. 27). What is important for our current understanding of mindfulness meditation is that against a climate of ascetic practices to calm the mind, he emphasized the necessity to confront and understand the reason we are distraught and distracted in the first place. He taught, therefore, an investigative meditation called Vipassanā. Vipassanā is a Pāli word from the Sanskrit prefix vi- and verbal root pas. It is often translated as insight, although the in- prefix may be misleading. Vi in Indo-Aryan languages is equivalent to the Latin dis. The vi in vipassanā may therefore mean to see into, or see through (Gunaratana, 1993). It is this investigative context within which the use of insight-meditation has found its way into contemporary western society under the name of mindfulness. It expresses the view that our lack of understanding about our personal and existential predicament causes aversion and desire, which results in greed, hatred and in fact all restless, anxious, angry and depressed mental states. In this sense, what was founded in early Buddhism was a causal model of psychology and mental health that emphasizes self-investigation and responsibility for one's mental well-being.

In the next four centuries after Gautama Buddha's death, his ideas were developed and expanded

1 The historical Buddha († 480 BCE) is often referred to as Šākyamuni (the sage of the Śākya or Śāka people). He was born into the Gautama clan. According to traditional accounts, his personal name before he left home to live a religious life was Siddhartha.
by Buddhist meditation practitioners and scholars, resulting in three collections of writings called the Tipitaka or ‘Three Baskets’. In one of these collections, the Abhidhamma Pitaka, we find an extensive treatise on mental factors which we would now call cognitive functions and mental states (Anuruddha & Bodhi, 2000). It is a conceptual cognitive framework of astonishing complexity, describing a causal model of mental processes that includes perception, feelings, recognition, intention and attention. Perhaps even more impressive than its scope, is its logical consistency. Mental functions and states are cross-referenced within a classification system that describes mutual causes, the ways in which mental factors are expressed and the functions they perform. Incredibly large and dense, the Abhidhamma is supplemented by explanatory commentaries such as the classical Abhidhamma Sangaha (Anuruddha & Bodhi, 2000). In the authoritative translation of the Abhidhamma Sangaha we find the Pali sati translated as mindfulness. It describes sati as follows: “The word sati derives from a root meaning ‘to remember,’ but as a mental factor it signifies presence of mind, attentiveness to the present, rather that the faculty of memory regarding the past. It has the characteristics of not wobbling, i.e. not floating away from the object. Its function is absence of confusion or non-forgetfulness. It is manifested as guardianship, or as the state of confronting an objective field. Its proximate cause is strong perception of the four foundations of mindfulness” (II-8, p. 86).

Interestingly, even when one disregards the idiosyncratic nomenclature, one notices that this description is not written for any obvious practical (i.e. therapeutic or spiritual) use. It is rather a second collection of writings, the Sutta Pitaka, that is explicitly didactic. In it one finds the descriptions of how to practice mindfulness meditation. In the famous Anapanasati Sutta, or Mindfulness of Breathing Sutta, the practitioner is required to find a quiet place, and to do the meditation in a straight posture: “There is the case where a monk, having gone to the wilderness, to the shade of a tree, or to an empty building, sits down folding his legs crosswise, holding his body erect, and setting mindfulness to the fore. Always mindful, he breathes in, mindful he breathes out.”

This is followed by instructions of what this mindfulness of breathing entails: “Breathing in long, he discerns, ‘I am breathing in long’. Breathing out long, he discerns, ‘I am breathing out long.’ Breathing in short, he discerns, ‘I am breathing in short’. Breathing out short, he discerns, ‘I am breathing out short.’ He trains himself, ‘I will breathe in sensitive to the entire body.’ He trains himself, ‘I will breathe out sensitive to the entire body.” The text then expands the instruction to include the observation of feelings, mental qualities and mental states, adding up to the “four foundations of mindfulness” mentioned earlier in the citation of the Abhidhamma Sangaha.

What becomes clear from juxtaposing these two descriptions of mindfulness, is that although they obviously refer to each other, they have been developed for very different purposes: on the one hand as a scholarly description of mindfulness as mental factor or function, and on the other

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hand as a very practical meditation instruction. In contemporary scientific literature this distinction between theoretical cognitive mechanisms and the actual practice of mindfulness meditation is rarely acknowledged but has determined to a large degree how the term mindfulness has been used. The resulting conceptualizations of mindfulness in experimental and clinical work seem therefore rather to diverge than converge in their understanding. The challenge in researching mindfulness is therefore perhaps not so much a potential incommensurability between Buddhist and western descriptions of mindfulness, but rather between strict cognitive definitions of mindfulness (as a cognitive function or ability), and the way they are developed and performed, (as behavior or as a cognitive-emotional set). It has, for instance, been argued that the ‘to remember’ in the Pali translation of sati, probably means to remember to remain aware and can therefore be best translated as “to be mindful” instead (Batchelor, 1997). Similarly, Grossman & Van Dam (2011) argue that the use of the noun “mindfulness” too easily implies a fixed trait, when it should more accurately be seen as a (lifelong) practice. In this thesis we will repeatedly encounter this problem as mindfulness will be defined either as a set of cognitive functions, a trait, a meditation or a clinical intervention. We will distinguish different uses of the term mindfulness when needed, and clarify their function by explicating their relationship with other concepts using the working model depicted in Figure 1.

![Figure 1. Schematic outline of mindfulness meditation describing the relationship between the psychological concepts and cognitive functions used in clinical research, clinical practice and experimental science.](image-url)
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Mindfulness in clinical interventions

Paramount to the successful introduction of mindfulness into the contemporary western world has been the explicit ‘stripping away’ of its Buddhist context. In the words of Jon Kabat-Zinn: “Mindfulness is often spoken of as the heart of Buddhist meditation. It’s not about Buddhism, but about paying attention. That’s what all meditation is, no matter what tradition or particular technique is used.” In 1979, Kabat-Zinn started the Mindfulness Based Stress Reduction program (MBSR) at the Stress Reduction Clinic at the University of Massachusetts Medical Centre. Based largely on this MBSR, a Mindfulness Based Cognitive Therapy (MBCT) was later developed to prevent relapse in recurrently depressed patients (Teasdale, Segal, & Williams, 1995; Teasdale et al., 2000). Although the MBCT, MBSR, Dialectic Behavioral Therapy (DBT, see Robins & Chapman, 2004) and Acceptance and Commitment Therapy (ACT, see Hayes, Luoma, Bond, Masuda & Lillis, 2006) are probably most widely known to the scientific community, these programs are certainly not the only ones that have integrated mindfulness in clinical interventions. In fact one could talk of a “third wave of behavioral therapy” that emphasizes mindfulness and acceptance, and is generally oriented more towards experiential than didactic practices (Hayes, 2004).

MBCT and MBSR are group interventions that last eight to ten weeks. They consist of weekly sessions lasting about two hours, along with a single all-day class. Much of the practice is done outside of classes, however. Formal meditation occurs at home via CD’s of guided meditations in which one is instructed to focus on bodily sensations and to respond to distractions in a focused but nonjudgmental way. This is done for periods of increasing duration, starting with 10 minutes during the first days, and increasing gradually to 45 minutes in the last week. Teasdale and colleagues (1995) explain formal meditation as follows: “In formal mindfulness practice, the student sits quietly in an erect and dignified posture and attempts, non-strivingly, to maintain attention on a particular focus, commonly breathing. When attention wanders from the breath to the thoughts and feelings that inevitably arise, the student ‘acknowledges and accepts’ the thoughts and feelings and gently redirects attention back to the breath. This procedure is repeated many times, whenever the student notices that the attention has wandered” (p. 33). Participants are also required to find moments throughout their day when they can do a short three-minute mindful breathing exercise. They are further instructed to find a regular physical daily activity that they can perform with similar attention and attitude, such as brushing their teeth or walking to work. In MBSR, and especially in MBCT, some form of psycho-education is provided as well, consisting mainly in explaining two alternative psychological modes by which one can respond to distressing experiences: either through reacting (without thinking or awareness) or by responding (considering the situation before choosing a productive response).
Defining mindfulness

While evidence that mindfulness based interventions can help a broad range of individuals cope with their clinical and nonclinical problems is accumulating (Baer, 2003; Chiesa & Serretti, 2009, 2010b; Grossman, Niemann, Schmidt, & Walach, 2004; Hofmann, Sawyer, Witt, & Oh, 2010), most studies suffer from methodological limitations and the lack of active controls. Importantly, effectiveness trials of mindfulness are far from identifying mechanisms by which mindfulness works, with theoretical and methodological advances lagging behind. In the words of Bishop and colleagues (2004): “As long as questions concerning construct specificity and operational definitions remain unaddressed it is not possible to undertake important investigations into the mediating role and mechanisms of action of mindfulness or to develop instruments that allow such investigations to proceed” (p. 231). A decade earlier, Kabat-Zinn (1994) did provide a concise definition of mindfulness: “paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally.” What Bishop and colleagues (2004) are referring to, is that such a definition does not, by itself, provide hypotheses about the cognitive mechanisms that underlie its salutary effects. Without such explicit proposals, it remains unclear how to go about testing its therapeutic claims. In a first attempt to operationalize mindfulness meditation, they suggest two components of mindfulness. The first is present-moment attention, operationalized as sustained attention, attention switching, and the inhibition of elaborative processing (i.e. inhibiting thoughts about experience). In this context they consider mindfulness a metacognitive skill, as it requires both cognitive control and monitoring of the stream of consciousness. The second component they propose is “a particular orientation toward one’s experiences in the present moment characterized by curiosity, openness and acceptance (...) involving the conscious decision to abandon one’s agenda to have a different experience and an active process of ‘allowing’ current thoughts, feelings and sensations.” They suggest that such experiential curiosity and openness should result in a decreased repressive coping style, increased dispositional openness and improved affect tolerance. Furthermore, they conceptualize mindfulness as a process of investigative awareness that involves observing the ever-changing flow of private experience. This would lead to increased cognitive complexity, e.g. the ability to differentiate feelings from bodily sensations and to describe the complex nature of emotional states. As such, mindfulness would be positively correlated with measures of emotional awareness and negatively correlated with measures of alexithymia. Similarly, a greater capacity to see relationships between thoughts, feelings and actions would be correlated positively with the ability for self-examination.

Mindfulness as a tool

This emphasis on the investigative use of mindfulness meditation clearly echoes the Buddhist
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vipassana practice and positions mindfulness practice within a process-oriented therapeutic context. However, reminiscent of the Buddhist distinction with sati, the first part of the definition offered by Bishop and colleagues (2004) describes mindfulness as a set of basic cognitive functions related to attention. Mindfulness is therefore defined on two different levels of description but without a description of how these levels might interact to result in therapeutic outcomes. For this, we will return to a description of the mindfulness practice in clinical interventions. We will take the MBCT as an example, but suggest that a similar approach is taken in other mindfulness based interventions. The MBCT is based on the idea that depressed patients in remission are likely to revert to destructive ruminations once a negative mood returns, resulting in a vicious circle of negative thoughts and feelings (Teasdale et al., 1995). Although this can be explained by the therapist intellectually, mindfulness meditation is thought to enable the patient to become personally aware of these mechanisms as they happen. This would enable them to undertake measures to prevent themselves from getting caught up in them. Importantly, this is not the end of the practice. The patients are taught to apply more productive (i.e. nonreactive) attitudes towards negative experiences during meditation so that they can experience the benefits first-hand, preparing them for real life contingencies. In a very literal way, therefore, mindfulness should be considered a tool rather than an end in itself. Patients must make an commitment to use this tool appropriately, namely by attending to spontaneous experiences that might not be pleasant, expected or understood. In doing so, patients learn which attitudes enable such an investigation, and can practice those that improve their well-being. The calm, nonreactive, nonjudgmental attitudes that are developed through mindfulness meditation can therefore be considered both as necessary attitudes for meditation practice, as well as a specific skill set that can be practiced to improve well-being. Mindfulness meditation therefore consists of the repeated application of a set of cognitive functions (present-moment attention) for the purpose of discovering beneficial (i.e. nonreactive) attitudes towards experience. In our model (Figure 1), the (negative) experiences are put under box E, the metacognitive investigation under box F, and the modulating attitudes under box C. We will discuss the attentional system at length in the second section of the introduction.

Mindfulness as a trait

Although mindfulness has been described in terms of present-moment attention and mindful attitudes, much questionnaire work has been done on mindful traits. In questionnaire research, mindfulness is regarded as an inherent capacity that is expressed amongst individuals in a greater or lesser degrees (Brown & Ryan, 2003; J. Kabat-Zinn, 2003; Kuhlman, 2002). The idea is that some people might be naturally inclined to be more mindful in daily life, while others are less so. Generally, these questionnaires conceptualize mindfulness as a trait that consists of psychological
characteristics that are considered important in mindfulness meditation or mindfulness based interventions. They are therefore designed for and administered to non-meditator samples. These questionnaire studies have several methodological limitations. First, because few people in the general population understand what the term “mindful” means or attribute to it a wide range of meanings, there is little use in asking explicitly how mindful they believe they are. To address this problem, questionnaires are phrased in ordinary language to ensure people do not need to understand the underlying concepts, and are not required to notice mindful aspects in their daily functioning. Often reverse-scored items are used, as experiences of mindlessness (doing things automatically) are considered to be more easily recognized. These questionnaires therefore only address hypothesized effects of a mindful disposition in ordinary daily experience and behavior.

Second, most mindfulness questionnaires aim at measuring different factors, or elements of mindfulness, but the vast majority ends up collapsing all items (questions) into one general score. Thus, important distinctions between various aspects of mindfulness are obscured. Third, although questionnaires treat mindfulness as a dispositional trait, there is little evidence that mindfulness is, in fact, consistent over time and across situations. To the best of our knowledge, only a single test-retest reliability of trait mindfulness has been reported so far, which did show good to excellent performance (Veehof, Ten Klooster, TaaL, Westerhof, & Bohlmeijer, 2011). Fourth, and perhaps most problematic, is the fact that mindfulness questionnaires operationalize mindfulness differently. The Freiburg Mindfulness Inventory (FMI; Buchheld, Grossman, & Walsh, 2001) was originally developed with participants in mindfulness meditation retreats and was designed to be used with experienced meditators. A later version of the FMI was developed for non-meditating populations (Walach, Buchheld, Buttenmuller, Kleinknecht, & Schmidt, 2006). In contrast, the Kentucky Inventory of Mindfulness Skills (KIMS; Baer, Smith, & Allen, 2004) and Cognitive and Affective Mindfulness Scale–Revised (Fieldman, Hayes, Kumar, Greenson, & Laurenceau, 2007) are mainly based on the mindfulness skills described in the DBT programs and later adapted to be consistent with the MBSR and MBCT. The Southampton Mindfulness Questionnaire (Chadwick et al., 2008) specifically measures mindfulness responses to unpleasant response while the Mindful Attention Awareness Scale (MAAS, Brown & Ryan, 2003) measures characteristics that are considered inconsistent with mindfulness and then reverses the scores. In chapter 1 and 2 we have used the Five Factor Mindfulness Questionnaire (FFMQ, Baer et al., 2006) which is the result of a factor analysis of these five previously developed questionnaires. Its subscales are: Observing (noticing or attending to internal and external experiences, such as sensations, cognitions, emotions, sights, sounds, and smells), Describing (labelling internal experiences with words), Acting with awareness (attending to one’s activities of the moment in contrast with behaving mechanically while attention is focused elsewhere), Nonjudging (taking a non-evaluative stance toward thoughts and feelings) and Nonreactivity (allowing thoughts and feelings to come and go, without getting caught up in or carried away by them).
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FREIBURG MINDFULNESS INVENTORY
“I am open to the experience of the present moment.”
“I sense my body, whether eating, cooking, cleaning, or talking.”
“When I notice an absence of mind I gently return to the experience of the here and now.”

MINDFUL ATTENTION AWARENESS SCALE
“I find myself doing things without paying attention.” (R)
“I break or spill things because of not paying attention, or thinking of something else.” (R)
“It seems I am “running on automatic” without much awareness of what I’m doing.” (R)

KENTUCKY INVENTORY OF MINDFULNESS SKILLS
“When I’m walking, I deliberately notice the sensations of my body moving.”
“I’m good at finding the words to describe my feelings.”
“When I do things, my mind wanders off and I’m easily distracted.” (R)
“I tell myself that I shouldn’t be feeling the way I’m feeling.” (R)

COGNITIVE AND AFFECTIVE MINDFULNESS SCALE - REVISED
“I am able to focus on the present moment.”
“I am preoccupied by the past.” (R)
“I am able to accept the thoughts and feelings I have.”

SOUTHAMPTON MINDFULNESS QUESTIONNAIRE
“When I have distressing thoughts or images, I am able just to notice them without reacting.”
“When I have distressing thoughts or images, I judge the thought or image as good or bad.” (R)
“When I have distressing thoughts or images, in my mind I try and push them away.” (R)

FIVE FACET MINDFULNESS QUESTIONNAIRE
This is a composite of the preceding five questionnaires and includes items from each.

Figure 2. Mindfulness questionnaires and example items. R = reverse-scored item. Adapted from BAER, 2011.
Although factor analysis suggest that these are facets of an overall mindfulness construct (Baer et al., 2006; Baer et al., 2008), no suggestions are made as to how these would interact to produce a mindful trait. The first three factors clearly describe metacognitive monitoring, while the latter two correspond to attitudes or cognitive sets. This suggests that the distinction between metacognitive monitoring and attitudes we have been making remains important when considering traits.

There is some evidence that the FFMQ captures a tendency of people to “be mindful” in daily life. It correlates positively with standard personality traits such as openness to experience, and correlates negatively with neuroticism and absent-mindedness. It also correlates negatively with clinically relevant traits such as difficulties in emotional regulation and alexithymia (Baer et al., 2006; 2008). Participants in MBSR and MBCT have shown significant increases in mindfulness scores over the course of treatment, suggesting that they can learn ‘to be more mindful’ in daily life and that mindfulness questionnaire are able to measure this progress (Carmody & Baer, 2008; Kuyken et al., 2010). Furthermore, Carmody and Baer (2008) found that improvements in self-reported mindfulness were strongly correlated with time spent in home mindfulness practice and with the extent of reduction in psychological symptoms and stress. Statistical analyses suggested that it was the increase in mindfulness skills brought about by home practice that was responsible for the improvements. Similarly, depressed persons who completed MBCT showed increases in mindfulness skills that predicted reduced depression 15 months later (Kuyken, Crane, & Dalgleish, 2012). These findings provide the first empirical evidence for the idea that practicing mindfulness leads to increased mindfulness in daily life, which in turn reduces psychological suffering.

However, the presumptive mindfulness traits map only indirectly onto the concept of mindfulness that is defined in terms of an accepting present-moment awareness. Neither does a description of mindfulness in terms of traits provide a mechanism by which these traits could be developed. At least not without resorting to a trivial definition of mindfulness practice, i.e. practicing those personality characteristic that are deemed mindful. We can clarify this issue by expanding our model and describing mindful traits (box D) as a disposition to express mindful attitudes (box C). These traits cannot be considered to completely determine the expression of mindful attitudes, as this would make any change impossible. We emphasize instead, that mindful attitudes can be expressed even when one is predisposed against them. Furthermore, through repeated use of mindful attitudes, they might become habituated, resulting in more productive, i.e. mindful, mental habits (box C to box D).
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Following these rather detailed descriptions, we can summarize the different ways by which mindfulness is used in clinical research.

1. **Mindfulness** as a tool, or set of attentional and metacognitive functions used for the introspective investigation of present moment experiences
2. **Mindfulness meditation** as the repeated application of (1)
3. **Mindful attitudes** as cognitive-emotional sets that enable (2)
4. **Mindful traits and skills** as those dispositions towards – or skills in - performing (3)

We can now provide a more comprehensive description of mindfulness that integrates all of these different ways in it is used: *Mindfulness is the metacognitive control of attention towards - and the monitoring of - present moment experiences, occurring in association with a mindful attitude that is conducive to its investigation, where discovery and practice of mindful attitudes are the primary vehicle of therapeutic change, and where the ability and tendency to use these attitudes is a function of its trait. Furthermore, as a long-term consequence of this practice, the expression of a mindful attitude might become habituated and promote further well-being.*

The process described in the model is repeated many times within a single meditation session. This is why in the model an *intentional* aspect of the meditation is included (box B). Mindfulness meditation can be a disquieting and often unpleasant experience. It is not undertaken as an quick escape from negative conditions, but as an experiential practice that provides the practitioner with insight into the causes of suffering and enables the exploration of self-regulation strategies. A commitment to maintain this meditative practice, for these reasons, we deem essential for any long term positive outcome to occur. In other words, only with the appropriate *intention* will the separate aspects of mindfulness be organized into a mindfulness meditation practice (i.e. Vipasanna).

Finally, for the sake of completeness the schema also allows for the inclusion of those aspects that are associated with mindfulness meditation in the original Buddhist context, such as its moral and soteriological motivations. However, we hereby suggest, together with modern secular scholars (i.e. Batchelor (1997) and J. Kabat-Zinn (2003)), that these are not essential aspects of the mindfulness practice.
Neuroscience of meditation

We have described how mindfulness meditation has been used in the clinical context in some detail, describing its main concepts and proposing a preliminary framework for understanding its salutary effects. We have seen that clinical research on mindfulness has suffered from being focused primarily on outcomes rather than on processes or mechanism of change. To gain a mechanistic understanding of mindfulness meditation, experimental neuroscience is indispensable, e.g. to test specific claims of long-term effects on cognition and affect regulation. More importantly, without direct evidence for the involvement of neural mechanisms that define mindfulness meditation, our understanding of its mechanisms and outcomes will remain subjective and inferential.

We will first give a short overview of the neuroscience of meditation and discuss recent theoretical advances that propose a set of cognitive functions that can distinguish mindfulness meditation from other forms of meditation. Neuroscience has long been a topic of fascination for researchers, proceeding the current popularity of mindfulness by decades. Mostly neuroscience on meditation has focused on state or trait effects on the brain. A seminal review by Cahn and Polich (2006), spanning over 50 years of electroencephalography and neuroimaging studies on meditation found the field in a sorry state. They identified a general lack of standardized designs for assessing meditation effects across studies, a wide variety of different meditation techniques used, and a lack of technical expertise, especially in earlier studies. Considerable discrepancy amongst results prevented them from formulating convincing conclusions. Only the most tentative observation was made that many studies showed a general increase in alpha power during meditation compared to control tasks, and that similar effects were reported as long-term effects. Given that increases in alpha have traditionally been associated with decreases in arousal, it remained an open question whether these findings show specific effects of meditation beyond those resultant from relaxation. The authors proposed that only a fine-grained topographical mapping could resolve this issue. Four years later these conclusions were repeated in a review of cognitive and neuroimaging results in which only controlled and cross-sectional studies of mindfulness meditation were included (Chiesa & Serretti, 2010b). In addition, they reported that long-term meditation was associated with an enhancement of cerebral areas related to attention (the prefrontal cortex and anterior cingulate cortex), which suggests that mindfulness meditation is an active attentional practice.

Focused Attention versus Open Monitoring

In the same year as Cahn and Polich’s massive overview, Lutz, Dunne and Davidson published an influential chapter called “Meditation as the Neuroscience of Consciousness”, published in the Cambridge Handbook of Consciousness (2006). In a monumental cross-
disciplinary effort, they reviewed different Buddhist meditation techniques in both scholarly and experiential detail, and provided an overview and taxonomy of meditation techniques for future neuroscientific research. The taxonomy is largely based on the relationship between attention and the object of attention. Mindfulness (Vipasanna) meditation is placed between two poles of practice they describe as focused attention (FA) and open monitoring (OM): "... on the one hand, one pointed-attention techniques cultivates a form of voluntary, effortful and sustained attention on an object [FA], and on the other hand vipasanna meditation cultivates a more broadly focused, non-judgmental mode of bare attention [OM]. (...) The emphasis on stabilizing the mind on an object [FA] or on the awareness of the intentional relation itself [OM] depends on the given technique but also, likely, on the degree of accomplishment of the practitioner in a given practice". In a later publication, Lutz et al. (2008) offers the following summary:

**FOCUSED ATTENTION MEDITATION (FA)**

◊ Directing and sustaining attention on a selected object (e.g. breath sensation)
◊ Detecting mind-wandering and distractors (e.g. thoughts)
◊ Disengagement of attention from distractors and shifting of attention back to the selected object
◊ Cognitive reappraisal of distractors, e.g. "just a thought" and "it is okay to be distracted"

**OPEN MONITORING MEDITATION (OM)**

◊ No explicit focus on objects
◊ Nonreactive meta-cognitive monitoring (e.g. for novices, labeling of experience)
◊ Nonreactive awareness of automatic cognitive and emotional interpretations of sensory, perceptual and endogenous stimuli.

The model in Figure 1 shows how FA consists of attentional control mechanisms (box G, Figure 1) for the purpose of sustaining attention on the intended object, typically the sensations of the breath (box I). Once attention is drawn towards a distracting thought or feeling (box E), it is returned back to the intended object. In OM, however, the new object of attention is attended to (thought, feeling or sensation) for as long as it is presents itself to conscious awareness. In our model the unintended object of attention is therefore placed outside of FA, and inside OM. Furthermore, as a certain degree of focused and sustained attention is necessary for OM to occur, FA is subsumed under OM. OM distinguishes itself from FA by an additional metacognitive monitoring of the intentional relationship with the objects of attention (Box F). In other words, OM consists of a conscious monitoring of shifts in attention, allowing the observation and
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investigation of the push-and-pull of experiential events. Note that in their description of OM, Lutz and colleagues (Lutz et al., 2006) used the term nonreactive. Although nonreactive monitoring is an important aspect of OM, similarly as in Bishop (Bishop et al., 2004), such a description creates a categorical confusion by coupling a cognitive function with a trait or attitude. Our model clarifies the issue by explicating their relationship with the distracting experience (Box E to Box D, and box D to Box C). In other words, how the experience it is likely to be processed (if at all) is not a property of metacognitive awareness but depends on the individual’s reactive trait and attitude. It is at this dispositional level that mindful traits describe the tendency to remain attentive to experience, and engage continued metacognitive awareness. If the person has a nonreactive disposition, the experience has more chance of being attended to. If instead the person has a tendency to respond to experiences ‘on automatic pilot’, the distracting experience will trigger further thoughts and feelings that will disengage the tentatively maintained attention, resulting in a loss of metacognitive awareness.

The authors also suggest that the degree to which either FA or OM is emphasized in the meditation practice is dependent on the accomplishment of the meditator. Indeed, traditional mindfulness meditation progresses from an emphasis on an object of attention to the intentional relationship with experience. For instance, in intensive vipasanna retreats, the first days are typically spent solely on focusing attention to sensations of the breath (Sayadaw, Aggacitta, & Wheeler, 2001). The purpose of this initial practice is to create a necessary degree of attentional stability so that attention can be ‘anchored’ onto experiences that occur in the present moment, instead of on thoughts and feelings about them. A degree of sustained attention is also needed to recognize sensations, thoughts and feelings when they occur. Gradually, the priority of this ‘anchor’ of attention can be released and former distractors included in the practice of mindful observation. Novice meditators often start by mentally noting their experiences using simple verbal labels (e.g. “hearing”, “feeling”, “thinking”) to maintain awareness of what is going on and to reduce mental and emotional elaboration. Finally, experiences can be merely noted, and attention is given more to the intentional relationship the meditator has with experience (rather than with the objects of experience). These later metacognitive stages are not achieved by everyone as easily within the time span of a mindfulness intervention, or within a single vipassana retreat. The fact that the effects of OM are expected to occur only after extensive practice might explain the inconsistency in top-tiered neuroscience publications that, while referring to the distinction between FA and OM, classify mindfulness meditation FA. (Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012; Lutz et al., 2009a; Slagter et al., 2007). In fact, in a recent review on the cognitive benefits of mindfulness meditation, Chiesa and colleagues (2011)4 showed that moderately brief mindfulness training (an eight week meditation program or a short-term

4 4515 studies on mindfulness, vipasanna and Zen were found until May 2010. 35 published papers investigated cognitive correlates of mindfulness meditation of which 23 were finally included in the meta-analysis.
retreat) only improved selective and sustained attention abilities. However, a majority of reviewed studies found significantly higher attentional abilities in long term mindfulness meditators as compared with matched controls as well as a significant positive relationship between total hours of meditation experience and attentional abilities. Chiesa et al. (2011) therefore suggested that, while there was evidence for increased abilities with FA meditation, effects related to OM might only develop as a result of extensive mindfulness training.

Summary and outline of thesis

We have given an overview of the ways in which mindfulness has been conceptualized and measured, from its Buddhist origins to contemporary clinical and neuroscientific research. We have shown that mindfulness is generally understood to consist of two aspects that distinguish it from mere Focused Attention, namely, nonreactivity and metacognitive monitoring. These were also argued to be essential for its clinical potential. Nonreactivity was described as a disposition or attitude to respond less automatically to experience. Metacognitive monitoring describes the ability to observe and reflect upon mental content or cognitive processes. Furthermore, we integrated all the relevant clinical and cognitive aspects of mindfulness in a preliminary model of mindfulness meditation.

The aim of this thesis is to investigate the behavioral and neural correlates of these two distinguishing aspects of mindfulness. In the first two studies we investigated whether the mindfulness trait correlated with objective measures of (non)reactivity. In the first study we measured automatic somatosensory responses to the observation of painful images. In the second, we measured the tendency to respond habitually to unconsciously acquired preferences. In the third study we developed a paradigm that could objectively measure metacognitive monitoring of the ongoing attentional state, in an experiment that simulated mindfulness meditation. In our last chapter we used this paradigm to compare Controls with novice and expert meditators, to test whether extensive mindfulness meditation increases the ability for metacognitive monitoring.

Second chapter

The mindfulness trait is assumed to reflect a tendency to react less automatically to affective experiences. Previous research suggests that observing pain in others automatically activates the somatosensory cortex. By measuring somatosensory alpha suppression using magnetoencephalography, we measured the automatic activation of bodily representations in response to the observation of painful images. We sought evidence for an individual trait of reactivity by correlating the degree of somatosensory alpha suppression with the Interpersonal Reactivity Index (Davis, 1983) and the Five Factor Mindfulness Questionnaire (Baer et al. 2006).
Third chapter

Much of our actions are habitual, performed automatically and without conscious awareness. Many of these are complex skills, such as language or riding a bike, which we can acquire implicitly, without conscious intention. Such implicit knowledge is expressed through habitual responses that are often hard to inhibit. In the second chapter we investigated whether the nonreactive mindfulness trait would correlate negatively with the tendency to respond habitually to such implicit knowledge. Participants performed a working memory task in which they were, unknowingly, exposed to complex regularities. It is a well-established finding that participants remain naïve about the existence of these underlying regularities. However, when asked, they show a preference for similar regularities above those that violate them. We hypothesized that participants who display a more mindful disposition would base their preference less on these implicit representations.

Fourth chapter

In the third chapter we developed a novel paradigm to measure metacognitive awareness of attention. Specifically, we tested whether participants were able to report on their degree of present-moment attentional focus. For this purpose, we measured magnetoencephalography while participants were attending covertly to either their left or right hand. At unpredictable moments participants were probed to report on their attentional state at that moment using a button press. We hypothesized that higher self-reported attention would correspond to lower contralateral alpha power. Furthermore, we predicted that a correspondence between alpha power and reported attentional state would be specific for the contralateral hemisphere but would not occur, or occur less, with ipsilateral alpha power. This would indicate that participants would indeed report specifically on attentional focus, rather than on a general attentional state or state of arousal.

Fifth chapter

In the fourth chapter we used the experimental paradigm developed in the previous chapter to investigate the effect of mindfulness meditation experience on the ability for metacognitive awareness of attention. We compared mindfulness meditators with a control group. Furthermore, within the meditation group, we compared those that had considerably more extensive meditation experience with novice meditators. We hypothesized that meditators would display a greater ability to accurately report on present-moment attentional focus than controls. Furthermore, we expected mindfulness meditators to show more consistent differences in contralateral alpha power over time, i.e. between ‘good’ versus ‘bad’ trials. Furthermore, we expected these differences to be expressed more strongly by expert meditators as compared to novice meditators.
CHAPTER 2. Sensorimotor alpha activity is modulated in response to the observation of pain

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Sensorimotor alpha activity is modulated in response to the observation of pain

Abstract

The perception-action account of empathy states that observation of another person's state automatically activates a similar state in the observer. It is still unclear in what way ongoing sensorimotor alpha oscillations are involved in this process. Although they have been repeatedly implicated in (biological) action observation and understanding communicative gestures, less is known about their role in vicarious pain observation. Their role is understood to provide a graded inhibition through functional inhibition, thereby streamlining information flow through the cortex. Although alpha oscillations have been shown to have at least visual and sensorimotor origins, only the latter are expected to be involved in the empathetic response. Here, we used magnetoencephalography (MEG), allowing us to spatially distinguish and localize oscillatory components using beamformer source reconstruction. Subjects observed realistic pictures of limbs in painful and no-pain (control) conditions. As predicted, time-frequency analysis indeed showed increased alpha suppression in the pain condition compared to the no-pain condition. Although both pain and no-pain conditions suppressed alpha and beta band activity at both posterior and central sensors, the pain condition suppressed alpha more only at central sensors. Source reconstruction localized these differences along the central sulcus. Our results could not be accounted for by differences in the evoked fields, suggesting a unique role of oscillatory activity in empathetic responses. We argue that alpha oscillations provide a unique measure of the underlying functional architecture of the brain, suggesting an automatic disinhibition of the sensorimotor cortices in response to the observation of pain in others.

CHAPTER 2. Sensorimotor alpha activity is modulated in response to the observation of pain

Introduction

When seeing a football player receive a painful tackle we cringe and might even grasp our own knee in affective resonance with the victim’s painful state. This phenomenon of vicarious pain experience is explained in the perception-action account of empathy: “The attended perception of the object’s state automatically activates the subject’s representation of the state, situation, and object, and the activation of these representations automatically primes or generates the associated autonomic and somatic responses, unless inhibited” (Preston & de Waal, 2002).

The perception-action account of empathy for pain has been greatly expanded upon in the last decade, resulting in a nuanced neuroscientific framework that integrates knowledge of affective and perception-action processes with an understanding of the influences of social context, expectation and attention (for a comprehensive review on its evolutionary basis and social expression in humans and animals see Preston and de Waal (2002) and for a systematic review on the neuroscience of empathy see de Vignemont and Singer (2006), Singer (2006) and Decety and Jackson (2004)). De Vignemont and Singer (2006) offer a precise definition of empathy, distinguishing it from cognitive perspective-taking on the one hand and emotional contagion on the other. They characterize empathy as being in an affective state isomorphic to another person’s affective state, elicited by observation or imagination of another person’s affective state, but without losing the understanding that it is the other person’s affective state that is the cause of one’s own. Two important remarks should be made, however, in light of the current experiment. First of all, the focus on the affective response should not ignore the importance of sensory processes, as we shall see. Secondly, although empathy is certainly not restricted to the sharing of negative affective states, most neuroscientific investigations, this one included, have used the observation of pain as a model to test the notion of shared representations in empathy. Indeed, it has been firmly established that the observation of pain in others involves a network of affective brain regions, such as the anterior cingulate, paracingulate gyrus and anterior insular, that are also activated during the first-person experience of pain (Ingvar, 1999; Rainville, 2002). Furthermore, responses in these regions have been found using a wide variety of paradigms, from presenting abstract cues of other people in pain (Jackson et al., 2005; Saarela et al., 2007; Singer et al., 2004), to pictures of body parts being pin-pricked (Lamm, Nusbaum, Meltzoff, & Decety, 2007) and painful facial expressions (Jabbi & Keysers, 2008). Empathetic responses in these brain regions have, furthermore, been shown to be influenced by social contexts such as group membership and perceived fairness (Hein, Silani, Preuschoff, Batson, & Singer, 2010) as well as task demands and knowledge about the reality of the stimulus (Gu & Han, 2007). Often, but less consistently, primary somatosensory regions are found to be involved, which seems to depend on the availability of the sensory information about the painful stimulus. In their meta-analysis of nine fMRI experiments, Lamm, Decety and Singer (2011) showed that vicarious activation of
the somatosensory cortex seems only to occur when visual details of the flesh-and-bone aspect of the painful situation are observed, not when these are inferred from abstract cues. The authors propose, however, that this somatosensory activation reflects unspecific co-activation elicited by the visual display of body parts rather than a specific matching of the other's somatosensory and nociceptive state. This is in line with their aforementioned characterization of empathy as, first and foremost, an affective state. Other authors, however, have argued for the functional importance of primary sensory cortices as part of the empathetic (pain) response, subserving pain-intensity and location coding (Keysers, Kaas, & Gazzola, 2010). Interestingly, in this respect individual propensities differ greatly, as shown by Osborn and Derbyshire (2010). They reported that those people that respond to painful images by experiencing a 'real' sensation of pain, show activation of somatosensory cortices, while these regions are not activated in those that do not have such first-person experiences. Further evidence for the involvement of sensory cortices in pain observation comes from electroencephalography (EEG) studies. Bufalari and colleagues (2007) recorded a reduction of early sensory evoked potentials after medial nerve stimulation when subjects were watching movies of limbs in painful situations (Blakemore, Bristow, Bird, Frith, & Ward, 2005). Pain systems are also tightly linked to action systems (Farina, et al., 2003; Ingvar, 1999; Joutonen et al., 2002; Saitoh, et al., 1999; Wager et al., 2004), and it has been repeatedly shown that observation of painful movies strongly inhibits corticospinal excitability specific for the muscle that was observed being pinpricked (Avenanti, et al., 2005, 2006, 2009). These findings together suggest that primary sensorimotor regions are indeed involved in the empathetic response in ways that entails more than a-specific increases in arousal.

Questions of when empathetic responses occur have been investigated using electroencephalography scalp recordings (EEG). Fan and Han (2008) found larger early (140-380 ms) frontal event-related potentials (ERPs) amplitudes in response to pictures of limbs in painful situations compared to those in control situations. These early empathic responses were influenced by contextual reality (real pictures versus cartoons). Later (380-500 ms) central-parietal effects of pain that were prominent in a pain judgment task, were greatly reduced when subjects only had to count the number of limbs. This shows that the empathetic response can be modulated at different times, due to different task contexts, in line with a model of empathy that permits modulation of an automatic perception-action response at multiple stages (de Vignemont & Singer, 2006). Frequency analysis of EEG and magnetoencephalography (MEG) recordings has also been a particularly successful tool in studying the involvement of the sensorimotor system in action, touch and pain observation. Alpha (~10 Hz) and beta (~20Hz) oscillations originating from the sensorimotor cortex (Hari & Salmelin, 1997) have been implicated in action observation (Caetano, Jousma, & Hari, 2007; Cochin, et al., 1999; Hari et al., 1998; Holz, et al., 2008; Jarvelainen et al., 2001; Kilner, Marchant, & Frith, 2006; Koelewijn et al., 2006;
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2008; Muthukumaraswamy & Johnson, 2004; Muthukumaraswamy, Johnson, & McNair, 2004; Nakamura et al., 2004; Oberman, Pineda, & Ramachandran, 2007; Pineda, 2005; Rossi et al., 2002; van Elk et al., 2008) recognizing point-light biological motion (Ulloa & Pineda, 2007), as well as in understanding communicative gestures (Nakamura et al., 2004). Muthukumaraswamy and Johnson (2004) were the first reporting a reduction of the beta rebound after medial nerve stimulation when subjects concurrently observed a hand being brushed or pricked, but not when only movement was observed. Cheng, Yang et al. (2008) also observed reduced alpha rebound after medial nerve stimulation while people watched static pictures of limbs in painful situations. Although these studies point to a modulation of the somatosensory cortex, they do not show how somatosensory oscillations respond to the observation of pain in the absence of actual somatosensory stimulation. To investigate such a visual-to-somatosensory process, three EEG studies investigated effects on ongoing alpha oscillations after observing images of painful situations versus control images, without a contingent transcranial or median nerve stimulation. Two of these studies showed more sensorimotor alpha suppression in response to pain than in response to control images (Perry et al., 2010; Yang et al., 2009), while a third study showed reduced alpha suppression (Mu, et al., 2008). One reason for these contradictory outcomes might have been the fact that volume conduction makes it difficult to separate sensorimotor alpha (or mu-rhythm) from posterior alpha sources in EEG scalp recordings (Hari & Salmelin, 1997). Since the strongest modulation of alpha power typically involves alpha-blocking in response to visual stimulation (Pfurtscheller, Stancak, & Neuper, 1996), this activity might have confounded the interpretation of alpha activity from central sources that was found by Mu et al. (2008). Indeed, Perry, et al. (2010) only found increased suppression by pain observation on fronto-central but not on posterior sensors, while Yang et al. (2009) only found increased central alpha suppression. Although these findings strongly suggest alpha suppression in response to the observation of pain in others, they suffer from a lack of spatial resolution needed to univocally establish a sensorimotor origin. These studies also suffered from underspecified or confounded time-windows of interest. In Perry et al. (2010) alpha suppression was calculated over the full 2 seconds post-stimulus, from stimulus onset to stimulus offset, while in Yang et al. (2009) the first 1.3 seconds directly after stimulus onset were used. In both cases stimulus-onset evoked responses were therefore included, making it ambiguous to what degree their observations can be interpreted exclusively as a modulation of ongoing alpha activity and to what degree evoked responses contributed (Lopes da Silva, 1991; Mazaheri & Jensen, 2010; Pfurtscheller & Lopes da Silva, 1999; Steriade, et al., 1990). Mu et al. (2008) did perform an analysis on separate time-windows and reported modulation of the alpha suppression only between 200 and 400 milliseconds after stimulus-onset. They also tried to minimize the effect of phase-locked activity on the power estimate by subtracting average ERP in response to stimulus-onset. Since images were presented for only 200 milliseconds, the power estimation might have still been confounded.
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by transients in response to stimulus offset. Finally, the evaluation of every stimulus in Mu et al.,
(2008) might have resulted in motor preparation which previously has been shown to interact
with sensorimotor oscillations in response to pain (Babiloni et al., 2008).

Concerns about the mixing of central and posterior sources, evoked activity and motor-
preparation aside, the differences in the direction of alpha modulation might also point to the
interesting possibility that different functional processes were involved. Historically, alpha activity
has been interpreted as reflecting a non-functional ‘cortical idling’ state (Pfurtscheller et al.,
1996). This view has recently been challenged, and a more functional interpretation of alpha has
been formulated that describes a mechanisms of gating-through-inhibition (Jensen & Mazaheri,
2010; Klimesch, 1999; Neuper & Pfurtscheller, 2001; Schack & Klimesch, 2002). According
to this view, task-irrelevant regions are inhibited through an increase of alpha oscillations, routing
information to task-relevant regions. For instance, it has been demonstrated that alpha activity
over visual areas increases in motor tasks and vice versa (Pfurtscheller et al., 1996). A similar
mechanism seems to function when attention is directed within the visual or somatosensory
domain. For instance, when covert attention is directed to one hemifield (e.g., the left), alpha
decreases in the contralateral (right) hemisphere but increases in the ipsilateral (left) hemisphere
(Handel, Haarmeyer, & Jensen, 2011; Kelly, Gomez-Ramirez, & Foxe, 2009; Rihs, Michel,
& Thut, 2007; Thut et al., 2006; van Gerven & Jensen, 2009; Worden, et al., 2000). Alpha
activity was also shown to decrease in the primary sensorimotor cortex contralateral to the engaged
hand while it increased in the ipsilateral hemisphere during a somatosensory working memory
task. In line with such a view, we propose that the findings of (Perry et al., 2010; Yang et al.,
2009) show how observation of pain in others induces a disinhibition of the somatosensory
cortex through alpha suppression. This would create the optimal cortical context in which
somatosensory processes such as location and intensity coding of the observed pain (Keysers
et al., 2010), can be performed. Such an account might also tentatively explain the increase in
alpha reported by Mu et al. (2008). The short (200 milliseconds) presentation of images, together
with the task of evaluating these on their painful content, could have resulted in an increase of
functional inhibition of the somatosensory cortices for the purpose of reducing interference
during the evaluation of the somatosensory (pain) representation. Similar processes have indeed
been shown during the retention interval in a visual long term memory task (Meeuwissen et al,
in press) as well as during as somatosensory working memory task (Haegens, Handel, & Jensen,
2011) where distraction in the visual or somatosensory modality was inhibited.

In the current experiment all of the previous concerns were dealt with for the purpose of
unequivocally identifying sensorimotor alpha suppression in the observation of pain in others.
Subjects viewed images of limbs in pain and no-pain situations in a passive task that required
no evaluation or motor responses to the stimuli. To reduce concerns of mixing sources from
different regions we recorded brain activity using magnetoencephalography (MEG) and applied a beamformer technique for source estimation. We did a time-frequency analysis over the whole post-stimulus interval, but restricted our statistical analysis on the non-evoked period (> 400ms). We hypothesized greater sensorimotor alpha suppression in response to painful images than in response to the observation of control images.

Methods

Participants

Twenty-one healthy participants (15 female, mean age 26.6 years, range: 20-49) enrolled after providing written informed consent and were paid in accordance with guidelines of the local ethics committee (CMO Committee on Research Involving Humans subjects, region Arnhem-Nijmegen, the Netherlands). Two participants were excluded from the analysis due to excessive eye or movement artifacts. One subject fell asleep during the experiment and was excluded as well. The experiment was in compliance with national legislation as well as the code of ethical principles (Declaration of Helsinki).

Stimuli

A series of 128 digital color pictures showing right hands and right feet in painful and non-painful situations were used. These stimuli were previously used and validated in behavioral and fMRI studies (JACKSON ET AL., 2005; JACKSON, RAINVILLE, & DECETY, 2006) and one magnetoencephalography (MEG) study (CHENG ET AL., 2008). All pictures depicted familiar events that can happen in everyday life involving mechanical, thermal, and pressure pain. The neutral pictures involved the same settings without any painful component. All pictures were edited to the same size (600 x 450 pixels).

Subjective empathy index

Within two weeks before the experiment commenced subjects filled in the Interpersonal Reactivity Index, a self-report questionnaire measuring different factors related to empathy (DAVIS, 1983).

Experiment

While seated in the MEG system, the stimuli were projected on a screen about 80 centimeters in front of the subject. These were all presented in random order for 1.5 seconds per trial, interleaved with grey fixations screens of 1.5 seconds (Figure 1). The procedure was repeated over three blocks resulting in a total experimental time of ~45 minutes. Subjects were instructed to remain relaxed and not move their limbs, their compliance observed by the experimenter using infrared
camera. To make sure subjects paid attention to the stimuli, ten percent of presentations showed a short twisted movement, created by shortly (~500 ms) presenting, within one stimulation, the same picture modified with a twirl filter (PHOTOSHOP, ADOBE SYSTEMS INC.). Subjects were required to internally count the number of these occurrences and report them to the experimenter after each block. Target stimuli were discarded from further analysis. The experiment was programmed in Presentation (HTTP://NBS/NEUROBS.COM).

![Figure 1. The experimental paradigm. Subjects were presented with pictures depicting limbs painful and non-painful situation, interleaved with grey fixation screens. 10% of the pictures showed a small rotation in the center of the picture (target), the total number of which they had to internally count and report back after each session.]

**Data acquisition**

Continuous MEG was recorded using a 275 sensor axial gradiometer system (CTF MEG TM SYSTEMS INC., PORT COQUITLAM, CANADA) placed in a magnetically shielded room. The ongoing MEG signals were low-pass filtered at 300 Hz, digitized at 1200 Hz and stored for off-line analysis. The subjects’ head position was continuously recorded relative to the gradiometer array using coils positioned at the subject’s nasion and at the left and right ear canals. High-resolution anatomical images (1 mm isometric voxel size) were acquired using a 1.5 T Siemens Magnetom Sonata system (ERLANGEN, GERMANY). The same earplugs, using vitamin E instead of the coils, were used for coregistration with the MEG data.
CHAPTER 2. Sensorimotor alpha activity is modulated in response to the observation of pain

Data analysis

MEG data was analyzed using the Matlab-based Fieldtrip toolbox, developed at the Donders Institute for Brain, Cognition and Behavior (http://fieldtrip.fcdonders.nl/). Trials containing movement, muscle and superconducting quantum interference device (SQUID) jumps were discarded by visual inspection. Independent component analysis (ICA) was used to remove eye and heart artifacts. For the sensor-level analysis, planar gradients of the MEG field distribution were calculated using a nearest-neighbor method comparable with the method described by (BASTIAANSEN & KNOSCHE, 2000) and also applied by e.g. JOKISCH AND JENSEN (2007), NIEUWENHUIS, TAHASHIMA ET AL. (2008), MAZAHERI ET AL. (2009), HAEGENS, OSIPOVA ET AL. (2010) AND HAEGENS, HANDEL ET AL. (2011)). The horizontal and vertical components of the estimated planar gradients approximate the signal measured by planar gradiometers while making the sensor-level data easier to interpret as the maximal activity is typically located above the source (HAMALAINEN, ET AL., 1993). For source reconstruction, however, we used the original data from the axial sensors.

Time-frequency and ERF analysis on the sensor level

For the time-window surrounding the stimulus (-0.4 s to 1.5 s), time-frequency representations (TFRs) of power were calculated using a Hanning taper approach applied to short sliding time windows (PERCIVAL & WALDEN, 1993) using an adaptive time window of four cycles length (\(\Delta t = 4/f\)). The data in each time window were multiplied with a Hanning taper. The power values were calculated as the sum of the horizontal and vertical component of the estimated planar gradient after subtracting the mean amplitude from the entire time interval. The planar gradient power estimates were subsequently averaged over trials for the pain and control condition. To investigate the event related changes in activity we calculated the change of power in response to stimulus presentation relative to the average power during the 200 ms before stimulus onset.

For the time-window surrounding the stimulus (-0.4 s to 1.5 s), event related fields (ERFs) were calculated. The data were then lowpass filtered at 40Hz using a butterworth filter (order of six), and averaged separately for every condition. Similarly as with the frequency analysis, averaging was done on the planar gradients after which they were summed.

Statistical analysis on the sensor level

To avoid ‘double dipping’ (Kriegeskorte, ET AL., 2009) we restricted our statistical comparison to those sensors where we have previously shown the central mu-rhythm to be maximally modulated in a somatosensory task (HAEGENS, HANDEL ET AL., 2010): MLC24, MLC25, MLC31, MLC32, MLP35, MLC42, MLP23, MRC24, MRC25, MRC31, MRC32, MRP35, MRC42, MRP23, see
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highlighted sensors in Fig 3A); We compared the mean log transformed alpha (7-14 Hz) and beta (15 - 25Hz) band power over one second post stimulus period, starting at 400ms to exclude the contribution of evoked components. Although no differences in the beta band activity were expected, a clear beta suppression in response to both pain and non-painful stimuli prompted an ad-hoc testing for differences between conditions.

Source reconstruction

Source reconstruction was performed using a frequency-domain beamformer approach (Dynamic Imaging of Coherent Sources) which uses adaptive spatial filters to localize power in the entire brain (GROSS ET AL., 2001; LILJESTROM, KUJALA, JENSEN, & SALMELIN, 2005). The brain volume of each individual subject was discretized to a grid with a 0.8 cm resolution. For every grid point a spatial filter was constructed from the cross-spectral density matrix and the lead field. The lead fields were calculated from a subject specific realistic single-shell model of the brain (NOLTE, 2003), based on the individual anatomical MRIs. We calculated the cross-spectral density matrix based upon both the post-stimulus (200 – 1400 ms) as well as pre-stimulus (1400 – 200 ms pre-stimulus) interval to obtain the most accurate estimation of the alpha source. Furthermore, both conditions were combined for the purpose of calculating the spatial filter, after which the power at each grid point was estimated for both conditions separately in every subject. Sources were estimated using a multitaper approach to accomplish accurate frequency smoothing for the alpha band (10 Hz +/- 2 Hz by using 3 Slepian tapers). Prior to averaging, the source estimates of the individual subjects’ functional data were spatially normalized using SPM2 to the International Consortium for Brain Mapping template (MONTREAL NEUROLOGICAL INSTITUTE (MNI), MONTREAL, QUEBEC, CANADA; http://www.bic.mni.mcgill.ca/brainweb).

Results

Subjects were presented with static images depicting limbs in painful and non-painful situations from a first-person perspective. We investigated the role of sensorimotor rhythms in processing the painful content.

Widespread modulation of alpha and beta band activity following visual stimuli

First, we investigated the responses to combined painful and non-painful stimuli. As shown in Figure 2A, these resulted in marked reductions in occipital alpha (mean 49.9% of baseline, SEM 5.3%), extending to central sensors power (mean 74% of baseline, SEM 4.3%). At central sensors separate alpha and beta components could readily be distinguished (Figure 2B and 2C). This demonstrates widespread modulation in the alpha and beta frequencies including both occipital and central regions.
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Figure 2. Oscillatory responses to visual stimuli. A The topographic representation of alpha (7-14 Hz) suppression in response to visual stimuli (0.5-1.35s). B Time-frequency representations of central sensors. C Time-frequency representations of occipital sensors. Time-frequency window of interest (0.4-1.35s; 7-14Hz) outlined in black.

Greater sensorimotor alpha suppression in response to painful pictures

We then tested if these oscillatory responses were different in response to painful compared to non-painful stimuli. As predicted, the strongest modulation was observed at central regions over the head (Figure 3A), showing consistency in topography with a previous investigation of attention-related alpha modulation using the same MEG system and comparable spectral analysis (Haegens et al., 2011). A t-test comparing the average (log transformed) power between pain and control pictures on these sensors yielded a significant difference (mean difference 2.19%, SEM = 0.63%, $p = 0.019$, one-sided) demonstrating that the painful stimuli resulted in stronger sensorimotor alpha suppression than pictures showing non-painful situations. Difference in beta power only showed a trend towards increased suppression (mean difference 1.41%, SEM = 1.07%, $p = 0.062$, one-sided). Source analysis confirmed that the origin of the alpha difference was located along the central sulcus (Figure 3d).
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First, we investigated the responses to combined painful and non-painful stimuli. As shown in Figure 2A, these resulted in marked reductions in occipital alpha (mean 49.9% of baseline, SEM 5.3%), extending to central sensors power (mean 74% of baseline, SEM 4.3%). At central sensors separate alpha and beta components could readily be distinguished (Figure 2B and 2C). This demonstrates widespread modulation in the alpha and beta frequencies including both occipital and central regions.
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Figure 2. Oscillatory responses to visual stimuli. A The topographic representation of alpha (7-14 Hz) suppression in response to visual stimuli (0.5-1.35s). B Time-frequency representations of central sensors. C Time-frequency representations of occipital sensors. Time-frequency window of interest (0.4-1.35s; 7-14Hz) outlined in black.

Greater sensorimotor alpha suppression in response to painful pictures

We then tested if these oscillatory responses were different in response to painful compared to non-painful stimuli. As predicted, the strongest modulation was observed at central regions over the head (Figure 3A), showing consistency in topography with a previous investigation of attention-related alpha modulation using the same MEG system and comparable spectral analysis (Haegens et al., 2011). A t-test comparing the average (log transformed) power between pain and control pictures on these sensors yielded a significant difference (mean difference 2.19%, SEM = 0.63%, p = 0.019, one-sided) demonstrating that the painful stimuli resulted in stronger sensorimotor alpha suppression than pictures showing non-painful situations. Difference in beta power only showed a trend towards increased suppression (mean difference 1.41%, SEM = 1.07%, p = 0.062, one-sided). Source analysis confirmed that the origin of the alpha difference was located along the central sulcus (Figure 3d).
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Figure 3. Sensorimotor alpha suppression in response to pain. A The topographical representation of the difference in sensorimotor alpha power (7-14Hz) calculated by subtracting average alpha power (0.4-1.35s; log transformed) of the no-pain stimuli from the painful stimuli. Highlighted sensors are taken from Haegens et al. (2011). B Time-frequency representation of the pain minus no-pain condition of the highlighted sensors in panel A. Box depicts time-frequency window of interest (p = 0.019). C Evoked responses and standard deviation for pain and no-pain averaged over highlighted sensors from panel A. D Source reconstructions of alpha difference obtained using beamformer, showing sources along the central sulcus.

No difference in the ERF between painful and control pictures

We also calculated the event related fields (ERFs) to investigate if pain observation could be observed in neuronal activity time-locked to the stimulus. Early visual evoked components (<400ms) were clearly reflected in the ERFs, while during the interval in which we found sustained alpha suppression (>400ms) the ERF deflection returned towards baseline. A cluster-based randomization test based upon every timepoint found no difference between conditions for neither occipital nor central sensors (depicted in the boxes of Figure 2A), nor for the central sensors selected for our frequency analysis (Figure 3C). Our findings of increased alpha suppression therefore seem unrelated to differences in evoked responses.
No correlations with subjective empathy reports

We also tested for correlations between the magnitude of the modulation of the neuronal response by the pain effect and subjective reports of empathetic distress in daily life. Individual scores on the Interpersonal Reactivity Index (M. H. Davis, 1983) did not correlate reliably with the magnitude of the alpha modulation (perspective taking: \( p = 0.494 \), empathetic concern: \( p = 0.862 \); fantasy: \( p = 0.433 \); personal distress: \( p = 0.248 \); total: \( p = 0.522 \)), nor with the magnitude of the beta modulation (perspective taking: \( p = 0.667 \), empathetic concern: \( p = 0.910 \); fantasy: \( p = 0.829 \); personal distress: \( p = 0.486 \); total: \( p = 0.960 \)).

Discussion

We used MEG to investigate neural oscillations in vicarious pain perception. We found widespread alpha- and beta-band depression in response to visual stimuli, predominantly at posterior sensors. In contradistinction to these widespread visual responses, observing pain depressed alpha power selectively more at central sensors. By applying source modelling we identified the sources of this difference along the central sulcus, implicating sensorimotor regions in the observation of pain. Strikingly, central and posterior ERFs did not show differences between conditions, suggesting a unique role for induced activity in the brain's response to observing other people in pain. These results provide support for the involvement of sensorimotor oscillations in empathetic responses.

Alpha oscillations might be providing a graded level of excitability and inhibition in task relevant and irrelevant regions, streamlining information flow dependent on moment-by-moment task demands (JENSEN & MAZAHERI, 2010; KLIMESCH, 1999; NEUPER & PFURTSCHELLER, 2001; SCHACK & KLIMESCH, 2002). Increased alpha suppression in the observation of pain is also in accordance with previous reports of oscillatory involvement in the subjective perception of (first-person) pain intensity (BABILONI ET AL., 2006) and in the anticipation of pain (BABILONI ET AL., 2008) and fits well within the general understanding that sensorimotor alpha oscillations provide a dynamically modulated cortical context for somatosensory processing (HAEGENS ET AL., 2011; HAEGENS ET AL., 2010; LOPES DA SILVA, 1991; PFURTSCHELLER & LOPES DA SILVA, 1999). What sensorimotor alpha suppression might represent in terms of underlying empathetic mechanisms remains under debate, however. While activation of sensorimotor regions in fMRI studies can be interpreted in terms of perception-action coupling (KEYSERS ET AL., 2010), or of unspecific co-activation (LAMM ET AL., 2011), our results taken together with the emerging understanding of the functional relevance of alpha oscillations (JENSEN & MAZAHERI, 2010; KLIMESCH, 1999; LOPES DA SILVA, 1991), however strongly suggest a disinhibition of the sensorimotor cortices in response to the observation of pain in others. It is in no way suggested, however, that sensorimotor alpha suppression is by itself sufficient for empathy. As has been argued convincingly at length elsewhere (DE VIGNEMONT &
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Singer, 2006; Keysers et al., 2010; Lamm et al., 2011), empathy is a multidimensional response to a variety of situations, real and imagined. Not one neural mechanism will be able to explain its full expression. Noteworthy are the results by Betti and colleagues (2009) who found increased gamma band coherence between primary sensory and motor regions when subjects watched painful movies. Their results further emphasize the importance of understanding empathy through dynamic oscillatory interactions of neuronal assemblies distributed within and across different specialized brain regions. Neither is it claimed here that sensorimotor alpha oscillations are specifically involved in social processes. We understand alpha oscillations more generally as a (sensory) mechanism for gating-through-inhibition, which, in this particular case, is involved in the task of disinhibiting sensory cortices in response to the observation of pain in others.

Although we were able to localize the source of the empathetic alpha modulation along the central sulcus, we were not able to distinguish between primary somatosensory from primary motor regions. This might have been a problem of lack of signal strength, compared to those studies that have been able to localized alpha modulation to postcentral sulcus in response to actual tactile stimulation. For instance, in Caetano and colleagues (2007) observation of movement resulted in only 42% of the beta suppression that was found in response to actual movement. As we localized the difference between the pain and no-pain condition, a difference of only a couple of percent, this problem might have been exacerbated even further.

The fact that this study is limited to the observation of limbs might limit a generalization to the observation of other body parts that afford less action related responses. In fact, as mentioned before, besides the fact that sensorimotor alpha is clearly implicated in somatosensory attention and perception, it has also been a hallmark of action-perception. In our study the amount of action suggested in the images was, however, kept similar between conditions. For instance, where in the control condition one situation depicts the sawing through of a wooden log, the painful counterpart differed only by the fact that the second hand was in a painful position underneath the saw. Any difference between the observation of painful and control images therefore cannot be explained by a difference in action-perception between these conditions. This fact, together with the fact that alpha oscillations are commonly found to have a postcentral source (Cheyne et al., 2003; Jurkiewicz, Gaetz, Bostan, & Cheyne, 2006; Salmelin & Hari, 1994) makes an interpretation of our findings in terms of motor processes less likely.

Although subjects were instructed to remain relaxed and not move their limbs, and no responses were required, this cannot fully rule out 'covert movement' or muscle tension in response to the painful images. Although some (e.g. Yang et al., 2009 but not Perry et al., 2010) record electromyography (EMG), a null-finding comparing average EMG across conditions will not be able to fully rule out differences below the sensitivity of the measurement, and any selection of
muscles would have its limitations. More importantly, we did not find significant differences in
the beta (~20Hz) band where effects of movement would be most pronounced (Cheyne et al.,
2003; Hari & Salmelin, 1997; Jurkiewicz et al., 2006; Parkes, Bastiaansen, & Norris, 2006;

We did not find any correlation with self-report questionnaires and contribute to the existing
confusion in the literature. In Fan and Han (2008), self-reported unpleasantness of the observed
pain stimuli correlated with early evoked potentials to painful observation, but did so only in
an evaluation task and not in the counting task, which would be more similar to our passive
paradigm. Mu and colleagues (2008) reported negative correlations for both perceived pain and
self-unpleasantness, also in a similar evaluation task. Conversely, Cheng and colleagues (2008)
found only positive correlations of perspective taking with sensory-evoked alpha rebound, and no
correlation with empathy quotient questionnaire (EQ: Baron-Cohen and Wheelwright (2004),
the emotional contagion scale, or ECS: Doherty (1997)) or any subscale of the interpersonal
reaction index (IRI: Davis (1983). Finally, Yang and colleagues (2009) found that the effect of
pain on the alpha rebound correlated with the personal distress subscale of the IRI, but only in
females. Taken together, it seems that the most consistent findings have been found correlating the
subjective quality of individual stimuli trials with oscillatory activity, while correlating individual
traits have been less conclusive.

Concluding, observing limbs in pain supressed ongoing alpha oscillations more than observing
control images. This effect was localized along the central sulcus, implicating somatosensory alpha
oscillations in the observation of pain in others. These findings support an interpretation in terms
of gating-through-inhibition where observation of painful images disinhibits the somatosensory
cortex through alpha suppression.
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3

Mindfulness reduces habitual responding based on implicit knowledge

Abstract

Participants were unknowingly exposed to complex regularities in a working memory task. The existence of implicit knowledge was subsequently inferred from a preference for stimuli with similar grammatical regularities. Several affective traits have been shown to influence AGL performance positively, many of which are related to a tendency for automatic responding. We therefore tested whether the mindfulness trait predicted a reduction of grammatically congruent preferences, and used emotional primes to explore the influence of affect. Mindfulness was shown to correlate negatively with grammatically congruent responses. Negative primes were shown to result in faster and more negative evaluations. This effect was negatively correlated with the ability to accurately describe the grammar, suggesting that affective heuristics are used in the absence of explicit knowledge. We conclude that grammatically congruent preference ratings rely on habitual responses, and that our findings provide empirical evidence for the non-reactive disposition of the mindfulness trait.

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Introduction

Implicit learning

Implicit learning is the ability to acquire knowledge of complex regularities without conscious intent or awareness (Seger, 1994). Skill learning, habit learning and procedural learning are related forms of implicit learning. Implicitly acquired knowledge is typically not accessible or represented explicitly (e.g., in a language-based manner) in the form of facts (knowing that). Nevertheless, implicit knowledge (knowing how), underlies much of our behavioral repertoire - from riding a bike to blind typing - and is important in understanding the world and people around us, from musical appreciation to navigating the complexities of language (Stadler & Frensch, 1998). In the lab, implicit knowledge is often inferred from faster processing of structured stimuli, that are comparable (on some stimulus dimension) to those individuals previously have been exposed to (in e.g. real life or in the lab). In addition, evidence for implicitly acquired knowledge is commonly observed through the development of a preference or ‘gut-feeling’ for similarly structured stimuli, typically in the absence of verbal access to what is known.

Artificial Grammar Learning

Artificial grammar learning (AGL) is probably the most studied paradigm for investigating implicit learning. The paradigm distinguishes an acquisition phase and test phase (Cleeremans, Destrebecqz, & Boyer, 1998; Forkstam & Petersson, 2005). In the acquisition phase, participants are exposed to a set of symbol sequences generated from a formal grammar (i.e., a complex rule system), often in the form of a short term memory task. In the subsequent test phase subjects are often first debriefed about the existence of an underlying complex set of rules and instructed to classify a novel set of sequences according to grammaticality, based on guessing or ‘gut feeling’. It is a robust and well-replicated finding that subjects perform significantly above chance on this type of task with little, if any, explicit knowledge about their classification capacity (Cleeremans et al., 1998; Forkstam, Elwer, Ingvar, & Petersson, 2008; Forkstam & Petersson, 2005). In fact, when subjects are not informed about the existence of a grammar, similar classification performance can be observed using forced-choice preference ratings (like/dislike) (Folia et al., 2008; Forkstam, Elwer, et al., 2008). There is good evidence that the frontal cortex and the basal ganglia (fronto-striatal circuits) are involved in implicit learning in humans. This has been characterized in patient (lesion) studies (Forkstam & Petersson, 2005; Seger, 1994), functional neuroimaging studies (Forkstam et al., 2006; Lieberman, et al., 2004; Rose, et al., 2002) and brain stimulation studies (De Vries et al., 2010). Furthermore, in healthy volunteers transcranial magnetic stimulation of Broca’s area has causal effects on classification after implicit learning of an artificial grammar (Udden et al., 2008). Imaging studies of AGL
repeatedly find activations in the basal ganglia, in particular the striatum (Forkstam et al., 2006; Petersson, Folia, & Hagoort, 2010). Taken together these findings suggest a common neural substrate of different forms of implicit learning (for a review see: Forkstam & Petersson (2005a) and Yin & Knowlton, (2006)).

The role and mechanisms of affect on preference for grammaticality

While implicit knowledge acquisition is a robust and well established phenomenon, a conclusive account of how such knowledge is expressed in implicit preference or explicit endorsement rates does not yet exist. Gordon and Holyoak (1983) proposed a role for the mere-exposure effect (Zajong, 1968). In the mere-exposure effect, repeated (unreinforced) exposure results in positive affect towards those stimuli (for an overview see Bornstein (1989)). In the structural mere-exposure effect grammatical sequences are processed more easily during classification due to the previous grammatical stimuli. Similarly to the traditional mere-exposure effect, this increased fluency is then interpreted as a preference. Interestingly, both Newell & Bright (2001) and Zizak & Reber (2004) showed that when classification sequences are presented with different or degraded surface features, performance based on preference is abolished while explicit ratings of grammaticality remain unimpaired. This suggests that familiarity with lower level features is required before structural mere-exposure effects can occur on more complex (grammatical) levels of stimulus processing. Scott and Dienes (2010) showed that while perceptual fluency influences preference judgments, under controlled conditions this provides participants only with a ‘dumb’ heuristic. In fact, preference judgments were shown to be based on perceptual fluency when participants had only very limited time to process the sequences and more accurate evaluations (based on familiarity) could not be made. Although these studies show that fluency can influence preference ratings, they do not explain in what way preference ratings are related to the implicitly acquired grammar. The question remains whether preference for grammatical sequences is the result of a positive (affective) association with the representation of the grammar, or whether preference instead should be understood as a response outcome of non-affective cognitive processes.

Feelings versus affect

It is important at this point to consider ‘affect’ separately from ‘feeling’. Cognitive appraisals and motivational processes are intimately involved in the former, resulting in action tendencies that do not necessarily involve subjective, felt experiences (cf., Frijda (1986), Damasio (2003) and Berridge & Winkelman (2003)). Preference judgments made in AGL classification might therefore not express actual preferences (i.e., conscious feeling states towards (non-)grammatical stimuli) but rather reflect motivational processes that result in automatically endorsing certain stimuli rather than others. In this study, we directly tested whether an affective component is
involved in AGL classification by using masked affective primes. Furthermore, we investigated the relationship between individual differences in AGL performance and mindfulness, describing an individual’s disposition to disengage from automatic reactions and attend to internal and external stimuli in a non-judgmental and non-reactive way.

Mindfulness state and meditation

Mindfulness had been formally defined as “paying attention in a particular way: on purpose, in the present moment, and non-judgmentally” (J. Kabat-Zinn, 1994), ‘the state of being attentive to and aware of what is taking place in the present’, (Brown & Ryan (2003) and in similar vein Bishop et al. (2004)). It prevents one from “...falling prey to automatic judgments or reactivity” (Segal, Williams, & Teasdale, 2002). Often contrasted to the conceptual mode of processing, a mindful mode of processing involves a receptive state of mind wherein attention is kept to bare registering of the facts observed. This permits the individual to ‘be present’ in reality as it is, rather than to automatically react to or habitually process it through conceptual filters (e.g. Brown & Ryan (2003) and Bishop et al. (2004)). This is not an uncontroversial claim to make since concepts, labels and judgments are often imposed automatically on all stimuli encountered (e.g. Bargh & Chartrand (1999)). However, evidence is accumulating that practicing mindfulness suspends automatic processes such as interference in the Stroop task (Moore & Malinowski, 2009), reduces cognitive rigidity in the Einstellung water jar task (Greenberg, Reiner, & Meiran, 2012) and improves cognitive (Heeren, Van Broeck, & Philippot, 2009) and executive flexibility (Hodgins & Adair, 2010). The claim that these effects are the result of attentional training is supported by findings showing that mindfulness training improves attention-orienting and alerting processes (Jha, Krompinger, & Baime, 2007), Jha et al., (2010) van den Hurk et al. (2010)), decreases the attentional blink effect (Slagter et al., 2007) and increases attentional stability (Lutz et al., 2009).

Mindfulness in clinical interventions

Mindfulness techniques have been successfully implemented within clinical interventions, e.g. in patients with recurrent major depression (see Chiesa & Serretti (2011) and Piet & Hougaard (2011) for recent reviews), in those suffering from residual negative ruminations (Kingston et al. (2007) and Ramei et al. (2004)), generalized anxiety (Roemer & Orsillo, 2002) and attentional deficits in ADHD (Zylowska et al., 2008). Although it is argued that its clinical efficaciousness relies partly on the development of a non-judgmental and non-reactive disposition (e.g. Brown et al. (2007) and Teasdale et al. (2002)), empirical work investigating this connection remains scant. To the best of our knowledge, only Raes et al. (2009) showed that the mindfulness trait correlated negatively with cognitive reactivity to sad mood, and importantly, that this cognitive reactivity was reduced after mindfulness training.
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The mindfulness trait and how to measure it

There is a growing consensus that the mindfulness disposition is an inherent capacity (Brown & Ryan, 2003; Kabat-Zinn, 2003; Kuhlman, 2002), which can be measured in the general non-meditating population using self-report questionnaires (see Baer et al. (2006) & (2011), Brown and Ryan (2004), but also see Grossman and Van Dam (2011) for a critical perspective) with good to excellent test-retest reliability (Veehof, et al. 2011). Self-report questionnaires range in complexity from one scale questionnaires (Brown & Ryan, 2003) to the Five Factor Mindfulness Questionnaire (FFMQ; Baer et al. (2006), for an overview see Baer (2011)). The FFMQ is the result of a factor analysis of five previously developed questionnaires and has good internal consistency as well as convergent and discriminant relationships with other constructs. It correlates positively with meditation experience and with standard personality traits such as openness to experience, while correlating negatively with neuroticism and absent-mindedness as well as clinically relevant traits such as difficulties in emotional regulation, alexithymia and dissociation (Baer et al. (2006, 2008)).

Individual difference in affective reactions, general cognition and implicit learning

Evidence for the role of affective states and traits in implicit learning performance or mere-exposure effects, comes from studies investigating individual differences. The mere-exposure effect has been shown to be under a positive influence of negative affective state (Harmon-Jones & Allen, 2001) as well as personality traits such as proneness for boredom (Bornstein, Kale, & Cornell, 1990) and intolerance of ambiguity (Crandall, 1968). Importantly, AGL performance seems to be independent of cognitive abilities such as general intelligence and working memory capacity (Gebauer & Mackintosh, 2007; Reber, Walkenfeld, & Hernstadt, 1991). Kaufman and colleagues (2010), however, found a positive correlation between implicit learning performance on the serial response time task (SRT) and processing speed, verbal reasoning and language abilities. Furthermore, they found a positive relationship with a Big Five personality style characterized by Openness. Notably, Norman and colleagues (Norman, Price, & Duff, 2006 & 2007) did not find such a relationship in their deterministic SRT task. Compelling evidence for the effect of an affective and motivational state of the individual comes from Proulx & Heine (2009), who showed an increased ability to identify grammatical sequences in an AGL task when participants had just read an anxiety-inducing short-story by Kafka or when they had argued against their self-unity. The authors interpreted their findings in terms of an increased desire to find and construct patterns after a meaning-threat. Finally, an influence of affective traits has also been found for the Iowa Gambling task, where neuroticism (Carter & Pasqualini, 2004) and trait anxiety (Schmitt, Brinkley, & Newman, 1999) correlated positively with performance.

Concluding, previous work has shown that, aside from general linguistic abilities, affective
CHAPTER 3. Mindfulness reduces habitual responding based on implicit knowledge

states and traits interact with implicit learning. In terms of clinical as well as non-clinical traits, affective processes and personality traits seem involved in implicit learning, including negative mood (Harmon-Jones & Allen, 2001), anxiety (Schmitt et al., 1999), neuroticism (Carter & Pasqualini, 2004) and meaning threats (Proulx & Heine, 2009). Importantly these display a remarkable overlap with states and traits negatively associated with mindfulness (described in paragraph 3.1.5 to 3.1.7). In other words, implicit learning seems to benefit from a disposition to respond habitually and reactively, traits strikingly opposite to the mindful disposition.

Manipulation of affective states: Affective primes

The causal effect of feelings on implicit learning can only be investigated by controlled experiments in which affect is systematically manipulated. Besides Proulx and Heine (2009) we know of no such studies. It is well established that masked semantic primes reliably induce congruent semantic facilitation on subsequent target stimuli (for a review see Van den Bussche et al. (2009) and Kouider & Dehaene (2007)). Furthermore, masked emotional faces have been shown to result in congruent affective judgments on subsequent ideographs (Rotteveel et al., 2001). In the current study were therefore used masked affective primes to explore whether primed affect influences retrieval of implicit knowledge.

Experiment

Participants performed a five day working memory task. Unbeknownst to them, sequences were generated according to complex rules. On three occasions novel items were classified according to preference (like/dislike): at baseline, after working memory sessions, and on the last day of the experiment. After the last preference task participants were debriefed about the existence of a complex rule system behind the working memory stimuli. They were then instructed to perform grammaticality judgments (grammatical/non-grammatical) on a new stimulus set. Also unknown to the participants, all target stimuli (classification sequences) were preceded by subliminally presented (backward and forward masked) neutral, positive (happy) or negative (disgust) faces. To estimate the degree of explicit knowledge about the grammar after the completion of the experiment, participants answered a structured multiple-choice questionnaire of the grammar's bigram state transitions. Finally, participants filled in the FFMQ.

Hypothesis

We hypothesized that individual endorsement rates (the preference for grammatical sequences over non-grammatical sequences, and grammaticality classification performance) would be negatively correlated with FFMQ scores. To control for a confounding relationship between mindfulness and verbal or general cognitive abilities, we tested for a correlation of mindfulness with working
memory performance and the ability of participants to make grammatical rules explicit after completion of the experiment. Explicit knowledge was expected to correlate positively with grammatical classification performance. Lastly, we predicted that sequences preceded by positive primes would result in more positive judgments (of preference and grammaticality), while sequences preceded by negative primes were expected to result in more negative judgments.

Methods

Participants

Eighteen university students volunteered to participate in the study (13 females, 5 males, mean age = 22.2, SD = 6.7 years) for course credits. They were all pre-screened for relevant medical history, medication use, drug abuse, head trauma, neurological or psychiatric illness, and family history of neurological or psychiatric illness. All subjects had normal or corrected-to-normal vision. All participants gave written informed consent according to the Declaration of Helsinki.

Stimulus material

We generated 569 grammatical (G) sequences from the Reber grammar (see Figure 1) with a sequence length of 5 to 12 symbols (M, S, V, R and X). A robust finding in the AGL literature is that subjects are highly sensitive to chunks of two or three adjacent letters (bi- and trigrams). Although early in acquisition a sensitivity to these chunks indicates an initial shallow processing of the grammar, at the end of acquisition the grammatical status of the complete sequence has become a better predictor of classification (Forkstam, et al. 2008). In this study we controlled for differences in the associative chunk strength (ACS), operationalized as the average chunk strength across all possible subsequences of two or three letters within the acquisition sequences. We calculated the complete associative chunk strength for each sequence in relation to the complete set of 569 sequences (c.f. Knowlton & Squire (1996), Meulemans & Van der Linden (1997) and Udden et al. (2008)). In an iterative procedure 100 sequences were randomly selected and tested with respect to its ACS content in order to generate the acquisition set which was representative in terms of ACS in comparison to the complete sequence set. The classification sets were subsequently derived from the remaining 469 grammatical sequences and for each of these a non-grammatical sequence was derived by a switch of letters in two non-terminal positions. Finally, 6 sets of 64 sequences were randomly selected from the 469 grammatical and their matched 469 non-grammatical sequences in an iterative procedure, in order to generate classification sets consisting of 50% grammatical and non-grammatical sequences, as well as 50% high and low ACS sequences relative to ACS information in the acquisition set and independent of grammaticality status. Working memory stimuli were presented in Arial (30 points font size) on a screen resolution of 1280x1024, 75 cm in front of the subject. Classification stimuli were
presented in an identical setup. For all classification sets, grammatical and non-grammatical sequences did not differ in terms of ACS.

Figure 1. Implicit grammar underlying acquisition and classification sequences. A grammatical sequence is generated by concatenating letters of valid transitions (arrows), going from the start node to the end node.

Primes

Frontal-facing neutral, happy and disgusted faces from the Averaged Karolinska Directed Emotional Faces set (Lundqvist, Flykt & Ohman, 1998; Oosterhof & Todorov, 2008) were used, consisting of (8 bit, 562x762 px) grayscale averages of 70 individuals (35 males and 35 females) showing emotional expressions. The forward mask was constructed by superimposing rotated pieces of the neutral, positive and negative primes. The resulting mask scrambled the contours of the face as well as details of the emotional expression, while keeping gradients of the original images. The backward mask was a horizontally flipped version (mirrored over the vertical axis) of the forward mask. Masks were presented for 50 ms (three frames at 60 Hz), sandwiching the prime that was presented for 33 ms (two frames). Primes and masks were presented in the middle of the screen, spanning 20.5 by 24.5 cm, or 15.7 by 18.7 degrees of visual angle.

Software

The experiment was programmed in Presentation (Neurobehavioural Systems, neurobs.com). All analyses were conducted in Matlab (mathworks.com) and PASW Statistics 18 (SPSS inc., SPSS.com).

Questionnaires

To provide our participants with a continuous focus and to maintain the cover of the working memory (WM) task, each WM-session was concluded with a short questionnaire in which they
had to report all strategies that they used to memorize WM sequences.

In a post-experimental pen-and-paper questionnaire, participants were first asked if they noticed anything particular about the classification sequences and if they used any strategies to classify them. They were then probed about knowledge of the grammar through multiple choice questions about all grammar bigram transitions. This created a structured way for participants to explicate knowledge about bigrams without being provided with any details of the rules. The following thirteen questions were asked: “What character(s) could the sequences start with?” (five response options, one for every character); “With what character(s) could the sequences end?” (idem). “What characters(s) could repeat themselves?” (idem). “What character(s) could follow character X?” (one question for each character with four response options per question, excluding X). “What character(s) could not follow X?” (idem). The total score for every subject was calculated by adding one point for every hit and subtracting one point for every miss or false alarm. The score was then divided by the number of questions, resulting values that could range from -2.2 (worst performance) to 2.2. This score will be referred to as the Explicit Knowledge score, and EXPLICIT in the analysis. Mindfulness was measured using the Dutch version (De Bruin et al., 2012) of the 39 item Five Factor Mindfulness Questionnaire (FFMQ, Baer et al. (2006)).

Procedure

The complete experiment spanned five days with one acquisition session each day. Before the first and after the second and fifth acquisition session a preference session was administered. After the last preference session participants were debriefed about the existence of underlying complex rules in the acquisition sequences (no details were given) and instructed to classify novel sequences in terms of grammaticality (yes/no) in a setup identical as the one used for the implicit classification sessions.

Working memory task

The acquisition task (~25 min) was presented as a short-term memory recall task. Every session twenty random items were drawn from the acquisition set, which was presented five times (a total of 100 presentations). During the acquisition task, the grammatical sequences were presented on the computer screen for four seconds. After the sequences disappeared, subjects had to repeat the sequence from memory by typing on a keyboard in a self-paced fashion. They were allowed to correct themselves using the backspace key. No performance feedback was provided.

Preference task

In the implicit classification task (~25 min) subjects were instructed to rate each sequence if they
liked it or not, based on their immediate impression or "gut feeling". They were told that this task might appear odd in the beginning but that they might develop a preference and could rely on guessing until then. The classification sequence was presented centrally on the screen for four seconds, followed by a response screen to which they could respond with left or right button press on a custom made response box. Inter-trial-interval was six seconds during which a fixation cross was presented. Subjects were allowed as much time as they needed but were instructed to respond quickly and without much deliberation (i.e., using their 'gut feeling' or immediate impression). A self-paced break was included after every ten trials. The session was split halfway into two blocks between which the valence of the response-buttons was switched. The initial valence for the buttons was determined at random at every session and clearly displayed during every response screen and before each block.

Grammatical classification task

After the third and final preference session subjects were debriefed about the existence of a complex system of rules generating the acquisition sequences in the working-memory task. They were told that during the next classification session they would be presented with new sequences of which only half were constructed according to those rules, and the other half violated the rules in an unspecified way. They were then instructed to decide whether the (novel) sequences were grammatical or not, based on their immediate intuitive impression or whatever strategy they have been using in the previous sessions (i.e., familiarity). Subjects were allowed as much time as they needed but were instructed to respond quickly and without much deliberation. The implementation of the task was identical to that of the preference session.

Priming

Unbeknownst to the participants, every letter sequence in both classification tasks was preceded by a forward and backwards masked emotional face. The prime valence (neutral, positive or neutral) was determined at random for each presentation.

Analysis

Working memory (WM) performance over sessions was analyzed with repeated-measures ANOVA. WM performance (LEVENSHTEIN) was indexed by mean Levenshtein distance between target sequence and remembered sequence. Levenshtein distance is the minimum number of edits (insertion, deletion, or substitution of a single character) needed to transform one sequence into the other. Low Levenshtein distances therefore represent good WM performance, and high Levenshtein distance poor WM performance. For the preference session, responses (PREFERENCE) were modeled using a linear model with grammaticality status (GRAMMATICALITY) as independent
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factor, subject (SUBJECT) as random factor and, if applicable, session (SESSION) as fixed factor. Responses during the explicit classification session (CLASSIFICATION) were modeled similarly. For the sake of simplicity, effects of GRAMMATICALITY on PREFERENCE (GRAMMATICALITY x PREFERENCE) or CLASSIFICATION (GRAMMATICALITY x CLASSIFICATION) will be reported as endorsement rates. Endorsement rates will therefore represent correct judgments of grammaticality status, as well as preference for grammatical and disliking of non-grammatical sequences. In figures endorsement rates will be depicted in percentages of total number of responses in the relevant condition. Effects of positive versus neutral primes (POS), and negative versus neutral primes (NEG), on PREFERENCE, CLASSIFICATION and response time (RT), were analyzed using a linear model with SUBJECT as a random effect variable and GRAMMATICALITY and POS or NEG as a fixed factor. When applicable, LEVENSHTEIN, post-experiment explicit knowledge (EXPLICIT) and mindfulness (FFMQ-total or subscales) were entered as covariates in a full factorial mixed model. Correlations between covariates (FFMQ, LEVENSHEIN and EXPLICIT) were calculated using Pearson's r.

Results

Acquisition task

Working memory performance improved over sessions (F(4,48) = 53.3, p < .001) and over repetitions (F(4,48) = 27.9, p < .001). Within-subject contrasts revealed that participants only improved in the first three sessions, showing no significant improvement between session 4 and 5 (session 1 vs. later: F(1) = 135.7 p < .001; session 2 vs. later: F(1) = 23.4, p = .001; session 3 vs. later: F(1) = 10.5, p = .007; session 4 vs. later: F(1) = .206, p = .658).

Preference task

Participants acquired a preference for grammatical sequences above non-grammatical sequences (F(1) = 128, p < .001), which increased with SESSION (see Figure 2) as shown by the significant interaction of GRAMMATICALITY with SESSION (F(2) = 53.1, p < .001). Preference was not congruent with grammatical status in the first session (F(1) = 1.42, p = 0.234), but strongly so on the second (F(1) = 13.6, p < .001) and third session (F(1) = 41.3, p < .001). In the final implicit classification session (session 3), participants preferred grammatical sequences an average of 63.2% (SD = 18.6%) over 36.4% (SD = 18.0%) for non-grammatical sequences.
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Figure 2. Development of endorsement rates for the preference task. Endorsement rates for grammatical (G) and nongrammatical (NG) sequences for each day. At baseline (Day 1) no preference for grammaticality was shown. The sensitivity to the grammar was improved over Days 3 and 5. ***p < .001.

Grammatical classification task

Participants were able to distinguish grammatical from non-grammatical sequences in the explicit session ($F(1,2316) = 668, p < .001$), responding affirmative to 77.4% (SD = 14.7%) of grammatical sequences, over only 29.9% (SD = 15.6%) when sequences violated the grammar. Grammaticality judgments also took longer than preference judgments (preference: $M = 741$ ms, SD = 16.7 ms; grammaticality: $M = 906$ ms, SD = 16.7; $F(1) = 5.82, p = .028$).

Effect of working memory performance on endorsement rates

In the preference task, no significant effect of working memory performance (LEVENSHTEIN) on PREFERENCE ($F(16) = .069, p = .796$) or endorsement (GRAMMATICALITY x LEVENSHTEIN; $F(2284) = .874, p = .350$) was found (see Figure 3C). In the grammatical classification task, LEVENSHTEIN had no effect on PREFERENCE ($F(16) = .922, p = .315$). LEVENSHTEIN did predict endorsement rate (GRAMMATICALITY x LEVENSHTEIN; $F(2298) = 66.4, p < .001$, see Figure 4C).

Correlations between working memory performance, explicit knowledge and mindfulness

Explicit Knowledge correlated significantly with LEVENSHTEIN on the first WM session ($r = -.537, p = .022$), and on later sessions (session 2: $r = -.611, p = .007$; session 3: $r = -.580, p = .012$; session 4: $r = -.534, p = .041$; session 5: $r = -.642, p = .007$). As expected, FFMQ did not correlate with LEVENSHTEIN on the first WM session ($r = .320, p = .196$), showing only marginal trends towards significance on the last two sessions (uncorrected: session
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2: $r = .274$, $p = .271$; session 3: $r = .024$, $p = .925$; session 4: $r = .486$, $p = .066$; session 5: $r = .438$, $p = .090$). Additional analysis showed that LEVENSHTEIN, when averaged over sessions, did not correlate with FFMQ ($r = 0.210$, $p = 0.402$). Only a marginal trend emerged when the correlation was based on a concatenation (not average) of LEVENSHTEIN of all five sessions ($r = 0.180$, $p = 0.089$). FFMQ did not correlate with EXPLICIT ($r = .003$, $p = .99$).

Individual differences in preference judgments

FFMQ showed no main effect on PREFERENCE ($F(1, 16) = .164, p = .70$). As predicted, FFMQ did influence endorsement rates (FFMQ x GRAMMATICALITY x PREFERENCE: $F(1, 2284) = 28.0, p < .001$), shown by the negative correlation between FFMQ and endorsement rates ($r = -0.393$, see Figure 3A). In contrast, EXPLICIT did not explain PREFERENCE (main effect: $F(1,16) = .128, p = .725$) or endorsement rates (EXPLICIT x GRAMMATICALITY: $F(1, 2284) = .404, p = .525$, see Figure 3B). To test for a possible dependency (shared variance) between FFMQ and EXPLICIT, they were entered separately, resulting in similar outcomes (FFMQ: $F(1, 2284) = 28.0, p < .001$, EXPLICIT: $F(1,2284) = .423, p = .516$).

We performed exploratory analysis to identify which subscales of the FFMQ most strongly influenced endorsement rates. Only the non-judgmental subscale would survive multiple-comparison corrections (observe: $F(1,2284) = .84, p = .028$; describe $F(1,2284) = 3.77, p = .052$; acting with awareness: $F(1,2284) = 3.38, p = .066$; non-judgmental: $F(1,2284) = 36.2, p < .001$; non-reactivity: $F(1,2284) = .031, p = .942$). The non-judgmental subscale also displayed the best predictor estimate, explaining most variance of all the subscales (observe: .001; describe: -.009; acting with awareness: -.01; non-judgmental: -.020; non-reactivity: -.001).

Individual differences in grammaticality judgments.

Both FFMQ as well as EXPLICIT showed a significant effect on endorsement rates (FFMQ: $F(1,2284) = 28.01, p < .001$, see Figure 4A; EXPLICIT: $F(1,2298) = 18.6, p < .001$, see Figure 4B), caused by a negative correlation with FFMQ ($r = -.603$), and a positive correlation with EXPLICIT ($r = .568$). To control for a possible influence of LEVENSHTEIN on the negative correlation between FFMQ and endorsement rates, we entered LEVENSHTEIN as a control variable in a partial correlation analysis. The negative correlation between FFMQ and endorsement rates remained large and statistically significant ($r = -0.545, p = 0.024$).

Similarly as for the preference session, the subscales of the FFMQ were separately tested (observe: $F(1,2299) = 14.1, p < .001$; describe: $F(1,2298) = 22.9, p < .001$; acting: $F(1,2298) = 7.27, p = .007$; non-reactivity: $F(1,2294) = 0.916, p = .339$; non-judgmental: $F(1,2298) = 9.20, p = .002$). None showed a significant main effect. The describe and observe subscale showed the best
predictor estimates (observe: -.017; describe: -.019; acting with awareness: -.013; non-judgmental: -.009; non-reactivity: -.005).

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**Effect of primes on preference judgments**

In the preference session, positive primes resulted in marginally faster response times ($F(1,1491) = 2.87, p = .090$, see Figure 5A) and more negative preference judgments ($F(1,1499) = 2.62, p = .038$). Negative primes also resulted in significantly faster response times ($F(1,1527) = 6.28, p = .012$, see Figure 4B), and marginally more negative preference judgments ($F(1,1527) = 2.945, p = .086$). Neither positive ($F(1,1499) = 2.618, p = 0.106$) nor negative primes ($F(1,1531) = 0.042, p = 0.837$) resulted in an effect on endorsement rate (i.e. in an interaction with grammaticality).
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Effect of primes on grammaticality judgments.

In the classification task, positive primes did not result in significant main effects on grammaticality judgments \((F(1,1497) = 1.10, p = .158)\), endorsement rates \((F(1,1509) = .743, p = .389)\), or response times \((F(1,1497) = 0.467, p = 0.495)\). Negative primes did not result in significant main effects on grammaticality judgments \((F(1,1538) = 1.96, p = .162)\) or response times \((F(1,1538) = .254, p = .615)\). However, there was a significant interaction effect between endorsement rates and the grammatical status of the stimulus \((\text{GRAMMATICALITY}: F(1,1545) = 4.02, p = .045)\). As can be seen in Figure 6, this interaction was the result of negative primes only affecting endorsement of the grammatical sequences.
Discussion

Mindfulness reduces ability to classify grammatical sequences

Mindfulness influenced the endorsement rates in both the preference and grammatical classification task. More mindful individuals displayed less sensitivity to the grammar in their preference judgments. This effect was repeated for judgments of grammaticality. Importantly, mindfulness did not correlate with initial WM performance. Also, after explicitly controlling for differences in initial working memory performance, the effects of mindfulness on endorsement rates remained large and statistically significant. Furthermore, mindfulness did not correlate with the ability to later recall explicit knowledge about the grammar. Together, these findings suggest that while mindfulness impairs both implicit as explicit classification performance, it does not reduce the ability to report bigram knowledge about the grammar or to perform general cognitive operations on similar stimuli. Thus, mindfulness specifically explained individual differences in endorsement of grammatical structures that cannot be explained by general cognitive abilities or the ability to verbally express the implicit knowledge base.

Post-hoc investigation of mindfulness subscales

Post-hoc analysis of the separate subscales of the FFMQ further substantiate an explanation of the effects of mindfulness in terms of non-habitual factors. The negative correlation of
mindfulness with endorsement rates in the preference task was strongest for the non-judging of inner experience subscale. This subscale refers to a non-evaluative stance toward thoughts and feelings (Baer et al., 2008). Within the context of the implicit classification task, preference judgments might have been less biased by internal representation of the grammatical structure. This would be consistent with the claim that mindfulness down-plays a general tendency to automatically judge internal representations (Brown & Ryan (2003) and Bishop et al. (2004)). Interestingly, when participants explicitly judged the grammaticality of the stimuli, the describe and observe subscale emerged as the most significant predictor of impaired performance. The describe subscale refers to the labelling of inner experiences with words. The observing subscale refers to the noticing or attending to internal and external experiences (Baer et al., 2008). The fact that such dispositions were not beneficial for grammaticality judgments implies that an observing and describing trait inhibits (automatic) acting on internal representations, i.e. using the 'gut feeling'. This would be in line with findings showing that such classification performance benefits from instructing subjects not to over-analyze the stimuli or their performance (Howard & Howard, 2001). Taken together, these results suggest that implicit knowledge is most reliably accessed by those that rely on habitual responses. Knowledge about the fact that grammatical rules exist (after debriefing) does not change this relationship. Furthermore, a tendency to observe (i.e., to be aware of one's thoughts, feelings and preferences) might reduce such habitual responses.

**Explicit knowledge and working memory**

It is important to note that neither WM performance nor explicit knowledge interacted with endorsement rates in the preference session, but did so significantly after subjects were debriefed. This suggests a qualitative difference between implicit and explicit classification, consistent with the understanding that that explicit knowledge about the grammar was used in the explicit classification but not during implicit endorsement rates. Similar findings were reported by Folia et al. (2008) who found that the number of grammatical items that participants were able to generate, predicted endorsement rates for grammaticality classification but not for preference ratings.

Interestingly, while previous work (Kaufman et al., 2010) has shown that working memory capacity is not a major source of variance in AGL performance, WM performance did correlate positively with grammatical classification in our study. However, in contrast to Kaufman et al., (Kaufman et al., 2010) who used an independent task to measure working memory (the Operation Span Task (Turner & Engle, 1989), our WM task shared both the grammatical structure with classification stimuli as well as the surface features such as the typeface and presentation duration. The WM task should therefore be considered less of a measurement of general WM capacity but rather of
a task-specific ability to hold relevant sequences online, specific for our task context. Note that the correlation between WM and explicit knowledge does not imply that WM performance was contaminated by (implicit) understanding of grammar. WM performance in the first session did not correlate significantly with endorsement rates of preference judgments. The last two working memory sessions did show a marginal trend towards significance. However, as participants learned the grammar, that knowledge would have facilitated the remembering of sequences in what constituted the WM task. As such, given that mindfulness appears to limit the learning (or at least the expression of that knowledge) this could have resulted in a negative correlation between WM and the FFMQ score. It should also be noted that the negative relationship between mindfulness and endorsement rates occurred for both the preference and classification task, while working memory performance only showed a correlation with the latter. Further evidence speaking against the possibility that the negative correlation between mindfulness and endorsement rates was mediated through a mutual correlation with (working) memory ability, comes from studies on the relationship between mindfulness and memory. In Jha et al., (2010) and Zeidan et al. (2010) mindfulness training was found to increase working memory performance. Furthermore, in Williams et al. (2000) mindfulness training increased autobiographical memory specificity in recovered depressed patients, which was replicated by Heeren et al. (2009) in healthy subjects. Lastly, working memory performance has been previously shown not to correlate with implicit learning performance (Gebauer & Mackintosh, 2007 and Reber et al. 1991). Taken together, we believe it is unlikely that individual differences in WM ability mediated the negative correlation between mindfulness and performance on the grammatical classification and preference task.

Primes

To test the involvement of affect on the retrieval of implicit knowledge, we preceded stimuli with subliminal affective primes. Preference ratings were found to be faster and preferred less when preceded by a negative prime. Negative primes did not have an effect on endorsement rates. This is consistent with an effect of prime on the response level, but not with an influence on the decision process itself. In fact, while affective primes are classically assumed to automatically activate attitudes towards target stimuli (e.g. Fazio et al., 1986 andForgas, 1995), it has been argued that affective primes also influence decisions regarding the attitude towards the response, instead of the stimuli that the response is about (Hermans, De Houwer, &Eelen, 2001). Our findings would be consistent with the latter.

Unexpectedly, positive primes showed a similar effect as negative primes, both speeding up response times and biasing preference judgments negatively. No interactions with prime valence were observed. A series of studies on the differential effects of the valence of primes used forty-eight and one-hundred-and-sixty participants (Rotteveel et al., 2001). Our study might
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therefore have suffered from a lack of power. However, a more parsimonious explanation would be that affective primes resulted in a general disruptive effect on the accuracy of implicit decision-making that was independent of prime valence. Our results suggest a general tradeoff between an increased speed of response and a decreased accuracy, after both positive and negative primes. Interestingly, when participants explicitly rated grammaticality (after debriefing), primes did not have an effect on participants’ judgment. As grammaticality judgments took about 200 ms longer than preference ratings, priming effects could by then have dissipated. In fact, priming effects degrade quickly over time, with the maximal effect obtained by a prime-mask SOA from 100 ms to 150 ms, with barely any effects after 300 ms (Hermans et al., 2001; Sohrabi & West, 2009). Alternatively, response times might have been less informative than in preference judgments due to more elaborate conscious decision-making processes.

Explicit knowledge of bigram transitions

The method by which explicit knowledge of bigrams was measured might offer several improvements over previously used methods. Open questions suffer from a possible lack of sensitivity, due to low confidence, different retrieval contexts or the absence of appropriate words to describe the knowledge base (Destrebecqz & Peigneux, 2005; Shanks & St. John, 1994). On the other hand, forced-choice recognition or sequences-completion tasks, although being more sensitive, suffer from the unavoidable problem that the use of (unconscious) implicit knowledge in their responses cannot be excluded (i.e., the exclusiveness criterion, see Reingold & Merikle, 1988 and Destrebecqz & Peigneux, 2005). Sampling knowledge of all bi-gram transitions with multiple-choice questions helps participants report bigram knowledge by providing a minimal structure in which the questions are contextualized. By penalizing misses and false alarms response biases can be controlled for. Secondly, the pen-and-paper format provides a different context in which implicit strategies are expected to play less of a role than in setups similar in task context. Note that we only sampled the bi-gram space and higher-order knowledge was not probed. However, given the complexity of higher-order rules, it is unlikely that such knowledge was accessible or used. In fact, none of our subjects reported higher level (tri-gram) rules in the free recall questions of the post-experiment questionnaire.

Conclusion

To conclude, mindfulness reduced habitual responding to unconsdously acquired preferences, providing experimental evidence for its core concepts: a non-reactive and non-judgmental disposition. Combined with our findings on the influence of affective primes, we show the importance of affective traits and states in implicit learning and retrieval.
Covert somatosensory attention is metacognitively accessible

Abstract

Studies on metacognition have shown that participants can report on their performance in a wide range of perceptual, memory and behavioral tasks. We know little, however, about the neuronal substrate reflecting the ability to report on one's attentional focus. The degree and direction of somatosensory attention can, however, be readily discerned through suppression of alpha band frequencies in EEG/MEG produced by the somatosensory cortex. Such top-down attentional modulations of cortical excitability have been shown to result in better discrimination performance and decreased response times. In this study we asked whether the degree of attentional focus is also accessible for subjective report, and whether such evaluations correspond to the amount of somatosensory alpha activity. In response to auditory cues participants maintained somatosensory attention to either their left or right hand for intervals varying randomly between five and 32 seconds, while their brain activity was recorded with MEG. Trials were terminated by a probe sound, to which they reported their level of attention on the cued hand right before probe-onset. Using a beamformer approach, we quantified the alpha activity in left and right somatosensory regions, one second before the probe. Alpha activity from contra- and ipsilateral somatosensory cortices for high versus low attention trials were compared. As predicted, the contralateral somatosensory alpha depression correlated with higher reported attentional focus. Finally, alpha activity two to three seconds before the probe-onset correlated with attentional focus. We conclude that somatosensory attention is indeed accessible to metacognitive awareness.

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Introduction

Metacognition refers to the general ability to reflect upon, and comment on mental states and cognitive processes. Traditionally, metacognition has been an important concept in understanding failure in memory performance such as false recognition and tip-of-the-tongue (for an overview see Metcalfe and Shimamura, 1994 and Dunlosky and Bjork, 2008). More recently the concept of metacognition has been embraced by a broader range of cognitive neuroscience researchers. In cognitive tasks requiring a behavioural response, the ability to report confidence about one's performance has been used as paradigmatic example of metacognition (Fleming & Dolan, 2012). In the perceptual domain metacognitive reports are taken as reflecting conscious awareness of the percept, both in human (Kunimoto, Miller, & Pashler, 2001; Szczepanowski & Pessoa, 2007) and non-human research (Smith, Couchman, & Beran, 2012). However, in some cases metacognition might be simply understood as second-order behaviour, i.e. as behaviour that is contingent on other (overt or nascent) behaviour, rather than on knowledge that is based on meta-cognition (Fleming, Dolan, & Frith, 2012). This issue is particularly relevant in studies of attention, where so far metacognition has only been investigated within the context of behavioural performance. Such experimental paradigms permit metacognitive reports to be based on performance and stimulus processing, rather than on introspection of the cognitive (attentional) state. The primary objective of this study was therefore to show that attentional focus is metacognitive accessible, independently from the task performance or exogenous stimulus processing.

Neuroimaging techniques can disambiguate the metacognitive accessibility of attention by providing objective proxies of covert attention. Visuospatial and somatosensory attention can be gauged using magnetoencephalography (MEG) or electroencephalography (EEG) measurements of the 10 Hz rhythms found in the visual and somatosensory cortex (Hari & Salmelin, 1997 and Pfurtscheller & Lopes da Silva, 1999). It is now a well-replicated finding that alpha activity decreases contralateral to the focus of attention, during visuospatial attention (Handel, Haarmeier, & Jensen, 2011; Kelly, Gomez-Ramirez, & Foxe, 2009; Rihs, Michel, & Thut, 2007; Thut, et al., 2006; van Gerven & Jensen, 2009; Worden et al., 2000) as well as during somatosensory attention (Haegens, Handel, & Jensen, 2011; Haegens, Luther, & Jensen, 2012; Schubert, et al., 2009; van Ede, de Lange, Jensen, & Maris, 2011; van Ede, Jensen, & Maris, 2010). Furthermore, visual and somatosensory alpha power have been shown to be modulated according to attentional demands (Gould, Rushworth, & Nobre, 2011; Haegens et al., 2011), affecting subsequent performance (Bengson, Mangun, & Mazaheri, 2012; Haegens et al., 2011; Handel et al., 2011; Kelly et al., 2009; O'Connell et al., 2009; Thut et al., 2006). These findings show evidence for the attentional role of visual and somatosensory alpha through their role in augmenting and attenuating task relevant and irrelevant regions, respectively (Klimesch, 1999; Neuper and Pfurtscheller, 2001; Schack and Klimesch, 2002; Jensen 64
Covert somatosensory attention is metacognitively accessible (Maazehi, 2010). In fact, combined EEG-fMRI studies have shown that posterior alpha power correlates negatively with visual BOLD activity (Scheeringa et al., 2011), while central alpha power correlates negatively with BOLD in somatosensory regions (Ritter, Moosmann & Villringer, 2009). Taken together, alpha power has been shown to be sensitive both the degree as well as the location of covert visuospatial and somatosensory attention.

Previous work suggests that attention might be metacognitively accessible. In a recent EEG study, Macdonald and colleagues (2011) let participants report their level of attention during each trial in a visual discrimination task. Self-reported attention on task correlated negatively with pre-stimulus alpha power. In Braboscz and Delorme (2011), subjects were instructed to count their breath and report by button-press whenever they noticed a distraction from the task. Posterior alpha and central beta power were shown to be reduced preceding these reports of mind-wandering. These findings were interpreted in terms of impaired working-memory during mind-wandering. In Christoff and colleagues (2009), attention was sampled during a sustained attention task (SART, Robertson et al. (1997)). Moments of mind-wandering were shown not to be associated with any decreases of BOLD activity in task-related regions. Rather, they were reflected by a pattern of increased activity in both executive regions (dorsal ACC and the dorsolateral prefrontal cortex) and the default network (medial PFC, posterior cingulate and posterior temporo-parietal cortex), consistent with previous reports of default mode network activity during mind-wandering (Mason et al., 2007). Interestingly, this effect was found to be reduced when participants reported to have been aware of being distracted, suggesting that mind-wandering was most pronounced when it lacked metacognition. Taken together, these findings suggest that the attentional state during task performance might be metacognitively accessible. However, it remains an open question whether metacognition of attention can occur in the absence of a concurrent task.

The current study was designed to measure metacognition of attention independently from concurrent task performance and stimulus processing. Participants were instructed to try to maintain maximal attention to their left or right hand as indicated by auditory cues. At random periods after the cue, trials were terminated by a probe sound. A button-press was then used to self-report the degree in which attention was directed to the cued hand at the moment preceding the probe sound. These subjective self-reports were associated with alpha as an objective proxy of attention. For this purpose, MEG was used in combination with the beamformer method to estimate alpha power at the left and right somatosensory cortex. We hypothesized that trials with higher self-reported attention would be associated with lower alpha power in the contralateral somatosensory region. Confirmation of this hypothesis permitted us to conclude that the attentional focus is indeed metacognitively accessible.
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Methods

Participants

Fifteen healthy participants (9 female, mean age 30.4 years, range: 19–63) enrolled after providing written informed consent and were paid in accordance with guidelines of the local ethics committee (CMO Committee on Research Involving Humans subjects, region Arnhem-Nijmegen, the Netherlands). One participant was excluded from the analysis due to excessive movement artifacts. The experiment was in compliance with national legislation as well as the code of ethical principles (Declaration of Helsinki).

Experiment

Participants were instructed to continuously attend to the cued hand while simultaneously trying to remain aware of their attentive state until a probe sound (2000Hz tone) was presented (Figure 1A). Cues consisted of two sequential tones of 400ms each, 200ms apart, with either ascending in pitch for the right hand (2000Hz followed by 2500Hz) or descending for the left hand (2000Hz followed by 1500Hz). Cue side was determined pseudo-randomly. Cue-probe intervals followed an exponential distribution with a mean of 3 seconds and a cut-off time of 27 seconds, providing a flat hazard rate. In other words, the chance of the probe occurring after trial onset was held constant. A minimal cue-probe interval of 5 seconds was added, resulting in an average cue-probe interval of 8 seconds and maximal of 32 seconds. After the probe sound, participants evaluated their level of attention on the cued hand using one out of four options: (1) not at all, (2) little, (3) much, (4) fully/maximally attentive. The experiment started with a training session, followed by three continuous blocks of 125 trials separated by self-paced breaks. The response hand at the first session was determined randomly, and then switched for each block. To minimize head movements and provide comfort participants were measured in supine position. To minimize eye movements and blinks and increase the chance of fluctuations in attentional focus, participants were instructed to remain with their eyes closed throughout the experiment.

Data Preprocessing

Continuous MEG data was recorded using a 275-sensor axial gradiometer system (CTF MEG TM SYSTEMS INC., PORT COQUITLAM, BC, CANADA) placed in a magnetically shielded room. The ongoing MEG signals were low-pass filtered at 300 Hz, digitized at 1200 Hz, and stored for off-line analysis. The subjects’ head position was continuously recorded relative to the gradiometer array using coils positioned at the subject’s nasion and at the left and right ear canals. High-resolution anatomical images (1 mm isotropic voxel size) were acquired using a 1.5-T Siemens Magnetom Sonata system (ERLANGEN, GERMANY). The same earplugs, using vitamin E instead
of the coils, were used for co-registration with the MEG data. MEG data was analyzed using the Matlab-based Fieldtrip toolbox, developed at the Donders Institute for Brain, Cognition and Behavior (Oostenveld, Fries, Maris, & Schoffelen, 2011). Trials containing movement, muscle, and superconducting quantum interference device (SQUID) jumps were discarded by visual inspection. Independent component analysis (ICA) was used to remove eye and heart artifacts.

Figure 1. Schematic of paradigm and example of the design matrix used for the source level General Linear Model. A Schematic depiction of paradigm showing timing parameters of trial. B Example design matrix showing regressors for conditions (0's and 1's) and confound regressors (normalized).

Source Reconstruction of Alpha Power

Source reconstruction was performed using a frequency-domain beamformer approach (Dynamic Imaging of Coherent Sources) which uses adaptive spatial filters to localize power in the entire brain (Gross et al., 2001 and Liljestrom, et al. 2005). The brain volume of each individual subject was discretized to a grid with a 0.8-cm resolution. For every grid point a spatial filter was constructed from the cross-spectral density matrix and the lead field. The lead fields were calculated from a subject specific realistic single-shell model of the brain (Nolte, 2003), based on the individual anatomical MRIs. We calculated the cross-spectral density matrix based upon the full interval between cue offset and probe onset to obtain the most accurate estimation of the alpha sources. Individual alpha frequencies were used for each subject (for all grid and time points), determined by the maximum log power between 7 and 15 Hz on all trials and sensors.

For each grid point and six one-second time segment preceding probe onset, alpha activity was then estimated. A sufficient number of trials (~100) had trial lengths of at least 6 seconds preceding probe onset to enable source statistics at those intervals. A (Slepian) multitaper approach was used to accomplish accurate frequency smoothing (± 2 Hz) around the subject-specific alpha peaks. To enable valid voxel-by-voxel comparisons in the face of the beamformer depth bias,
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alpha estimates were standardized over trials.

Source level GLM

A voxel-by-voxel first-level GLM approach was then used for every subject and time segment. Figure 1B shows an example design matrix, including cue side (left/right) and self-report (high/low), dichotomized according to a median split per subject and time-point. In addition, trial number as well as the mean X, Y and Z position of the three fiducial coils were entered as separate regressors. The locations of the fiducial coils indicate the position of anatomical landmarks of the subject’s head (nasion and pre-auricular points) in the MEG helmet. By including the average fiducial positions during each trial, variance that was caused by differences in head position over trials was also reduced. To further reduce variance that could be explained by response preparation, regressors for evaluation response times and cue-probe duration were added to the GLM, together with separate regressors for the response hand, which was switched between each block and randomized over subjects. The cue side and self-report predictors consisted of 0’s and 1’s, thereby yielding mean standardized alpha power after multiplication with the standardized data. By standardizing the remaining covariates (response time, trial length, fiducial position, etc) multiplication with the standardized data resulted in correlation values (r). Prior to averaging and group statistics, the resulting beta-values and correlations values were spatially normalized using SPM2 to the International Consortium for Brain Mapping template (Montreal Neurological Institute, MNI, Montreal, QC, Canada).

Functional localization of primary somatosensory regions

After the reconstruction of alpha power for each voxel and time-point, somatosensory regions of interest (ROIs) were determined based on alpha power during the last second preceding probe onset. A voxel-by-voxel comparison was made between left and right attention trials. A cluster-based permutation test (MARIS & OOSTENVELD, 2007) was then used to identify significant spatial clusters. This resulted in a distinct somatosensory alpha-ROI for each hemisphere. Each ROI therefore depended on cue condition (left versus right), but remained independent of the self-reported evaluation of attention.

Region of interest analysis

Alpha power values within the left and right ROI voxels were averaged according to cue condition (ipsi versus contra), evaluation (high versus low) and time-point (six one-second intervals preceding probe onset). The effects of cue condition and evaluation on mean alpha power were tested over time using repeated measures ANOVA. Differences in these effects over time were tested using post-hoc t-tests per time-point.
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Results

Participants were instructed to try to maintain maximal attention to either their left or right hand as indicated by auditory cues. At random periods after the cue, trials were terminated by another (probe) sound. After each trial participants reported by button-press (1 to 4) the degree of attention that was allocated to the cued hand at the moment right before the probe sound.

Behavior

Attentional focus fluctuated over time, as reflected by the use of the full range of responses (Figure 2A). The number of responses per evaluation, differed significantly \( (F(3) = 9.896, p < 0.001) \), showing a linear relationship \( (F(1) = 24.778, p < 0.001) \), with evaluations being generally high. This shows that participants were confident about their performance. Evaluation times also differed for the different levels \( (F(3) = 28.739, p < 0.001) \). Evaluations that were rated high were also made quicker, showing again a linear trend \( (F(1) = 47.133, p < 0.001) \). Furthermore, evaluation times correlated negatively with cue-probe duration \( (\text{mean } r = -0.130, t(13) = -5.5048, p = < 0.001) \), showing that longer cue-probe durations did not result in a loss of vigilance or ability to do the task.

![Figure 2. Behavioral differences between evaluation responses. A Distribution of trials according to evaluation of attention show that attention was generally rated high. B Evaluation times were reduced when attention was evaluated higher.](image)

Functional localization of primary somatosensory regions

Somatosensory alpha regions of interest (ROIs) were determined on the basis of the distribution of alpha power in the brain volume estimate using the beamformer approach applied to the MEG data during the last second before probe onset. A cluster-based permutation test (MARS
& Oostenveld, 2007) was used to identify the significant clusters responsive to cue direction. The analysis resulted in two significant clusters, one in each hemisphere in primary sensorimotor areas (see Figure 3). These ROIs were used for further analysis of the alpha power preceding metacognitive evaluations. For this purpose estimates of alpha power in the left and right hemispheric ROI’s were separated into an ipsi-lateral ROI and a contra-lateral ROI on the basis of hemisphere and cue direction. In other words, ipsi-lateral alpha power consisted of the left ROI during left-attention trials, and the right ROI during right-attention trials. Similarly, contra-lateral alpha power consisted of the left ROI during right-attention trials and the right ROI during left-attention trials. The ipsi-contra distinction was therefore orthogonal to the left-right hemisphere distinction.

Region of interest analysis

Alpha power was first averaged over grid points in the left and right ROI and over the six seconds interval preceding probe onset. As predicted, differences in self-reported evaluation corresponded to differences in preceding alpha power, showing lower alpha power for high attention versus low attention (F(1,13) = 7.163, p = 0.019; Compare top panel with bottom panel in Figure 4A and 4B). We then went on to analyze alpha power preceding probe onset in a time-resolved, post-hoc manner, to investigate the temporal profile of alpha activity preceding probe onset (Figure 4C and 4D, respectively). Only the contralateral ROI showed significant differences between high and low evaluations, for the last 3 seconds preceding probe onset (two-tailed: [-3:-2] t(13) = -2.357, p = 0.035; [-2:-1] t(13) = 0.017; [-1:0] t(13) = -2.648, p = 0.020).
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Figure 4. Topographic and time-resolved difference in alpha power show consistency with self reported attention. A Surface plot of standard MNI brain showing mean standardized alpha power on the contralateral hemisphere for the 6 seconds preceding probe onset, separately for high- and low-attention. B Surface plot of standard MNI brain showing mean standardized alpha power on the ipsilateral hemisphere for the 6 seconds preceding probe onset, separately for high- and low-attention. C Time resolved alpha power for 6 seconds preceding probe onset, based on contralateral region-of-interest (see Figure 3), separately for high- and low-attention. Asterisks depict significant differences between high- and low-attention on separate time points. Shaded surface represents standard error of mean. D Time resolved alpha power for 6 seconds preceding probe onset, based contralateral region-of-interest (see Figure 3), separately for high- and low-attention. Curve width represents standard error of mean.
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Confound regressors analysis

Control regressors were used to control for variance due to potential differences in response times, cue-probe duration, elapsed time (trial number) and movement (3D position of fiducial coils). These regressors were standardized and entered as covariates in the design matrix. Resultant correlation values ($r$) were tested against zero using cluster-based permutation tests (Maris & Oostenveld, 2007). Cue-probe duration was shown to be significantly positively correlated with superior-parietal alpha power, and this correlation was shown to be maintained over time (Figure 5A). This means that alpha activity in these regions gradually increased as the trial became longer. Response time correlated with some alpha activity at somatosensory and visual regions, although these effects did not remain significance for any extended period of time (Figure 5B). In conclusion, the level of subjective attention was mainly reflected by contralateral alpha in somatosensory regions and was not confounded by correlations with response times or cue-probe interval.

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**Figure 5.** Parietal alpha power correlates with cue-probe duration, not with evaluation time. A Cluster-statistics shows significant correlations between superior-parietal alpha and cue-probe duration, consistent over time before probe-onset. B No consistent correlations between alpha power and evaluation times were found.
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Discussion

The main purpose of this study was to investigate whether the degree of somatosensory attentional focus is metacognitively accessible, as shown by a correspondence between contralateral alpha and self-reported attentional focus. As a prerequisite for our study, alpha activity produced in primary somatosensory regions was first shown to be hemispherically lateralized in response to cued attention to the left or right hand. Furthermore, by demonstrating significant lateralization in the somatosensory cortex during the second preceding probe onset, it was shown that this lateralization can be sustained for extended periods of time (from 8 to 32 seconds). The main finding was that participants’ subjective rating of their attentional focus was reflected in somatosensory alpha power contralateral to the attended hand. This somatotopic specificity supports the notion that participants were not reporting on a general attentional state, but were able to report specifically on their attentional sensory specific focus. This study therefore provides strong support for the metacognitive accessibility of attentional focus. Moreover, this is the first study showing metacognition in the absence of either exogenous stimulation or evaluations of task performance based on overt behavior. Furthermore, response times were shown not to contribute to somatosensory alpha power, supporting the behavioral independence of our findings.

Our findings are consistent with previous electrophysiological studies on metacognition. A previous investigation by Braboszcz and Delorme (2011) showed reduced posterior alpha during mind-wandering, which the authors interpreted in terms of impaired working-memory processes. However, the role of alpha oscillations during working memory has also been understood to reflect active inhibition of task-unrelated activity, suppressing visual processes during memory retention (Jensen & Mazaheri, 2010; Klimesch, 1999; Neuper & Pfurtscheller, 2001; Schack & Klimesch, 2002). The results of Braboszcz and Delorme (2011) could therefore have reflected mal-adaptive attention to visual processes during mind-wandering. This would put their findings in line with ours, providing converging evidence for the metacognitive accessibility of the internal attentional state. A recent sophisticated EEG study by Macdonald and colleagues (2011) found a negative correlation between pre-stimulus parieto-occipital alpha power and self-reported attention during a visual detection task. Interestingly, parieto-occipital alpha and self-reported attention correlated over periods of several minutes. Such slow fluctuations of attention are in accordance with O’Connell et al. (2009), where lapses in visual attention were preceded by increased parieto-occipital alpha for at least 20 seconds before an error occurred. Importantly, neither O’Connell and colleagues (2009) nor Macdonald and colleagues (2011) used cued spatial attention, but rather correlated self-reports with the measurement of general visual attention. Our data extends these findings by showing that self-reported attentional focus corresponds most strongly with contra-lateral (to cued side) somatosensory alpha. This demonstrates that
the correlation between self-report and alpha activity can be spatially specific. In other words, while the findings by O’Connell and colleagues (2009) and Macdonald and colleagues (2011) suggest metacognitive access to the visual attentional state, our findings provide strong evidence for metacognitive access to spatial focus as well.

Previous work has shown, that in visuospatial (Fu et al., 2001; Kelly, Lalor, Reilly, & Foxe, 2006; Worden et al., 2000) and somatosensory attention tasks (Haegens et al., 2012), the inclusion of distracting stimuli at the un-cued side can result in an increase of ipsilateral alpha power, reflecting active suppression of the distracting sensations. In the current experiment, participants were only required to attend continuously to the cued hand while no distractors were presented. Consistent with the idea that sensations from the un-cued hand posed little challenge and did not need to be actively inhibited, alpha power tended to be lower rather than higher at the ipsilateral hemisphere when attention was reported to be higher, although they did not do so significantly. This suggests that metacognitive reports were not based on the unattended hand. Future experiments, however, could investigate the potential to not only report on the degree of attention, but also on the degree of suppression of distraction.

Interestingly, in our analysis of confound regressors, cue-probe duration was found to correlate positively with superior parietal alpha power at regions. The superior parietal lobule (SPL), in particular the inferior parietal sulcus (IPS), has been implicated in body-centered coding (Galati et al., 2010) and movement preparation (Cohen & Andersen, 2002). Furthermore, the SPL/IPS is considered part of the Dorsal Attention Network (DAN; Corbetta & Schulman, 2002 & 2011), involved in goal-directed orientation of attention. Not much is known about the role of SPL alpha oscillations, however. The question remains if superior-parietal alpha has similar inhibitory effects as in sensory regions (Jensen & Mazaheri, 2010; Klimesch, 1999; Neuper & Pfurtscheller, 2001; Schack & Klimesch, 2002). A recent study on parietal alpha of local field potentials in the macaque monkey (Premereur, Vanduffel, & Janssen, 2012) does suggest that parietal alpha actively inhibits the onset of target-oriented saccades, consistent with the involvement of parietal alpha in encoding gaze-centered reference-frames (Buchholz, Jensen, & Meendendorp, 2011; Van Der Werf, Buchholz, Jensen, & Meendendorp, 2012). As a matter of speculation, our results could therefore suggest increased suppression of reorienting activity with increasing trial duration.

Decades ago, Narens and Nelson (Nelson & Narens, 1994) argued eloquently for metacognition as a topic of interest in its own right as well as a bridge between many areas of cognitive and psychological investigation, e.g., between decision making and memory, learning and motivation. Recently, action and perceptual processes have been added to this list (see Fleming et al., 2012 for an overview) and with our and other recent studies (Braboszcz & Delorme, 2011; Christoff
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attention and mind-wandering as well. This speaks to the general role of metacognition as cognitive processes that monitor and control cognition (cf. e.g., Fernandez-Duque, Baird, & Posner, 2000). According to metacognitive principles, cognition can be split into two interrelated levels: the metalevel and the object level (Nelson & Narens, 1990). While the metalevel is continuously updated by bottom-up information, it asserts controls over the object level by providing top-down input and initiating or terminating its actions (Nelson & Narens, 1990). In this light, our measure of somatosensory attention reflects the subservient object level rather than the metalevel. Our paradigm did not enable a valid comparison between trials in which metacognition was present and trials where it was absent. However, a recent study on interoception of event-times (Guggisberg, Dalal, Schnider, & Nagarajan, 2011) has done so. Interestingly, the patterns of neural activity that was related to introspection depended on the target of introspection, i.e., whether it concerned auditory perception, intentional or motor events. Each was related to a specific introspection-related network. Along similar lines, future studies can be expected to delineate frontal brain networks that are specifically involved in metacognitive monitoring of attention. Such research could take into account the rich literature on executive control in metacognition (see e.g., Botvinick et al., 2001 and Fernandez-Duque et al., 2000) as well as recent models of attention that organize brain networks in terms of their relationship to internal goals and external cues (e.g., Corbetta & Shulman, 2002 and Miller & D'Esposito, 2005). Our data suggests that part of the introspective process might involve the maintenance of attention through the suppression of reorienting responses arising from the Dorsal Attention Network (Corbetta & Shulman, 2002, 2011).
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5

Mindfulness meditation enables proactive metacognition of attention

Abstract

The distinguishing practice of mindfulness meditation is the intentional regulation of attention towards the present moment. Mindfulness meditation therefore emphasizes metacognitive functions, in particular the ability to monitor the attentional focus on a moment-by-moment basis. In this study we set out to test whether mindfulness meditation experience is associated with an increased ability to monitor moment-by-moment fluctuation in the attentional state. In response to auditory cues, participants maintained somatosensory attention to either their left or right hand. At random moments, trials were terminated by a probe sound to which participants reported their level of attention at that moment. MEG was recorded during the attention interval preceding probe onset. Using a beamformer approach, alpha activity in contralateral primary somatosensory regions was quantified. Alpha activity for self-reported high versus low attention trials was compared both within and between groups of either highly experienced experienced mindfulness meditators, novice meditators or meditation-naive participants (controls). As predicted, generally contralateral alpha power was associated with self-reported attention. Novice meditators (<1000hrs of meditation) showed temporal profiles similar to controls, displaying a correspondence between self-report and alpha power preceding probe onset. Expert meditators (>>1000hrs) showed a strikingly different pattern, however. Their self-reported attentional state corresponded with alpha power during a more extended time interval preceding those of controls and novice meditators. In addition, self-reported low attention trials showed a distinctive alpha suppression preceding probe onset, suggesting that the ability for moment-by-moment monitoring of the attentional state permitted greater attentional control.
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Introduction

The goal of this study is to investigate whether extensive meditation experience can be associated with changes in meta-metacognitive monitoring of attention. While meditation practices are generally considered to incorporate the practice of attentional control, mindfulness meditation distinguishes itself by an emphasis on continuous metacognitive monitoring of mental contents and processes (Lutz et al., 2006 & 2008). Mindfulness based interventions have been proven successful in treating a wide range of clinical syndromes ranging from depression (Chiesa & Serretti, 2011; Piet & Hougaard, 2011; Van Aalderen et al., 2012) to anxiety (Roemer & Orsillo, 2002; Wurtzen et al., 2012) and ADHD (Zylowska et al., 2008). Several clinical interventions have integrated mindfulness, e.g. in Mindfulness Based Stress Reduction (MBCT, Kabat-Zinn 1990a, 1994), Mindfulness Based Cognitive Therapy (Segal et al., 2002; Teasdale et al., 1995) and Acceptance and Commitment Therapy (Steven C. Hayes, Strosahl, & Wilson, 1999). The mechanisms by which mindfulness meditation might benefit the mental health of the practitioner remain unclear, however. Initial proposals have been put forward from cognitive psychological (e.g. Baer, 2003 and Brown, Ryan & Creswell, 2007) or neuroscientific perspectives (e.g. Chiesa & Serretti, 2010a; Holzel et al., 2011 and Tang & Posner, 2013). in which mindfulness has been defined in terms of “paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally” (Jon Kabat-Zinn, 1994) or “the state of being attentive to and aware of what is taking place in the present” (Brown & Ryan, 2003 and similarly in Bishop et al. 2004). The practice of mindfulness meditation is therefore understood beyond the ability to maintain attention upon a specific object or to safeguard oneself from (especially negative) distraction. Rather, mindfulness meditation emphasizes metacognitive awareness of experience regardless of its desirability or relevance. In fact, it is this explicit awareness of ongoing mental content, called meta-awareness (Schooler et al., 2011) or metacognition (Fleming et al., 2012), that allows distracting mental content to be noticed so that attention can subsequently be reoriented (Schooler et al., 2011; Smallwood, Mcspadden, & Schooler, 2007; Smallwood & Schooler, 2006). Mindfulness, or “attending to the present moment”, can therefore be operationalized as the metacognitive monitoring of the focus of attention.

It is well known that mind-wandering often occurs without the awareness that one’s mind has drifted (Giambra, 1995; Schooler, 2002). Importantly, recent work has show that the tendency to mind-wander correlates negatively with a mindful disposition (Mrazek, Smallwood, & Schooler, 2012). Furthermore, successful outcome after MBCT has been associated with increased availability of metacognitive reflection on negative experiences (Teasdale et al., 2002). Although metacognition is understood to be an important aspect of mindfulness, experimental evidence for improved metacognitive functioning after mindfulness meditation has been only inferred indirectly from studies showing increased performance in tasks requiring cognitive...
control and response inhibition. Jha and colleagues (2007) found that mindfulness meditation improved conflict monitoring in the Attention Network task. Allen and colleagues (2012) showed a reduction in affective Stroop conflict and in Heeren and colleagues (2009), mindfulness training was associated with increased cognitive inhibition in go/no-go task.

Metacognition has been a traditional topic of interest in memory research for decades (see Metcalfe, Shimamura (1994) and Dunlosky and Bjork (2008) for an overview). Recently, metacognition of action and perceptual processes have become a topic of interest as well (see Fleming et al. (2012) for an overview). Since mindfulness meditation is first and foremost an attentional practice, recent work on metacognition of attention, or conversely of mind-wandering, could be a promising direction of neuroscientific research. Previous experiments on metacognition of attention or mind-wandering have used control tasks or external stimulation (Braboszcz & Delorme, 2011; Christoff et al., 2009; Macdonald et al., 2011; Whimzig et al., 2008). When studying neural correlates of attention during meditation, however, the performance of a concomitant task can be expected to interfere with attentional monitoring, as well as preventing ecologically valid conclusions regarding meditation. Furthermore, task performance and stimulus processing might provide information about the attentional state during stimulus processing or task performance, preventing conclusions in terms of metacognition of attention per se (Fleming et al., 2012). Importantly however, the attentional state can be determined without a control task or external stimulus. Cortical alpha activity has been shown to reflect both the degree and the location of covert somatosensory attention (Haegens et al., 2011; Haegens et al., 2012; van Ede et al., 2011; van Ede et al., 2010). Furthermore, occipital alpha power was shown to be strongly correlated with self-reported attention during a visual detection task (Macdonald et al., 2011). In a recent study, we reported that contralateral alpha power corresponds to self-reported attentional focus as well (Whitmarsh, et al., 2013). In this study we used an identical paradigm as in Whitmarsh et al. (2013) to investigate whether metacognitive awareness of attention is improved after extensive mindfulness meditation.

Participants were presented with auditory cues to attend either to their left or right hand while their brain activity was measured using MEG. After a random time interval trials were terminated with a probe sound to which they reported the degree of attentional focus. Self-reported attentional focus was compared with contralateral somatosensory alpha preceding probe onset, in eleven one second intervals. We compared the degree of correspondence over time between novice and expert mindfulness meditators as well as with that previously reported for meditation-naive participants (Whitmarsh et al., 2013). We predicted that meditators would show a stronger and more sustained correspondence between self-reported attentional focus and contralateral alpha power over time. Furthermore, we expected these differences to be more pronounced for expert meditators compared to novices.
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**Methods**

**Participants**

The control group consisted of fifteen healthy participants (9 female, mean 29.4 years, SD = 10.4). One control participant was excluded from the analysis due to excessive movement artifacts. The meditation group consisted of sixteen healthy experienced mindfulness meditators (5 female, mean 48.0 years, SD = 16.1). They were recruited via personal network of mindfulness teachers or contacted directly. To be included in our study they had to be familiar with mindfulness meditation through a meditation retreat and had to practice mindfulness mediation regularly for at least a year at the time of the study. Participants were enrolled after providing written informed consent and were paid in accordance with guidelines of the local ethics committee (CMO Committee on Research Involving Humans subjects, region Arnhem-Nijmegen, the Netherlands). The experiment was in compliance with national legislation as well as the code of ethical principles (Declaration of Helsinki).

**Procedure**

Participants were instructed to attend continuously to the cued hand while remaining aware of their attentive state until a probe sound (2000Hz tone) was presented (Figure 1A). Cues consisted of two sequential tones of 400ms each, 200ms apart, either ascending in pitch for the right hand (2000Hz followed by 2500Hz) or descending for the left hand (2000Hz followed by 1500Hz). Cue side was determined pseudo-randomly. The subjective evaluation of attention was done by button press, selecting one out of four options: (1) not at all, (2) little, (3) much, (4) fully/maximally attentive. To minimize head movements and provide more comfort participants were measured in supine position. To minimize eye movements and blinks and increase the chance of fluctuations in attentional focus, participants were instructed to remain with their eyes closed throughout the experiment.

The experiment started with a training session until participants were familiar with the paradigm, followed by three continuous experimental blocks of 125 trials (~25 minutes each) separated by self-paced breaks. Non-evaluation trials (10% ad random) were indicated by the presentation of an extra third cue of similar pitch to the second. Participants were instructed that no evaluation of attention was needed at these trials, but to respond as quickly as possible with their index finger. On these trials only, participants received a short electrical stimulation of the cued hand after probe offset, to provide an additional functional localizer (which was not used in the analysis). Non-evaluation trials were discarded from all further analysis. Cue-probe intervals were generated according to an exponential distribution with mean of 3 seconds and a cut-off time of 27 seconds, providing a flat hazard rate. In other words, the chance of the probe occurring after trial onset
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was held constant. A minimal cue-probe interval of 5 seconds was added, resulting in an average cue-probe interval of 8 seconds, and maximal of 32 seconds.

**Figure 1.** Schematic of paradigm and example of the design matrix used for the source level General Linear Model. A) Schematic depiction of paradigm showing timing parameters of trial. B) Example design matrix showing regressors for conditions (0’s and 1’s) and confound regressors (normalized).

**Data Preprocessing**

Continuous MEG data was recorded using a 275-sensor axial gradiometer system (CTF MEG TM SYSTEMS INC., PORT COQUITLAM, BC, CANADA) placed in a magnetically shielded room. The ongoing MEG signals were low-pass filtered at 300 Hz, digitized at 1200 Hz, and stored for offline analysis. The subjects’ head position was continuously recorded relative to the gradiometer array using coils positioned at the subject’s nasion and at the left and right ear canals. High-resolution anatomical images (1 mm isotropic voxel size) were acquired using a 1.5-T Siemens Magnetom Sonata system (ERLANGEN, GERMANY). The same earplugs, using vitamin E instead of the coils, were used for co-registration with the MEG data.

**Data Analysis**

MEG data was analyzed using the Matlab-based Fieldtrip toolbox, developed at the Donders Institute for Brain, Cognition and Behavior (OOSTENVELD ET AL., 2011). Trials containing movement, muscle, and superconducting quantum interference device (SQUID) jumps were discarded by visual inspection. Independent component analysis (ICA) was used to remove eye and heart artifacts.

**Source Reconstruction**

Source reconstruction was performed using a frequency-domain beamformer approach (Dynamic Imaging of Coherent Sources) which uses adaptive spatial filters to localize power
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in the entire brain (GROSS ET AL., 2001; LIJESTROM ET AL., 2005). The brain volume of each individual subject was discretized to a grid with a 0.8-cm resolution. For every grid point a spatial filter was constructed from the cross-spectral density matrix and the lead field. The lead fields were calculated from a subject specific realistic single-shell model of the brain (NOLTE, 2003), based on the individual anatomical MRIs. We calculated the cross-spectral density matrix based upon the full interval between cue offset and probe onset to obtain the most accurate estimation of the alpha sources. Individual alpha frequencies were used, determined by the maximum log power between 7 and 15 Hz on all trials and sensors.

Separate analyses were performed for one second segments preceding probe onset, to a maximum of 11 seconds before probe onset. A sufficient number of trials (~100) had trial lengths of at least 11 seconds to enable source statistics at those intervals. After calculating the spatial filter for each grid point and one-second time segment, alpha activity was estimated using a (Slepian) multitaper approach to accomplish accurate frequency smoothing for the alpha band (± 2 Hz) around the subject-specific alpha peaks. To enable valid voxel-by-voxel comparisons in the face of the beamformer depth bias, alpha estimates were standardized over trials.

A voxel-by-voxel first-level GLM approach was then used for every subject and time segment. Figure 1B shows an example design matrix, including cue side (left/right) and self-report (high/low), dichotomized according to a median split per subject and time-point. In addition, trial number as well as the mean X, Y and Z position of the three fiducial coils were entered as separate regressors. The locations of the fiducial coils indicate the position of anatomical landmarks of the subject's head (nasion and pre-auricular points) in the MEG helmet. By including the average fiducial positions during each trial, variance that was caused by differences in head position over trials was also reduced. To further reduce variance that could be explained by response preparation, regressors for evaluation response times and cue-probe duration were added to the GLM, together with separate regressors for the response hand, which was switched between each block and randomized over subjects. The cue side and self-report predictors consisted of 0's and 1's, thereby yielding mean standardized alpha power after multiplication with the standardized data. By standardizing the remaining covariates (response time, trial length, fiducial position, etc) multiplication with the standardized data resulted in correlation values (r). Prior to averaging and group statistics, the resulting beta-values and correlations values were spatially normalized using SPM2 to the International Consortium for Brain Mapping template (MONTREAL NEUROLOGICAL INSTITUTE, MNI, MONTREAL, QC, CANADA).

Functional localization of somatosensory regions

After the reconstruction of alpha power for each voxel and time-point, somatosensory regions of interest (ROIs) were determined based on alpha power during the last second preceding probe
onset. A voxel-by-voxel comparison was made between left and right attention trials. A cluster-based permutation test (Maris & Oostenveld, 2007) was then used to identify significant spatial clusters. This resulted in a distinct somatosensory alpha-ROI for each hemisphere. Each ROI therefore depended on cue condition (left versus right), but remained independent of the self-reported evaluation of attention.

**Region of Interest analysis**

Alpha power values within the left and right ROI voxels were averaged according to cue condition (ipsi versus contra), evaluation (high versus low) and time-point (eleven one-second intervals preceding probe onset). The effects of cue condition and evaluation on mean alpha power were tested over time using repeated measures ANOVA. Differences in these effects over time were tested using post-hoc t-tests per time-point.
Results

Attentional focus fluctuated over trials, as was reflected by the use of the full range of responses (Figure 2A). Participants were generally confident about their ability to perform the task, as was shown by the large fraction of high evaluations. A repeated measures ANOVA with one within-subject factor with four levels (evaluation) and one group factor (meditators vs. Controls) showed that the number of trials per level of attention were significantly different (F(3) = 30.931, p < 0.001), and assumed a negative linear relationship (F(1) = 73.889, p = <0.001). No effect of group on evaluation was found (F(3) = 1.451, p = .234). Evaluation times were also significantly different between levels of attention (F(3) = 55.390, p < 0.001) and showed a positive linear relationship (F(1) = 69.862, p < 0.001). No effect of group on evaluation time was found (F(3) = 2.038, p = .116). Furthermore, evaluation times correlated negatively with cue-probe duration for both controls (mean $r = -0.130$, t(13) = -5.505, p = < 0.001) and meditators (mean $r = -0.078$, t(15) = -2.648, p = 0.018), showing that longer cue-probe durations did not result in a loss of vigilance. The correlation between evaluation times and cue-probe duration did not differ between the groups (t(28) = -1.3450, p = 0.189). The behavioral analysis therefore showed no differences between meditators and Controls, and both groups were confident in their performance of the task.

**Figure 2.** Behavioral differences between evaluations. A Distribution of number of trials per evaluation of attention show that attention was generally rated high, showing a negative relationship with level of attention. B Evaluation times were reduced when attention was evaluated higher, showing a positive relationship with level of attention. No differences between groups were found.
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Regions of interest analysis

Somatosensory alpha regions of interest (ROIs) were determined for controls and meditators on the basis of the lateralization of alpha power (alpha cue left minus alpha cue right) during the last second before probe onset. A cluster-based permutation test (Maris & Oostenveld, 2007) was used to identify the significant clusters responsive to cue direction. In both groups the analysis resulted in two significant clusters, one in each hemisphere, including primary sensorimotor areas (see Figure 3). A cluster-based permutation test of alpha lateralization showed no significant differences between groups. Mean values of alpha power within the group-specific regions-of-interest were used in further analysis. We then computed contralateral alpha power preceding probe onset. Evaluations were dichotomized according to a median split per subject and time-point, resulting in time courses for high versus low attention trials (Figure 4).

Figure 3. Somatosensory alpha power lateralized in response to cue direction in both groups. Source reconstructed alpha activity during one second preceding probe-onset shows clear lateralization in areas including primary somatosensory regions. Significant voxels were thresholded based on cluster-based permutation test (p< 0.05) (Maris & Oostenveld, 2007).

Controls versus meditators

We performed a repeated measures ANOVA with time and self-report (high vs. low) as within-subject factors and group (meditators vs. controls) as a between-subjects factor. Self-report showed a significant effect on contralateral alpha power (F(1,28) = 9.509, p = 0.005). Time showed to be a significant factor as well (F(10,19) = 2.983, p = 0.019). No significant interaction with group or between time and self-report effects were found. As expected, no effect of self-report was found for the ipsilateral ROI (F(1,28) = 2.318, p = 0.139). We took a closer look at the temporal profile of alpha in the high versus low evaluated trials. In controls, the last three
second interval before probe onset showed significantly lower alpha power in high versus low attention trials (Figure 4A; paired t-tests, two-tailed: [-3:-2], t(13) = -2.357, p = 0.036; [-2:-1], t(13) = -2.746, p = 0.017; [-1:0], t(13) = -2.648, p = 0.020). Although the full model ANOVA did not show a significant interaction between time and group, differences in alpha power preceded those of controls (paired t-tests, two-tailed: [-10:-9], t(15) = -2.806, p = 0.04; [-6:-5], t(15) = -2.156, p = 0.048; [-5:-4], t(15) = -4.413, p < 0.001; [-4:-3], t(15) = -2.275, p = 0.036). As predicted, no time points showed a difference between high and low attention on the ipsilateral ROI, for either the control group or the meditation group.

**Figure 4.** Time-resolved analysis of contralateral alpha power for Controls (A) and meditators (B). Asterisk depict significant differences between high- and low-attention at individual time points. Shaded surface represents standard error of mean.

Differences between high and low attention trials were shown to be uncorrelated with age at any of the significant time points for either controls ([3:-2], r = -.31, p = .915; [-2:-1], r = -.016, p = .956; [-1:0], r = .313, p = .275) or meditators: ([10:-9], r = -.912, p = .476; [-6:-5], r = .096, p = .724; [-5:-4], r = .191, p = .478; [-4:-3], r = .188, p = .486).

**Novice versus expert meditators**

To explore differences between novices and expert meditators we applied a median split of the meditation group on the basis of total hours of meditation experience. Hours of meditation experience were calculated from the self-reported estimated time spend in meditation per week, multiplied by the total duration of consistent meditation practice. For meditation retreats an
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estimated ten hours per day were added. The median split resulted in two very separate groups for novices (n = 7, mean = 555 hrs, range 220-885 hrs) and expert meditators (n = 8, mean 12962 hrs, range 3275-24819 hrs). One meditator did not reply to our follow-up questions and could not be included in the analysis.

As can be seen in Figure 5A, the temporal profile of the novice meditators showed a remarkable similarity with those of controls, showing a significant effect of self-report at a distinct period directly preceding probe onset ([-2:-1] t(6) = -4.057, p = .006; [-5:-4] t(6) = -2.298, p = .062; [-6:-5] t(6) = -3.865, p = 0.008). Expert meditators, however, showed a dramatically different profile (Figure 5B), with significant differences in alpha power preceding the differences found in novices ([-10:-9] t(7) = -2.391, p = 0.048; [-8:-7] t(7) = -2.201, p = 0.064 (trend); [-7:-6] t(7) = -2.008, p = 0.085 (trend); [-5:-6] t(7) = -2.580, p = 0.036; [-5:-4] t(7) = -3.769, p = 0.008). Furthermore, the last interval in high meditators showed a significant difference in the opposite direction after what seems to be a gradual reduction of alpha power in low attention trials during the last seconds of the trial (t(7) = 3.593, p = 0.009). We therefore divided the temporal profile midway in time and averaged alpha power for high and low self-report within the late and early period preceding probe onset. An ANOVA with self-report (high vs. low) and time (early vs. late) as within-subjects factors and group (novice vs. expert) as between-subjects factor showed a significant main effect of self-report (F(1,13) = 7.672, p = 0.016) as well as significant interaction between self-report, time and group (F(1,13) = 8.908, p = 0.011).

Figure 5. Time-resolved analysis of contralateral alpha power for novice meditators (A) and expert meditators (B). Asterisk depict significant differences between high- and low-attention at individual time points. Shaded surface represents standard error of mean.
Discussion

Compared to both meditation-naive controls and novice meditators, expert mindfulness meditators showed a distinctly different temporal profile of metacognitive awareness. While the self-reported attentional state of controls and novices were reflected by differences in alpha power preceding probe-onset, expert meditators showed a correspondence between self-report and alpha power during an extended period of time preceding that of both controls and novice meditators. Furthermore, expert meditators displayed a pronounced suppression of contralateral alpha power before probe onset, even surpassing those of high attention trials. Both these results are unexpected and warrant only tentative conclusions. Given these reservations, the results suggest shed light on previously unexplored territory and suggest new avenues of exploring neurocognitive mechanisms of mindfulness meditation. Firstly, the findings suggest that while novice meditators and controls were able to report on their attentional state retrospectively (i.e. after probe onset), expert meditators monitored their attention continuously and used it proactively rather than reactively. The ability maintain moment-by-moment evaluation of attention is in accordance with the proposed aim of mindfulness meditation. This might have enabled expert meditators to reestablish their attentional focus when distraction was noticed, as reflected by the suppression of alpha power in the latter half of low attention trials. However, since these trials were still reported as low attention trials, expert meditators might have confounded metacognitive awareness of their attentional state with that of attentional control. Future research could test this hypothesis by using additional self-report probes of both attentional state as well as effort/control. Positive findings on both indexes would provide objective evidence for the claim that mindfulness meditation increases the ability to differentiate internal cognitive processes (Bishop et al., 2004).

Alpha values for each voxel and time interval were standardized over all trials to remove the beamformer depth bias. Because we were interested in the correspondence between self-reports and alpha power over time, our data was standardized per time-interval as well. This made our paradigm particularly sensitive to metacognitive awareness of attention, but might have missed other effect of mindfulness meditation such as an increased ability to modulate somatosensory alpha (Kerr et al., 2011). Our findings are, however, in line with recent studies reporting improvements in attentional stability (Lutz et al., 2009b) and improved conflict monitoring (Jha et al., 2007) as both are considered to be under metacognitive control (Fleming et al., 2012).

The experiment required a minimum of behavioral responses, and these were not experienced as interfering with the usual practice of mindfulness meditation. In fact, the paradigm was well received by the expert meditators we measured. The benefit of a less intrusive paradigm in meditation research cannot be overstated. The absence of any external stimuli or behavioral
measurements too often precludes unequivocal interpretation of psychophysical findings (see e.g. CAHN AND POLICH, 2006), while at the same time, exogenous perceptual and behavioral tasks might interfere with the introspective practice.

A possible limitation to our study is the fact that the meditation and control groups were not matched in age, with the meditation group being significantly older. However, for both controls and meditators, age did not correlate with the differences in alpha power between high and low attention trials. It is therefore highly unlikely that results were dependent on age. As a between-subjects cross-sectional study our results might also suffer from a selection bias. The fact that our findings depended on the hours of meditation experience speaks against an interpretation in terms of differences preceding their meditation practice. Lastly, we cannot exclude any 'third variable' that might correlate both with meditation experience as well as metacognitive ability. For instance, it is shown that metacognition is impaired under conditions such as cigarette craving (SAYETTE, SCHOOLER, & REICHEL, 2010) or inebriation (SAYETTE, REICHEL, & SCHOOLER, 2009). Since meditation is often practiced in a social and religious context, it cannot be excluded that influences of life-style might have played a role.

Mindfulness meditation has been theorized to distinguish itself from meditation practices that focus on sustained and selective attention through its emphasis on metacognitive monitoring (LUTZ ET AL., 2006; LUTZ ET AL., 2008). While there is growing evidence that mindfulness meditation improves attentional abilities, convincing evidence for improved ability for metacognitive monitoring has been lacking (CHIESA ET AL., 2011). This is unfortunate, since these metacognitive abilities are proposed to underlie its clinical efficacy (BAER, 2003 and TEASDALE ET AL., 2002). Our findings therefore provide important preliminary evidence for the involvement of metacognitive monitoring in mindfulness meditation. Furthermore, our results suggest that such proactive attentional monitoring abilities could improve the ability to manage attentional resources on a moment-by-moment basis. However, in line with the conclusion of Chiesa and colleagues (2011), our results also show that measurable effects might require extensive practice.
CHAPTER 6. General discussion

General discussion

Abstract

The aim of this thesis was to investigate neural and behavioral correlates of mindful traits and mindfulness practice (meditation). We pursued these research questions from two perspectives that have received limited attention in experimental studies of mindfulness, while at the same time being theorized to be its defining characteristics. Nonreactivity was conceived as the disposition or ability to respond less automatically to thoughts and feelings, while metacognitive awareness was operationalized as the ability to observe and report upon mental content and cognitive process. We will first summarize the preceding empirical chapters and interpret their results in terms of the model offered in the introduction. We will then discuss a possible convergence between metacognitive monitoring and nonreactivity.
Summary of findings

Second chapter

In the second chapter we began our search for a physiological marker of (non)reactivity by investigating the automatic somatosensory response to the observation of pain. Using MEG we showed that observing painful stimuli results in a suppression of alpha power at primary somatosensory regions, representing an automatic disinhibition of the somatosensory cortex. These findings can be seen as reflecting attentional processes underlying the perception-action account of empathy: “The attended perception of the object’s state automatically activates the subject’s representation of the state, situation, and object, and the activation of these representations automatically primes or generates the associated autonomic and somatic responses, unless inhibited” (Preston & de Waal, 2002).

However, the effect on somatosensory alpha suppression did not correlate with the Interpersonal Reactivity Index (Davis, 1983), nor with the Factor Mindfulness Questionnaire, (Baer et al., 2006, unreported). So although we were able to report a measure of reactivity, this measurement did not correlate with trait measures of (non)reactivity considered to be important for the mindful trait. Although somewhat unexpected at the time, in hindsight these results were consistent with the model we proposed in the introduction. They indicate that the mindfulness trait refers to our habitual or skilful responses to affective experiences, but not necessarily to the processing of the sensory experience. In other words, the results we obtained from our first study reflects early sensory and attentional responses to an aversive stimulus that precedes possible effects of mindful attitudes and traits. The differences in reactivity that are observed between individuals in mindfulness research might therefore correspond more to subsequent affective and cognitive processes. One brain region that is central to affective processing is the amygdala (Davis & Whalen, 2001; Pessoa, 2008; Phelps, 2006). Amygdala responses to emotional stimuli have been shown to differ across individuals according to their personality traits (Davidson, 1998; Davidson & Irwin, 1999; Lapate et al., 2012). In addition, reactivity to negative emotional stimuli of the medial prefrontal cortex also correlates with neuroticism (Haas & Canli, 2008). Neuroticism is a trait that is characterized by negative mood states, sensitivity to negative information and negative appraisal; and importantly, has been shown to correlate negatively with the FFMQ (Baer et al., 2006). Effects of mindfulness meditation training on the amygdala have also been observed. In a longitudinal study, Goldin & Gross (2010) reported that after 8 weeks of MBSR training, social anxiety patients exhibited a faster return to baseline in right amygdala activity while viewing phrases of negative self-beliefs. Similarly, in a control group study by Desbordes et al. (2012), MBSR resulted in reduced amygdala activity when viewing emotional pictures. After only 1 week of practice, the amygdala response to emotional images was shown to be down-regulated.
when in a “mindful” meditative state, compared to a non-meditation baseline (Taylor et al., 2011). Interestingly, in the same study, highly experienced meditators did not reduce amygdala activity but instead deactivated medial prefrontal and posterior cingulate cortices. According to the authors, this discrepancy is consistent with an effect of mindfulness meditation on cognitive process that occur after the initial response, i.e. through a reduction of cognitive elaboration and judgments. From this perspective, mindfulness targets cognitive processes related to acceptance, interpretation and evaluation of emotional responses rather than voluntary or automatic emotional inhibition or modulation. Such an interpretation is in line with our observation of an absence of correlations between somatosensory reactivity and trait measures of reactivity.

Taken together, our investigation of sensory reactivity revealed that trait measures of (non)reactivity might be reflected by higher-order cognition, more frontal brain-regions and more complex behavioral tasks rather than initial sensory, affective or attentional responses.

Third chapter

Our brain is exceptionally able to pick up complex regularities in our environment, and it does so generally without our conscious intention or awareness. In fact, implicit knowledge underlies much of our skilled behavior - from knowing how to ride a bicycle, to our ability to appreciate music and to communicate by using language (Stadler & Frensch, 1998). This knowledge is typically not consciously accessible in the form of facts (knowing that) but rather expresses itself through our actions (knowing how). Once learned, implicit knowledge is hard to inhibit, as it expresses itself as a habit. Take for instance the classic Stroop task (Stroop, 1935) in which one is instructed to read out aloud the color of the word, but not the word itself. People are much faster when the word and the color are congruent, e.g. with RED, than when they are incongruent, e.g. with GREEN. This is one example of how our ability to read has become a habitual response to implicit knowledge. For the purpose of investigating the (non)reactive mindfulness trait, we measured the correlation between the tendency to respond habitually to implicit knowledge and mindfulness traits as measured by the FFMQ.

We used the artificial grammar learning paradigm (AGL) to induce implicit learning under controlled conditions. For five days participants were unknowingly exposed to a set of symbol sequences generated from a formal grammar (a complex rule system) in the form of a short-term memory task. Participants gradually preferred those sequences that were congruent with the grammar over those that violated the grammar. However, we showed that more mindful individuals expressed less sensitivity to the unconsciously learned regularities. In other words, when more mindful participants were asked to respond on the basis of their “gut feeling”, their responses corresponded less to the grammatical status of the sequences they had acquired. This effect was independent of differences in effort, working (verbal) memory or linguistic abilities.
These findings therefore indicated that a more mindful trait corresponds to a smaller tendency to respond habitually to implicit representations. Furthermore, this effect was expressed strongest for the non-judgmental and non-reactive subscales of the FFMQ.

These findings provide novel evidence for the nonreactive mindfulness trait. They suggest that more mindful individuals are less under the sway of unconscious representations (that underlie much of our habitual actions). Since such a nonreactive disposition can be trained within a mindfulness program (Carmody & Baer, 2008 and Kuyken et al., 2010 & 2012), such training could help individuals better manage clinical problems that are caused by destructive but persevering behavioral patterns. In other words, these findings suggest that a mindful disposition could free individuals from responding habitually and affirmatively to unconscious representations or memories. Although the influence of implicit knowledge in our experiment could be considered weak or even inconsequential compared to implicit representations that might underly the symptoms of e.g. depressed patients, as a general principle, a mindful trait might have salutary effects on both clinical and non-clinical problems.

A limitation of our study was that it did not measure acquisition of implicit knowledge separately from its effect on behavior. Our results could therefore be explained by a reduced acquisition of implicit representations rather than a reduced reactivity. While control analysis suggested otherwise, it remains to be tested whether a mindful disposition could impair the ability to learn and perform productive habitual skills. It has to be pointed out here that in our task the acquisition occurred implicitly. In other words, participants were not aware of the fact that they were learning a grammatical regularity and that they would be asked to use this knowledge later. Our results therefore do not generalize to situations wherein one is consciously (explicitly) engaged in learning or remembering. In these cases an interaction between the mindfulness trait and learning could be of a dramatically different nature. A nonreactive disposition towards internal representations might, in fact, help reduce interference from those habits that are nonproductive or inefficient for the task at hand. This hypothesis could be tested using a learning task that provides trial-by-trial feedback or in which the learning goal is made explicit. Interestingly, some evidence for a positive influence of mindfulness on reducing dysfunctional representations comes from recent studies that show that specificity in autobiographical memory increases in healthy and formerly depressed people after MBCT (Hargus et al., 2010; Heeren et al., 2009; Williams et al., 2000). Taken together, we believe that our results provide evidence for a nonreactive mindfulness trait on the response level rather than during encoding, providing cues to a potential mechanism for its salutary effects.

Fourth chapter

We then proceeded to study the second aspect of mindfulness we introduced, namely
metacognitive monitoring. Specifically, we investigated whether the degree of somatosensory attentional focus is metacognitively accessible on a moment-by-moment basis. For this purpose we indexed the attentional focus through measurements of contralateral somatosensory alpha power (magnetoencephalography, MEG). Participants were cued to direct their attention to either their left or right hand. At unpredictable moment the trials were terminated with a probe sound. Participants had to report about their attention focus at the moment of the probe. Self-reported attentional focus was shown to correspond with their somatosensory alpha power preceding probe onset. Furthermore, self-reports were shown to be based on attentional focus rather than on a general attentional state (e.g. vigilance) because the correspondence between alpha power and self-reports only occurred for the contralateral but not for the ipsilateral hemisphere. This study therefore provides strong support for the metacognitive accessibility of attentional focus. Moreover, this is the first study showing metacognition in the absence of either exogenous stimulation or evaluations of task performance based on overt behavior. This provides us with a measure of metacognitive awareness of attention that is ideally suited to simulate the minimal sensory and behavioral context in which mindfulness meditation is commonly practiced.

Fifth chapter

In the fifth chapter we investigated whether meditation experience could be associated with an improved ability for metacognitive monitoring. Using the paradigm we developed in the previous chapter, we replicated our findings in a group of mindfulness meditators, showing the robustness of the paradigm and our initial findings in controls. In this study we extended the analysis of brain activity to include eleven seconds before probe onset. Differences between the meditators and controls manifested as different temporal profiles rather than differences in average alpha power. Whereas in controls self-reported attention corresponded to differences in alpha power during the last three seconds preceding probe onset, self-reports by meditators were reflected by alpha power differences preceding those of controls. Importantly, a median split between novice (<1000hrs) and expert meditators (>>1000hrs) showed that this difference only occurred in expert meditators, while novice meditators showed a profile remarkably similar to that of controls.

Unexpectedly, expert meditators showed a pronounced suppression of contralateral alpha power preceding probe onset for those trials that were identified as low attention trials. These findings suggested that once expert meditators observed their attention faltering, they corrected their contralateral alpha level back (and beyond) those of good trials. These corrected trials were still reported as low attention trials, suggesting that the refocusing of attention was identified as corresponding to a suboptimal (low attention) trial. This suggests that expert meditators were able to distinguish their momentary attentional state as well as their attentional control. This would be in
line with the hypothesis formulated by Bishop and colleagues (2004) that mindfulness meditation might increase cognitive complexity, permitting finer discriminations of sensory, affective and mental states. Future research could further explore this interesting proposal through the use of additional self-reports such as perceived effort, difficulty and confidence. Importantly, future research should investigate whether the differences that were found between expert and novice meditators resulted from changes in metacognitive ability, rather than differences in the execution of the instruction, i.e. if the expert meditators reported their attentional effort rather than their attentional state. Interestingly, in expert meditators the earlier part of the trial displayed a sustained correspondence between alpha levels and self-reported attention. These results were unexpected as well, and only the most tentative conclusion are warranted at this point. They do suggest that expert meditators were continuously monitoring their attentional state, enabling the aforementioned compensatory adjustment to their attentional state. Since controls and novice meditators showed neither a correspondence between self-report and alpha in the early phase, nor the compensatory alpha suppression in the later phase, we suggest that novices and controls might have been evaluating their attention retrospectively instead, i.e. after the probe, whereas the experience of expert meditators allowed more proactive monitoring.

Together, although tentative, these results provide a novel view on the metacognitive processes during mindfulness meditation, as well as into the potential long-term effects of its practice. Importantly, the possible increased ability of expert mindfulness meditators to continuously monitor their attentional focus could be considered preliminary empirical support for the theoretic model put forward by Lutz et al. (Lutz et al., 2006). In their taxonomy of meditation practices, Focused Attention refers to those practices that revolve around sustaining selective attention, while in mindfulness metacognitive monitoring of experience is emphasized. Furthermore, the fact that the differences were only shown by expert and not novice meditators, substantiates the suggestion by Chiesa aand colleagues (2011) that improvements in metacognitive functioning might only occur after extensive mindfulness meditation practice.

**Metacognitive monitoring and nonreactivity converging?**

In this thesis we have argued that nonreactivity and metacognitive monitoring are of crucial importance for understanding mindfulness meditation - from its historical to its contemporary practice - as well as the mechanisms underlying its purported clinical and nonclinical benefits. The question we should pose now, however, is how these two aspects of mindfulness meditation might be related.

Although we have focused on nonreactivity, this is only one of a number of skilful responses to emotional or distracting experiences (box E) that comprise the set of mindful attitudes (Figure 1,
box C). As we already mentioned in the introduction, the first three factors of the FFMQ (observing, describing and acting with awareness, Box F) reflect aspects of metacognitive monitoring, while the last two (nonjudging and nonreactivity, Box C & D) reflect mindful attitudes or traits that refer to the cognitive and affective response to experience (Box E). In our model we have separated these processes. However, by using a bidirectional arrow we do suggest that mindful attitudes not only affect metacognitive monitoring but that the reverse is likely true as well. How this could be the case is an important research question that has remained unaddressed in questionnaire research. Similarly, while Bishop and colleagues (2004) defined mindfulness in terms of these two aspects, they did not address the nature of their interrelationship. While the research reported in this thesis does not directly address this question, we allow ourselves to make this interaction explicit and propose ways by which it could be considered in future research.

As we extensively argued in the introduction, we consider mindfulness meditation as a metacognitive investigation of experience, enabled by the application of attitudes that are conducive to this investigation. In fact, often the attitudes that we bring to experiences are the problem. Identifying these attitudes and engaging in more beneficial ones are part and parcel of the mindfulness meditation practice. These unproductive attitudes are identified as the “hindrances” or “obstacles” in both traditional (GUNARATANA, 1993) and contemporary clinical practice (KABAT-ZINN, 1990b), comprising states of desire, aversion, sleepiness, restlessness or doubt. Jon Kabat-Zinn, founder of the MBSR, describes that the appropriate response to counteract the distraction and loss of awareness that results from these attitudes, is to adopt an attitude of non-judging, patience, curiosity, trust, non-striving, acceptance and non-attachment. Interestingly, there is some direct experimental evidence for an effect of mental states on the ability for metacognitive monitoring, as the latter is shown to be impaired under conditions such as cigarette craving (SAYETTE ET AL., 2010) and inebriation (SAYETTE ET AL., 2009). Similarly, mind-wandering is shown to be increased by states of anxiety (SMALLWOOD & SCHOOLER, 2006). Although as of yet untested, we suggest that mindful states or attitudes will be beneficial for metacognitive monitoring by inhibiting mental and emotional elaboration (i.e. nonjudging) and by reacting less automatically to thoughts and feelings (i.e. nonreactivity). However, we also propose that it is only through the ability of metacognitive monitoring that dysfunctional attitudes can be recognized so that beneficial ones can be engaged.

Conceptual clarity and a precise and coherent terminology should be amongst the guiding principles of all future research into mindfulness, for which this thesis provides some initial directions. In particular, we propose that the mutually beneficial relationship between mindful attitudes and metacognitive monitoring promises to bridge the seeming incommensurability between the paradigms of neurocognitive research - with its focus on the cognitive mechanisms of mindfulness meditation - and clinical research, which aims to understand and develop mindful traits and attitudes.
Some research fields know what they are studying. Others do not know yet, and therefore spend a great deal of time trying to figuring out what they are trying to figure out. Science is the business of questioning, and has equipped itself with a large collection of shiny measurement devices, savvy statistical techniques and strict methodological procedures. Some of these are inherited from other fields of study, while others are developed by the field itself, in due course. Especially the latter helps to establish an experimental paradigm that has its own identity, its own research questions, theories and acronyms. However, before you can use all these shiny instruments, you first need to know where they should be pointed at. Metaphorically that is, since in psychology (the study of the mind) the object of study is not a where, but a whom. The object of study is the subject.

More often than not research fields generate their own questions. That’s the great thing about science: its inherent momentum and ability to discover new questions by learning new ways to look for them. Sometimes, however, a question is found just laying around. Minding its own business, in a way. Or rather, not being minded by other people’s business. It can lay there for quite a while not being noticed, until by some insight or inspiration someone does. Once noticed, people start to question what it’s doing there, if it’s been there for long, where it came from, and most importantly: if it’s going to leave by itself. Sooner or later people will start arguing that somebody needs to do something about it: “We can’t have questions just laying around. It makes us all look rather, well... unprofessional.”

Some questions attract more attention than others. A question wouldn’t be noticed at all, of course, if it didn’t. And if it didn’t before, it’s because people didn’t notice it before. The point is that once people do notice it, it inevitably starts attracting even more attention. The more people that start pointing at it, the more it gains attention, drawing in more attention, until the

9 Many books are written about this rather unsettling issue. In fact, some have argued these books raise even more questions, and that one should’ve written a book with answers in them instead, of which they, by change, have one “right here”. In turn, even more books have been written about these books, starting the whole business anew and leaving everyone a bit angry.
situation becomes critical. Soon afterwards, questions are typically carried away by the experts. They wrap their arms protectively around it and, while mumbling apologies and explanations under their breath, jostle it out of the crowd. Sometimes, when the experts are not forthcoming, or if the question has become rather popular the crowd was waiting for then, the very people that found it might decide to carry it home instead, starting a new field of study themselves. They might name it for the person who saw the question first. Far more importantly, however, is to decide on a name for the question. This is typically done with much haste so to make sure they know what they are talking about. As such things go, choosing a name is not unknown to cause considerable discussions amongst the new members. It might even result in questions being called by different names by different people, or by the question being abandoned altogether. Although this is generally considered to be a bad thing for all those involved, it is also generally considered to be caused by the question, rather than by those trying to answer it.

It is a sad thing when questions finally leave us. Their caretakers are never quite the same. Sometimes they might even say they killed it, often with a kind of melancholic pride. According to some books, however, questions never really die. Instead, they became a part of all other questions, or of an even bigger question, if you like. Some say all questions will someday inevitably come back, but only if they were true questions.

This thesis was about a question that's been around. It had many names, although it is not in its nature to remember the past. It is in its nature to feel young and be free. It is in its nature to be found and then forgotten.
8

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CHAPTER 8. Appendix


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Nederlandse Samenvatting

In dit proefschrift hebben we de neurale mechanismen en gedragscorrelaten van mindfulness onderzocht. Wat mindfulness precies is, is echter lastig vast te stellen. Mindfulness wordt onder andere beschreven als een verzameling cognitieve functies, als een persoonlijkheidsstrek, of als een specifieke verzameling vermogens of attitudes. In het eerste hoofdstuk gaven we een overzicht van deze verschillende conceptualisaties en poogden ze te integreren in een werkmmodel ten behoeve van ons eigen en toekomstig onderzoek. We beschreven hoe, vanuit een Boeddhistische oorspong, mindfulness zijn weg heeft gevonden naar hedendaagse klinische interventies en experimenteel onderzoek. De definitie en operationalisatie van mindfulness bleken nog in de kinderschoenen te staan. De meeste kennis over mindfulness kwam namelijk voort uit onderzoek dat verricht was binnen de kliniek, waarbij de nadruk lag op uitkomstmaten van klinische interventies en minder op de cognitieve mechanismen die daaran ten grondslag zouden kunnen liggen. In combinatie met - het dus tot nog toe vrij beperkte - experimenteel neurowetenschappelijk onderzoek, bleken vooral twee aspecten voor mindfulness van cruciaal belang: non-reactiviteit en metacognitief monitoren. Met non-reactiviteit verwezen we in dit proefschrift naar een dispositie (en vermogen) om verminderd automatisch te reageren op gedachten en gevoelens. Metacognitief monitoren verwees naar het vermogen om mentale inhoud en processen bewust te observeren en daarop te reflecteren.

In het tweede hoofdstuk begonnen we onze zoektocht naar een fysiologisch correlaat van (non) reactiviteit. We onderzochten de automatische reacties van de hersenen op de observatie van pijnlijke plaatjes met behulp van de MEG (magneetoencephalografie). We vonden dat tijdens de observatie van deze plaatjes bepaalde hersengolven (hersengolven van ongeveer 10 oscillaties per seconde, ook wel alfa-golven genoemd) werden onderdrukt in de hersengebieden waarin ons eigen lichaam gerepresenteerd wordt. Dat wil zeggen dat onze eigen lichaamsrepresentaties automatisch geactiveerd worden wanneer we naar andere mensen in een pijnlijke situatie kijken. Deze hersenactiviteit bleek echter geen verband te houden met de scores op vragenlijsten waarmee we empathie, individuele reactiviteit of mindfulness maten. Hieruit concludeerden we dat non-reactiviteit niet zozeer te maken zou kunnen hebben met het verwerken van emotionele informatie, maar meer met onze automatische reactie op deze emotionele informatie.

In het derde hoofdstuk vervolgden we ons onderzoek door ons te richten op de (automatische) reacties op emotionele informatie. Onze hypothese was dat personen die hoger scoren op een mindfulness vragenlijst zich minder door emotionele processen zouden laten leiden. Proefpersonen werd verteld dat ze aan een onderzoek naar geheugen meededen. Daarbij werd hen op vijf verschillende gelegenheden gevraagd om honderden letterreeksen een-voor-een te onthouden en te reproduceren. De proefpersonen waren zich er echter niet van bewust dat het experiment in werkelijkheid over het indirect leren van grammaticale regels ging. De letterreeksen...
Die ze moesten onthouden waren namelijk helemaal niet willekeurig samengesteld, maar gecreëerd op grond van onderliggende regels. Zowel tijdens als na afloop van de geheugentaak, vroegen we proefpersonen om te beoordelen of ze (nieuwe) letterreeksen als prettig of onprettig ervoeren. De proefpersonen lieten een duidelijke voorkeur zien voor letterreeksen die zich aan dezelfde regels hielden als degene die ze in de geheugentaak hadden geleerd. Ze waren zich echter niet bewust van het doel van het experiment, noch van de (correcte) grammaticale regels. We toonden hiermee aan dat er op grond van onbewuste informatie gehandeld kan worden (bijvoorbeeld door een voorkeur aangeven), zonder dat we ons bewust zijn van die kennis (of invloed) waarop we ons gedrag baseren. Zoals we voorspelden, was de invloed van onbewuste kennis op het gedrag kleiner, tot geheel afwezig, bij proefpersonen die hoger scoorden op de mindfulness vragenlijst. Dit suggereert dat mindfulness geassocieerd kan worden met een nonreactieve dispositie die de invloed van automatische reacties verminderd.

In het vierde hoofdstuk ontwikkelden we een experiment waarmee we metacognitief monitoren maten, het tweede concept dat ten grondslag ligt aan mindfulness. Tijdens mindfulness meditatie is het voor de meditator namelijk van cruciaal belang zich bewust te blijven van de locatie en de toestand van de aandacht. Middels het ontwikkelen van dit experiment hoopten we metacognitie van aandacht objectief vast te kunnen stellen. We beoogden dit te doen door te onderzoeken of de zelf rapportage van aandachtsfocus samenhangt met hersenmetingen die aandacht reflecteren. Omdat het object van aandacht tijdens mindfulness meditatie vaak het lichaam is (in het bijzonder, de ademhaling), richtte dit experiment zich op de metacognitie van de lichaamsaandacht. Het experiment verliep als volgt: Proefpersonen lagen op hun rug met hun ogen dicht en hun hoofd in de MEG helm. Ze werden door middel van verschillende geluiden geïnstrueerd om hun aandacht te richten op hun linker of rechter hand. Vervolgens werd hen gevraagd hun aandacht zo goed mogelijk bij de aangegeven hand te houden totdat, op een onverwacht moment, er een tweede geluid klonk. Met een druk op de knop gaven de proefpersonen vervolgens aan hoe goed ze dachten dat hun aandacht op dat moment op de aangegeven hand was gericht. Als objectieve maat van aandacht gebruikte we het niveau van alfa golven in de sensorische hersenschors: die gebieden waar het lichaam geregistreerd wordt en lichaamssensaties verwerkt worden. We vonden dat de zelf rapportage inderdaad correspondeerde met het niveau van alfa golven in hersengebieden van de desbetreffende hand.

In het vijfde hoofdstuk gebruikte we het experiment dat we in het vierde hoofdstuk hadden ontwikkeld, om te onderzoeken of de beoefening van mindfulness meditatie ons beter in staat stelt accuraat over onze aandachtstoestand te rapporteren. Daartoe vergeleken we twee groepen meditatore: de ene groep had enige meditatie ervaring (<1000 uur), terwijl de andere groep zeer ervaren was (3000 tot 30000 uur). We vonden een verrassend sterke overeenkomst tussen de resultaten van de eerste groep (de onervaren meditatoren) met de resultaten van de meditatie-
naïeve proefpersonen uit de vorige studie. Deze replicatie laat niet alleen zien dat zowel het experiment als de analyse robuust zijn, maar suggereert ook dat enige meditatie-ervaring wellicht niet genoeg is om tot veranderingen in metacognitie te leiden. Bij zowel de proefpersonen uit de vorige studie, als bij de onervaren meditatoren in deze studie, correspondeerde de zelfrapportage met de hersentoestand direct voor de rapportage. Echter, bij de zeer ervaren meditatoren vonden we een ander patroon: hun zelfrapportage correspondeerde met de hersentoestand tijdens de gehele periode voorafgaand aan het moment van rapportage. Bovendien vonden we bij de ervaren meditatoren dat wanneer de aandacht als “slecht” gerapporteerd werd, de hersenactiviteit “gecompenseerd” leek te worden. Vervolgonderzoek is noodzakelijk om de betekenis van dit resultaat nader te verklaren. Echter, deze resultaten suggereren dat ervaren meditatoren in staat waren hun aandacht continue (i.a.w. proactief) te monitoren, terwijl de andere proefpersonen hun aandacht vooral achteraf evalueerde. De ervaren meditatoren leken daardoor in staat al tijdens de trial op te merken dat hun aandacht was verslap, en ter compensatie hun aandacht weer aan te sterken. Dat de meditatoren deze trials nog steeds als “slecht” beoordeelden, suggereert echter ook dat deze extra moeite die deze compensatie kostte, werd meegenomen in hun zelfrapportage. Toekomstig onderzoek zal moeten uitwijzen of dit resultaat verklaard kan worden doordat de ervaren meditatoren de instructies anders interpreteerden, of dat ze daadwerkelijk in staat waren om niet alleen over hun aandachtstoestand, maar ook over hun aandachtscontrole te rapporteren.

In dit proefschrift werd gesteld dat non-reactiviteit en metacognitief monitoren essentiële concepten zijn om mindfulness (meditatie) te kunnen begrijpen; Van de historische oorsprong, tot aan de mechanismen die aan de basis liggen van de klinische en niet-klinische effecten. Hoewel het onderzoek zich richtte op non-reactiviteit, kan non-reactiviteit beschouwd worden als één eigenschap van een ruimere set ‘mindful attitudes’, zoals b.v. zelf-compassie. In dit proefschrift maakte we een conceptueel onderscheid tussen mindful attitudes en metacognitief monitoren. We kunnen echter een wederkerige relatie veronderstellen: Door middel van mindful attitudes wordt de meditator in staat gesteld metacognitief te monitoren - door bijvoorbeeld minder snel afgeleid te zijn door emotionele gebeurtenissen. Vice-versa, dankzij het vermogen metacognitief te monitoren, kunnen disfunctionele attitudes (b.v. kwaadheid en stress) geïdentificeerd worden en vervangen worden door meer mindful attitudes (b.v. minder reactief en beoordelend). Toekomstig onderzoek zal zich daarom dienen te richten op de relatie tussen deze twee cruciale aspecten van mindfulness. Conceptuele helderheid en een coherente terminologie zouden hierin een leidraad moeten zijn. We hebben geprobeerd in dit proefschrift hieraan een bijdrage te leveren. Het onderzoeken van de relatie tussen klinisch relevante attitudes en metacognitief monitoren zal daarmee kunnen helpen een brug te slaan tussen klinisch onderzoek, waarin onderzocht wordt welke attitudes klinisch relevant zijn en hoe ze ontwikkeld kunnen worden, en neurocognitief onderzoek, dat op zoek is naar mechanismen die aan de basis liggen van mindfulness.
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This thesis would not have been possible, or at least be in an even worse state, without the wonderful support of my family, so many colleagues and dear friends. It is a pleasure to take some time to mention those that come to mind most readily, partly because they have been responsible for keeping me informed, inspired and dedicated, and partly because I am just unable to imagine the last years without them.

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After I finally dared to take my seat at the Donders Centre for Cognitive Neuroimaging (DCCN), I was surrounded by some of the savviest neuroscientists this side of the globe can offer. Besides hoping something might have rubbed off in the meantime, having befriended so many kind and generous colleagues has been my great fortune. From the neuronal oscillations group a shout-out go to Bad Boy Ali Mazaheri, Whats in a Bow Tie Saskia Haegens, Samurai Yuka Okazaki, my
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My officemates probably deserve the most gracious acknowledgements. I was the third wheel, joining Martini van Schouwenburg and Kirsten Weber in room 0.84. I admit it took a while to settle in and to start communicating. I vaguely remember an early period of non-intentional grunts and gasps, which was followed by a longer period (a year?) of non-verbal gestures and curses. As I’m writing this both Kirsten and Martini have left, however. It leaves me in a melancholic mood realizing that our romance ended just when we started talking in full sentences. I now share the office with Diana Dimitrova and Maarten Mennes. They are surely nice roommates, but I am not ready for them yet and have reverted back to grunting.

During first study (don’t worry, I’m not going over all of them, but its a good start) I leaned heavily on the help of Ingrid van Nieuwenhuis who always made time, even in those last days of her PhD - which I know now, was a great kindness. Most of all, she showed me to dig deep into the FieldTrip code. This led to me hanging out with the cool kids of the FieldTrip gang, in particularly Robert Oostenveld, Jan-Mathijs Schoffelen, Saskia Haegens, Roemer van der Meij, Arjen Stolk, Johanna Zumer and Lilla Magyari. I want to thank Robert in particular for actively building on our confidence, for always being available for technical and scientific advice, and for tending to my future career as well. Jan-Mathijs has spent hours trying to explain the simplest matrix operations to me, mostly in vain, although that was not his fault. Saint Beckmann, after trying to explain the most elementary linear models ended up borrowing me a comic book on statistics. My sincere thanks and apologies to them and all the others who tried.

The second chapter was the result of an engaged and inspired collaboration into a field I quickly discovered I knew not much about. I owe it to Julia Udden and Karl-Magnus Petersson that I found my way through the field of implicit learning relatively unscathed, although I may have developed some unintended affection for language research. Our research would not been possible without gracious support from the Fundação Bial. In particular I would like to thank Luís Portela and Paula Guerdes for their great kindness, expertise and unique vision in sponsoring high-risk and atypical research.

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The worst thing that can happen during your PhD is that you lose sight of the bigger picture - of the fact that science is a social endeavor as well, and that you are not alone. Especially when your topic is a topic as broad as consciousness. Many, many thanks therefore go out to Abi Behar-Montefiore for making me part of all those inimitable Towards a Science of Consciousness Conferences (TSCC) where so many new friends and ideas were made every time. Thanks to Stuart Hameroff and the rest of the organizers, attendees and speakers. Without TSCC I would have not met Frank Echenhofer, to who I owe the most amazing research EEG expedition to the Peruvian jungle. The fully embedded science we did there has been a hallmark of scientific exploration for me ever since. Without TSCC I would also have never met Alan Hobson, who, after an animated conversation during lunch, made me (unknowingly) decide to pursue a career in neuroscience. Most importantly, without TSCC I would not have met David Aaron Holmes, who has been my most valuable friend, co-researcher and advisor in our mutual exploration of the full scope of meditation and Buddhism.
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It is increasingly asked of scientists to communicate and explain their work to an audience that is not of a scientific creed. However, not only is it required that one should be able to communicate scientific findings and ideas, but also that one is comfortable taking the role of “the scientist”. You really only experience being one of those “scientists” when you find yourself outside of the scientific context. I been very fortunate, therefore, to have been part of OuUuPo, in which artists, critics and researchers explore the borders of art, science and curatorial practice through performative art, lectures and meetings. Our continuous meetings across the globe have all been beautiful and formative experiences. Thanks to (amongst many others, in alphabetical order again): Alessandra Sandrolini, Claudia Squitieri, Elena Nemkova, Fatos Üstek, Jacopo Miliani, Klas Eriksson, Per Hüttner, Natasha Rosling, Samon Takahashi, Sara Giannini and Yane Calovski. Special thanks to Elena for designing the cover of this thesis.

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Curriculum Vitae

Stephen Whitmarsh was born on April 27th, 1979 in Woerden, The Netherlands. He started his studies in 1999 at the University of Amsterdam where he obtained a MSc degree in Psychology. In November 2008 he started as a PhD student in Nijmegen, at the Foundations of Mathematics and Computer Science department of the Radboud University under supervision of Prof. dr. Henk Barendregt, and Prof. dr. Ole Jensen’s Neuronal Oscillations group at the Donders Centre for Cognitive Neuroimaging. After finishing his PhD work in February of 2013, he was assigned as a postdoc at the Donders Centre under supervision of Dr. Robert Oostenveld. In September 2013, Stephen will start as a postdoctoral researcher at the Karolinska Institutet where he will further pursue his research interests at NatMEG, the National Swedish facility for Magnetoencephalography.
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