# Neurophysiological support for enhanced attentional processing through the practice of mindfulness

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## Abstract

In this study it is examined whether participating in the Mindfulness Bases Stress Reduction (MBSR) training enhances attention processing. The electroencephalogram of 32 participants was measured before and after the training and analyzed through the Lateralized Power Spectra. Both between- and within group results have been analyzed. It was expected that the enhanced attentional processing would be revealed by increased ipsilateral  $\alpha$  and  $\theta$  power compared to contralateral power. Results on the  $\alpha$ -bands revealed increased ipsilateral  $\alpha$ -power compared to contralateral power in both analyses. In the within group analysis on the  $\theta_2$ -band unexpected decrease of ipsilateral power compared to contralateral power was found. On the  $\theta_3$ -band increased ipsilateral power has been visible in the between group analysis. These results indicate a positive effect of mindfulness on attentional processing. The significance of the results is elucidated in the discussion and recommendations for further research have been made.

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## 1. Introduction

#### 1.1. Support for effects of mindfulness

Meditation is a strong emerging phenomenon in the west, in which mindfulness is one of the widest spread techniques. Mindfulness is defined as "paying attention in a particular way: on purpose, in the present moment, and non-judgmentally" (Kabat-Zinn, 1994, p. 4). Nowadays this form of meditation is often used in clinical settings as a health care intervention. The first developed and most cited of these mindfulness programs is Mindfulness Based Stress Reduction (MBSR; Kabat-Zinn, 1982; Baer, 2003). This program is widely implemented for treating chronic pain, depression, anxiety, stress and chronic somatic diseases. Also the clinical effectiveness of this program is repeatedly reported (Baer, 2003; Bohlmeijer, Prenger, Taal & Cuijpers, 2010; Carlson, Speca, Patel & Faris, 2007; Miller, Fletcher & Kabat-Zinn, 1995).

Mindfulness, as practiced in the MBSR program, is thought to improve the mental- and physical health by means of focusing on somatic sensations in a neutral non-judgmental way. Furthermore, MBSR is suggested to improve the control of attention (i.e. self-regulation; Bishop et al., 2004; Chiesa, Serretti, & Jakobsen, 2013). The fundament of mindfulness therefore may be seen as a modification of attentional processing. However, the support for this claim is still limited. Partly this is due to the fact that most studies on mindfulness are evaluating the efficacy based on the subjective support of self-reports. Self-reports are limited in providing strong support as there are many potential problems with errors on the parts of the respondents. Secondly, the support is still not very strong due to the fact that studies focussing on objective outcomes, such as electroencephalogram (EEG), often shortfall in the application of standardized designs (Shapiro, Carlson, Astin, & Freeman, 2006; Cahn, & Polich, 2006, Chiesa et al., 2013). To overcome these shortcomings in this study a randomised design will be used. Both between- and within group results will be analysed in order to gain more thorough support for the modification of attentional processing by means of mindfulness. When similar effects are visible in both analysis then this will provide stronger evidence for the effects of mindfulness.

#### 1.2. Attentional processes involved in mindfulness

The basic concept in mindfulness is to attend to objects of observations, such as breathing and bodily sensations, in a neutral and non-judgmental mode. By changing the attentional processes participants learn to self-regulate their focus of attention on somatic sensations (Kerr, Sacchet, Lazar, Moore & Jones, 2013). Mindfulness is thought to appeal to higher order of attention in which attention is consciously and intentionally aimed at relevant information for the current cognitive goal (Shapiro et al., 2006). As the direction of attention towards an object of the environment is guided by higher cognitive processes, this can be seen as endogenous focusing of attention.

Bishop et al. (2004) have suggested that mindfulness increases both the efficiency of sustained attention as the switching of attention. The first, sustained attention, is to keep a state of alertness over prolonged periods of time (Posner & Rothbart, 1992). According to Bishop and colleagues (2004) in mindfulness meditation sustained attention is the maintenance of awareness of the current experience. Previous research revealed a reduction in the P3 component after participating in an MBSR program when presented with a nociceptive stimuli (Van der Lubbe, De Kleine, Blom, Schreurs & Bohlmeijer, 2013). The P3 component is suggested in a review by Polich (2007) to indicate a decrease in the 'call for attention' which would reflect an increase in the efficiency of sustained attention. As the P3 is observed to be more reduced when higher intensity stimuli is delivered at the to-be ignored side, it is proposed to indicate suppression (Van der Lubbe et al., 2013). These results suggest that mindfulness indeed improves the self-regulation of sustained attention. Comparable effects might be present for the efficacy of transient attention (i.e. switching of attention). This is a flexible state of attention in which the focus shifts from one object to another (Posner, 1980). One of the main exercises in the MBSR training is the body-scan practice of: "moving a focused spotlight of attention from one part of the body to another" (Kerr et al., 2013, p 2). This can be seen as transient attention as the participants are switching their attention between body parts. Also Bishop and colleagues (2004) have proposed that the switching of attention is necessary in order to bring attention back to the object of observation when being distracted. Switching of attention is important in every mindfulness practice. Therefore, in this study the transient attentional modifications through the practice of mindfulness are examined.

#### 1.3. Research method Lateralized Power Spectra

The neurophysiological mechanisms underlying attentional processes might be revealed by changes in the different frequency bands. Oscillation in the  $\alpha$ -band (8 – 13 Hz; known since Berger, 1929) has been associated with attentional processes, and the relation with mindfulness has been frequently reported (Chiesa & Serretti, 2010; see also Cahn & Polich, 2006). Whereas previously  $\alpha$ -power has been seen as a cortical idling state (Pfurtscheller, Stancak & Neuper, 1996), more recent theories claim that modulation of  $\alpha$ -power reflects the suppression and inhibition of task-irrelevant information. Also oscillations in the  $\theta$ -band (4 – 8 Hz) are frequently reported to correlate with attentional processes, as well as to relate with mindfulness (Chiesa & Serretti, 2010; see also Cahn & Polich, 2006). This  $\theta$ -power is seen as a process that: "brings together activity of sensory- and/or memory activated neurons in time, thereby affection behavioral output and plasticity" (Buzsáki, 2002, p 336). It is argued that  $\theta$ -power reflects enhanced encoding and retrieval of new information (Staudigl & Hanslmayr, 2013).

However, the problem in research on modulation in the frequency bands is that the changes that are found might be due to hemispherical changes. It is stated that lateral differences are highly relevant in attentional processes (Posner & Petersen, 1989; Vallar & Perani, 1986). To gain further inside into these hemispherical differences in attentional regulation a new method is developed: the so called lateralized power spectra (LPS; Van der Lubbe & Utzerath, 2013; Van der Lubbe, Bundt &

Abrahamse, 2014). The LPS method is developed as an alternative to Event Related Lateralizations (ERLs; De Kleine & Van der Lubbe, 2011; Oostenveld, Stegeman, Praamstra & van Oosterom, 2003; Van der Lubbe & Utzerath, 2013). ERLs show the relevant hemispherical differences as a reaction to a specific event, the so called evoked activity. However, the averaging over trials in ERPs and ERLs might exclude relevant information of the variation that takes place over trials and between individuals (Buzsáki, 2006). As for the calculation of LPS the raw EEG data is used, the LPS includes information of the variation, therefore providing more thorough insight into attentional processes (Van der Lubbe & Utzerath, 2013). First examination of the LPS method showed activity in the LPS that wasn't visible in the ERLs (see Van der Lubbe & Utzerath, 2013). This suggests that effects have indeed been cancelled out in the ERLs due to phase differences between trials and participants. As this makes the LPS highly relevant for examining lateral differences in this study the LPS method will be used to examine the modulation of attentional processing. In this study the following ten symmetrical electrode pairs will be analyzed: FC5/FC6, C3/C4, CP3/CP4, CP5/CP6, P3/P4, P5/P6, P7/P8, PO3/PO4, PO7/PO8 and O1/O2. To a large extent these electrode pairs are comparable to LPS analyses done by Van der Lubbe and colleagues (2014) on spatial attention. These electrode pairs overlay the potentially relevant brain areas like the hand motor areas, parietal areas, occipito-parietal areas, and occipito-temporal areas. As the focus of this study is on  $\alpha$ -power and the  $\theta$ -power the frequency bands that will be are analyzed are:  $\theta_1$  (3.2 – 4.8 Hz),  $\theta_2$  (4.2 – 6.3 Hz),  $\theta_3$  (5.5 – 8.2 Hz),  $\alpha_1$ (7.2 - 10.7 Hz) and  $\alpha_2 (9.4 - 14.0 \text{ Hz})$ .

#### 1.4. Supramodal attention control

In spatial attention often several sensory modalities are involved as information comes from different sensory modalities. It is thought that integration of different sensory modalities is required for adaptive control of behavior (Eimer, Van Velzen & Driver, 2002; Spence & Driver, 1997; Ward, McDonald & Golestani, 1998). This integration is called cross-modal interaction.

Spence, Pavani and Driver (2000) presented participants with visual targets on the left or right side, and tactile targets on the left or right hand. In various blocks, one of these target modality was more likely to occur than the other, and targets within this primary modality were highly likely to occur on one side. The targets in the secondary modality were somewhat more likely on the other side. For stimuli presented on the side attended in the primary modality the reaction times (RTs) were faster. This was for both within that modality and also in the secondary modality, revealing crossmodal interaction. Another research of Eimer and Driver (2000) showed similar effects. Endogenous attention on the left or right side within either touch or vision was instructed, while ignoring the taskirrelevant modality. On the visually attended side the attentional modulation of the P1 and N1 components were observed, which were also found when attending to tactile stimuli. For tactile stimuli attentional negativities were found at midline and lateral central electrodes when attending to one side in touch. The same modulations of somatosensory ERPs were observed when endogenous attention on the left or right side within vision was instructed.

Furthermore, it is claimed that there is supramodal attention control independently of which modality is attended to. Supramodal attention is thought to be a kind of spatial presentation related to the visual modality. Research with a somatosensory modality task quite similar to the one used in this study is done by Eimer, Van Velzen, Forster & Driver (2003). They have given participants the instruction to detect infrequent tactile targets delivered to the cued hand while ignoring visual stimuli. Even when the room was darkened processing of task-irrelevant visual events was still modulated by spatial attention for the tactile task. The conclusion was made that the crossmodal attention control is independent on selection being guided by ambient visible information in a lit environment. According to the authors this suggests that spatial shifts of attention are controlled supramodally (Eimer et al., 2003). For the task used in this study in which subjects are instructed to attend to their hands supramodel attention control can be expected. Even though subjects are in a dark room and instructed not to look at their hands, it is possible they are directing attention to either the left or right space where the to-be-attented hand is.

#### 1.5. Design of the study: between- and within group comparisons

In order to test the hypothesis two groups of randomly assigned healthy young adults concurrently received an MBSR training. First the between group effects will be analyzed, and next the within group effects. The results of both the between and within group analysis will be compared in order to give more thorough support for the effect of MBSR on transient attention. When the expected effects are present in both the between- and in the within group analysis this will provide strong support for the hypothesis that MBSR increases the efficacy of transient attention. Both analyses consist of an exploratory t-test, to see whether there are effects of lateralization present. For the bands, electrodes and time windows where lateralization is visible, further analyses will be done to see if these effects are representing differences between / within the groups.

The between group results consist of measures of group 1 prior to the MBSR training and group 2 direct after the MBSR training. In the second analysis the within group results of group 1 prior the MBSR training and the same group direct after the MBSR training will be examined. For both analyses EEG data, of the 1-s cue target interval, derived from an endogenous Posner cuing paradigm (Posner, 1980) will be used. In this paradigm, which is often used to research spatial attention, a cue is provided that indicates with some validity the location of the target. In this study the cued location is either the left or right forearm, where nociceptive stimuli are given intracutaneously. If the cue indicates pseudo randomly the to-be attended sides from trial to trial this is considered as a transient attention paradigm. This study will focus on these transient attentional mechanisms underlying mindfulness, as this reflects the switching of attention involved in mindfulness. The task of attending

to the left or right forearm is reflecting the mean practice of MBSR where the attention is focused on somatic sensations (Kerr et al., 2013).

1.6. Hypothesis: lateral differences on the  $\alpha$ -band and the  $\theta$ -band with cross-modal interaction In this study it is expected that the efficiency of transient attention is enhanced by practicing mindfulness. This modulation of attentional processing is expected to be visible in the  $\alpha$ - and  $\theta$  bands. In previous research increased ipsilateral  $\alpha$ -power was present when covert attention was directed to one visual field. This increased ipsilateral  $\alpha$ -power is thought to reflect an inhibition of the taskirrelevant side, whereas decreased  $\alpha$ -power in the contralateral hemisphere is reflecting disinhibition of the task-relevant side (Handel, Haarmeier & Jensen, 2011; Kelly, Gomez-Ramirez & Foxe, 2009; Rihs, Michel & Thut, 2007; Thut, Nietzel, Brandt & Pascual-Leone, 2006; Van Gerven & Jensen, 2009; Worden et al., 2000). In line with these findings, it is expected to find on the  $\alpha$ -band increased ipsilateral power compared to contralateral power, as an indication of enhanced efficacy of focussing of attention. Similarly, increased ipsilateral power on the  $\theta$ -band is expected.

Furthermore, supramodal attention control is assumed to be involved. Therefore, the hypothesis it is expected to find activity in the occipito-parietal cortex and the somatosensory cortex (involved in attending to a part of the body).

## 2. Method

#### 2.1. Participants

In this experiment 34 students, 5 male and 29 female, from the Faculty of Behavioral Science of the University of Twente participated, and in exchange were given the Mindfulness Based Stress Reduction training free of any costs. The age of the participants varied between 20 and 34 years, with a mean age of 23.7 years (SD: 3.3). One participant was left-handed, one ambidexter and 32 right handed, as assessed with Annet' handedness inventory (Annet, 1970). All participants had a normal or corrected to normal vision, were free of pain and didn't use painkillers before the experiment. Prior to the experiment all participants signed an informed consent, and agreed to participate in two EEG sessions, with each a duration of three hours. For each participant the Five Facet Mindfulness Questionnaire – short form (FFMQ – SF; Bohlmeijer, Ten Klooster, Fledderus, Veehof & Baer, 2011) was administered before each session, assessing the degree of mindfulness. The study was approved by the medical ethical commission of the 'Medisch Spectrum Twente' (NL 37791.044.11).

#### 2.2 Inclusion and exclusion criteria

The participants had to be aged between 18 and 65 years. Participants were not to consume any alcohol or drugs 24 hours, and no caffeine and nicotine one hour prior to the experiment. Also,

physical- or mental disorders, neurological illness, motor skill problems, physical complaints of pain and poor visual capacity where exclusion criteria. Using these criteria one participant was excluded, because of reported to be dyslectic.

#### 2.3. Design

Participants were randomly assigned to group 1 or group 2. Both groups concurrently received an MBSR training, and participated in an EEG experiment consisting of two EEG sessions. The first session for group 1 was before the MBSR training and the second session was right after the training. The first session for group 2 was right after the training and the second session was eight weeks after the training. In this study a between group comparison is made for which the first session of group 1 is compared with the first session of group 2. Next, a within group comparison is made for which the first session of group 1 are compared.

#### 2.4. MBSR-training

The Mindfulness Based Stress Reduction training had a duration of eight weeks, in which the participants took part in weekly group sessions of 2.5 hours. Besides these sessions the participants had homework assignments which took about 45 minutes for 5 days a week. Participants kept a log of their practice at home, which indicated the range of practice at home was between 17 and 53 days (M: 40, SD: 9.0). The content of the training was according to the standard of the MBSR protocol. Except in this study the full-day session at the end of the training was excluded. According to the protocol the training also was conducted by an experienced teacher of meditation and yoga. The training existed of the body scan, mindfulness meditation, meditative walking, yoga and mindful-communication (for more details see Hulsbergen, 2009). The aim of the training was to improve attention during daily activities and to becoming more aware in the present moment.

#### 2.5. Procedure

Each EEG session had a duration of approximately three hours and was held at the University of Twente. In the EEG session participants perceived eight random presented stimuli: four on the rightand four on the left forearm, and each side were delivered two low intensity and two high intensity stimuli. The EEG session started with applying the EEG electrodes and stimulation electrodes on the right and left forearm at the dorsal wrist. At the start of the Posner task the room was darkened.

#### 2.6. Stimuli and task

The participants were seated at approximately 60 cm of the computer screen during the experiment. An example of the stimuli and their order as employed in the Posner paradigm is depicted in Figure 1. The instruction was given to gaze at the center of the computer screen. First a white fixation cross (1.05° x 1.05°) was shown for 1200 ms in a black background after which it was replaced by a cue for 400 ms. The cue, a rhomb (5.15° x 2.20°) consisted of a red and green triangle pointing to opposite directions (left and right). At the beginning of each block of trials, the relevant color was given. Participants were instructed to attend to the forearm indicated by the relevant colored triangle of the cue. The cue alternated between blocks. This true/false rate of the cue was 50%. After the cue the fixation cross was shown for 4600 ms. During this interval, 600 ms after rhomb offset, an intracutaneous stimulus was delivered. The nociceptive stimuli were randomly presented on the left or the right forearm and given either as a high intensity of five pulses or as a low intensity of two pulses. Half of the participants were told only to react on high intensity stimuli, while the other half of the participants were told to react only on low intensity stimuli. The instruction was to react by pressing the foot pedal when the relevant intensity of nociceptive stimuli was presented at the attended hand, which was the case in 25% of the times. The individual participant's sensation-, pain- and pain tolerance threshold was identified in a pretest by increasing the amplitude from zero with steps of 0.1 mA. The sensation threshold was explained to the participants as the first amplitude they could detect; the pain threshold was described as a somewhat painful prickling sensation, and the pain tolerance threshold as the maximal amplitude the participants allows to apply during the experiment. The experiment consisted of four blocks, each consisting of 96 trials. Two blocks contained a sustained attention version in which the cue indicated one to be attended hand for the first half of the block, and the second half of the block the other to be attended hand. Whereas the other two blocks consisted of a transient attention version, pseudo randomly alternating cue sides from trial to trial. The latter is used in this study.



Figure 1. The sequence of event on a trial. At the start of a trial a fixation cross was shown for 1200 ms. Thereafter a cue was presented for 400 ms. Next, the fixation cross was shown again. The electrocutaneous stimulus followed 600 ms after the cue. Participants had 4000 ms time to give a response.

#### 2.7. Recordings and data processing

Stimulus presentation, response registration and production of external triggers were controlled by E-Prime Software (version 2.0). The EEG and EOG were amplified with a Quick-Amp amplifier (72 channels, DC) and were recorded with Brain Vision Recorder (version 1.05). EEG was recorded from 61 Ag/AgCl ring electrodes located at standard positions of the extended 10/20 system. An online average reference was employed. EOG was recorded bipolarly, vertically from above and below the left eye and horizontally from the outer canthi of both eyes. Electrode impedance was kept below  $5k\Omega$ . The EEG and EOG were sampled at a rate of 500Hz, and digitally filtered online (low-pass 140 Hz, DC). For the behavioral analysis, pedal presses and digital codes related to stimulus events were recorded and registered. The statistical tests were conducted with SPSS (statistical package of the social sciences, version 21.

#### 2.8. Data analyses

#### 2.8.1. Questionnaire data

The Related-Samples Wilcoxon Signed Rank Test was used to analyze the FFMQ-SF scores for the within group results. The Independent-Samples Wilcoxon Signed Rank Test was used to analyze the FFMQ-SF scores for the between group results.

#### 2.8.2. Statistical approach

Analyzing of the EEG data was carried out with Brain Vision Analyzer 2.0.4 (Brain Products GmbH, 2012). The data was first segmented in -500 ms to 2500 ms intervals relative to the markers that signaled the cue with a baseline set from -100 ms to 0 ms. Trials with horizontal and vertical eye movements were removed when amplitudes on the hEOG en vEOG channels exceeded the values +/- 60  $\mu$ V and +/- 120  $\mu$ V, respectively. The value of +/- 60  $\mu$ V is approximately corresponding with 3 degrees horizontal eye movement. Even though participants were instructed not to look at their attended side (i.e., the left or right forearm), mistakenly eye movements to the attended side are excluded with this procedure. Furthermore, trials were removed in which eye movements were detected from 0 ms to 1000 ms relative to stimulus, which left on average 85% of the trials. Subsequently, EEG channels containing artifacts were removed by using individual channel mode (gradient criterion: 100 $\mu$ V per 1 ms, low activity criterion: 0.5  $\mu$ V for 100 ms and when exceeding the values +/- 200  $\mu$ V for frontal electrodes, +/- 150  $\mu$ V for central electrodes, and +/- 100  $\mu$ V for parietal electrodes). On average the number of trials removed varied from .008% to 8.90%.

Next, time windows of 50 ms were segmented to evaluate the time range from 200 - 1000 ms after cue onset time. The activity for ten electrode pairs was explored: FC5/FC6, C3/C4, CP3/CP4, CP5/CP6, P3/P4, P5/P6, P7/P8, PO3/PO4, PO7/PO8, O1/O2. For this the power of different frequency bands was extracted starting from the lower theta ( $\theta_1$ ) to the upper alpha band ( $\alpha_2$ ), separated in five

steps, by performing a wavelet analysis on the raw EEG. A complex Morlet wavelet was chosen with Gabor normalization. The five frequency bands (see table 1) were specified:  $\theta_1$  (3.2 – 4.8 Hz),  $\theta_2$  (4.2 – 6.3 Hz),  $\theta_3$  (5.5 – 8.2 Hz),  $\alpha_1$  (7.2 – 10.7 Hz) and  $\alpha_2$  (9.4 – 14.0 Hz).

Individual averages of these estimates were computed, per side of the relevant condition. Next, normalized lateralization indices ([ipsilateral – contralateral] / [ipsilateral + contralateral]) were calculated for the different frequency bands, both for the left and right relevant side. These power indices were computed for all symmetrical electrode pairs. Furthermore, an average was computed across the indices for both relevant sides, thereby constructing the LPS through the following formula:

$$LPS(\omega_p)_t = ((left cues \frac{(\omega_{pt}(PO7) - \omega_{pt}(PO8))}{(\omega_{pt}(PO7) + \omega_{pt}(PO8))}) + (night cues \frac{(\omega_{pt}(PO8) - \omega_{pt}(PO7))}{(\omega_{pt}(PO7) + \omega_{pt}(PO8))}))/2$$

(see Van der Lubbe & Utzerath, 2013). Values of the LPS vary from -1 to +1. A positive sign indicates that the power within a specific frequency band was larger above the hemisphere ipsilateral to the cued side than contralateral, whereas a negative sign indicates the opposite pattern. A value of zero signifies the absence of hemispherical differences.

The analyses for both the between- and the within group comparisons consisted of a t-test followed by a One Way Anova. To reduce the possibility of a Type 1 error, a strict significance criteria of  $\rho < .005$  was used for four consecutive time windows. The One Way Anova was carried out for those effects that were visible on the t-test. It was felt that for this second procedure a less strict criteria was needed, therefore a significant level of  $\rho < .05$  was used.

## **3. Results**

#### 3.1. Questionnaire data

The FFMQ-SF was presented to all the participants to assess the self-reported mindfulness at the start of the study and immediately after the MBSR training. The MBSR training led to increased self-reported mindfulness for participants in the within group analyses (Z = -2.0, p = .047) and for the between group results (Z = -3.9, p < .001). The subscales Conscious-acting (Z = -2.0, p = .048), and Non-reactive (Z = -2.2, p = .025) were improved for the within group analyses. The subscales Observing (Z = -3.1, p = .002), Conscious-acting (Z = -2.3, p = .019) and Non-reactive (Z = -3.6, p < .001). Overall this suggests that both groups increased in their self-reported mindfulness.

#### 3.2. EEG analyses of the cue-target interval

The overall between group results that fulfilled the significance criteria (four consecutive time windows, p < .005) are depicted in Table 2. These are the t-test results, revealing all electrode pairs that are significantly deviating from zero. Results for the group differences that fulfilled the significance criteria (p < .05; only for those effects that were significant in the overall results) are depicted in Table 3. These results show the differences in ipsi- and contralateral activity in the pre-

and post-condition (i.e. before and right after the MBSR training). Topographical maps of the relevant frequency bands for the between group comparison are shown in Figure 2 for the  $\theta$ -bands and Figure 3 for the  $\alpha$ -bands. The overall within group results that fulfilled the significance criteria (four consecutive time windows, p < .005) are depicted in Table 4. In the within analyses only the four frequency bands that revealed significant between group differences have been analyzed ( $\theta_2$ ,  $\theta_3$ ,  $\alpha_1$  and  $\alpha_2$ ). Results for the group differences that fulfilled the significance criteria (p < .05; only for those effects that were visible in the overall results) are depicted in Table 5. The topographical maps of the frequency bands for the within group comparison are shown in Figure 4 for the  $\theta$ -bands and Figure 5 for the  $\alpha$ -bands.

### 3.3.1. Overall between group effects

The overall LPS results for both groups revealed significant deviation from zero in all five frequency bands ( $\theta_1$ ,  $\theta_2$ ,  $\theta_3$ ,  $\alpha_1$  and  $\alpha_2$ ; see Table 2). For the lowest  $\theta_1$  band a significant deviation from zero was visible at parietal-, occipital- and occipito-parietal sites starting at 200 ms to 550 ms after cue onset. The most pronounced and most significant at the P3/P4 electrode pair (from 200 - 450, t(33) > -3.45,  $\rho < .0015$ ). This negative t-value indicates that the contralateral power was higher compared to the ipsilateral power in the  $\theta_1$  band. For the  $\theta_2$  band a significant deviation from zero was visible at parietal, occipito-parietal- and parito-central sites from 450 - 1000 ms after cue onset. All effects were higher ipsilateral power compared to the contralateral power. The longest, most pronounced and most significant at the PO7/PO8 electrode pair (from 450 to 1000 ms, t(33) > 2.98,  $\rho < .0015$ ). For the higher  $\theta_3$  band a significant deviation from zero was visible at parietal, occipito-parietal and paritocentral sites from 300 to 1000 ms after cue onset. All effects were higher ipsilateral power compared to the contralateral power. The longest, most pronounced and most significant at the CP5/CP6 electrode pair (from 450 to 650 ms and from 750 – 1000 ms, t(33) > 2.98,  $\rho < .0025$ ). For the lower  $\alpha_1$ band a significant deviation from zero was visible at parietal, occipito-parietal-, central- and paritocentral sites from 350 to 1000 ms after cue onset. All effects contained of a higher ipsilateral power compared to the contralateral power. The most pronounced and most significant at the P5/P6 electrode pair (from 500 to 1000 ms, t(33) > 3.54,  $\rho < .001$ ). For the upper  $\alpha_2$  band a significant deviation from zero was visible at parietal, occipito-parietal-, central- and parieto-central sites from 350 to 1000 ms after cue onset. The most pronounced and most significant at the P5/P6 electrode pair (from 400 to 1000 ms, t(33) > 3.32,  $\rho < .002$ ).

Wavelets		LPS	
Band	Windows (ms)	Maxima	<i>t</i> (33)
$\theta_1$	200 - 450	P4	-3.45*4.16***
	250 - 550	PO4	-2.98*3.95***
$\theta_2$	450 - 950	P6	3.10* - 4.85***
	450 - 1000	PO8	2.98* - 5.00***
	500 - 950	P8	2.88* - 4.35***
	500 - 850	P4	2.77* - 3.22*
	500 - 900	O2	2.81* - 3.88***
	650 - 850	CP6	3.13* - 3.72**
	700 - 950	PO4	3.21* - 3.88***
$\theta_3$	300 - 600	P8	2.94* - 3.89***
	350 - 600	P08	2.81* - 4.78***
	400 - 700	P6	2.82* - 4.27***
	450 - 650	CP6	3.05* - 4.00***
	450 - 650	P4	2.86* - 3.24*
	500 - 700	CP4	2.78* - 3.28*
	700 - 1000	P4	2.93* - 4.21***
	750 - 1000	CP6	3.00* - 4.27***
	750 - 1000	P6	2.97* - 3.66**
$\alpha_1$	350 - 1000	CP6	2.77* - 6.00***
	400 - 600	PO8	3.13* - 3.68**
	400 - 500	PO4	2.85* - 2.78**
	500 - 1000	CP4	3.04* - 5.39***
	500 - 1000	C4	3.70** - 4.42***
	500 - 700	P8	2.95* - 3.54**
	500 - 1000	P6	3.54** - 6.03***
	600 - 1000	P4	3.02* - 4.75***
	800 - 1000	PO8	3.59** - 4.34***
	850 - 1000	PO4	2.78* - 3.50**
$\alpha_2$	350 - 1000	P8	2.74* - 4.49***
	350 - 600	PO8	2.89* - 5.26***
	400 - 1000	CP6	3.10* - 7.35***
	400 - 1000	P6	3.32* - 5.33***
	500 - 1000	C4	3.04* - 5.18***
	500 - 1000	CP4	2.88* - 7.04***
	500 - 1000	P4	2,87* - 6,01***

Table 2: Overall Between Group Effects for Electrode Pairs When the Significant Criterion was

00-000		5.05 - 4.00
50 - 650	P4	2.86* - 3.24*
0 - 700	CP4	2.78* - 3.28*
0 - 1000	P4	2.93* - 4.21***
50 - 1000	CP6	3.00* - 4.27***
50 - 1000	P6	2.97* - 3.66**
50 - 1000	CP6	2.77* - 6.00***

Crossed for at Least Four Successive Time Windows.

Note: Effects are described in terms of ipsi-contralateral differences (therefore P4, PO4 etc.). Positive outcomes = ipsilateral power higher than the contralateral power; negative outcomes = contralateral power higher than the ipsilateral power. \*  $\rho < .005$ . \*\*  $\rho < .001$ . \*\*\*  $\rho < .0005$  (one tailed).



Figure 2: Topographical maps of the between group results for the relevant  $\theta$ -bands before and after the MBSR training. Here, the left hemisphere reflects contra vs. ipsilateral power, whereas the right hemisphere reflects ipsi vs. contralateral power. Thus negativity at the left hemisphere means that the power in a specific frequency band (e.g., the  $\theta_2$  band) was higher above ipsilateral than above contralateral sites. Pre = before the MBSR training; post = after the MBSR training.



Figure 3. Topographical maps of the between group results for the α-bands before and after the MBSR training. For further description, see figure 2.

#### 3.3.2. Between group differences

Separate analyses of the group differences showed significant lateral differences between groups in the bands  $\theta_2$ ,  $\theta_3$ ,  $\alpha_1$  and  $\alpha_2$  (see Table 3). For the lowest  $\theta_1$  band no significant differences between the groups were obtained. For the  $\theta_2$  band differences between the groups were visible at parietal- and occipital sites from 650 ms to 800 ms after cue onset. At the P3/P4 electrode pair (from 650 to 750 ms, F(1,32) > 4.34,  $\rho < .05$ ) the mean of group 1 (M = .06, SD < .08) is significantly higher than the mean of group 2 (M = .01, SD < .05). This difference between groups is indicating more ipsilateral power in group 1 compared to group 2, thus a decrease of ipsilateral power in the  $\theta_2$  band after receiving a MBSR training. At the P5/P6 electrode pair a similar effect of decreased ipsilateral power is visible (from 750 to 800 ms, F(1.32) = 4.24,  $\rho < .05$ ) with the mean of group 1 (M = .07, SD = .06) higher than group 2 (M = .03, SD = .01). Comparable, at the O1/O2 electrode pair an effect is visible (from 750 to 950 ms, F (1,32) > 4.49,  $\rho$  < .05) with a mean group 1 (M > .04, SD < .05) higher than group 2 (M = .01, SD < .05). As for the higher  $\theta_3$  band a reverse effect is found, namely the increase of ipsilateral power after receiving the MBSR training. At the CP5/CP6 electrode pair (from 850 - 1000 ms, F(1,32) > 4.94,  $\rho < .05$ ) the mean of group 2 (M = .07, SD = .06) is higher than group 1 (M = .02, SD < .06). This is indicating more ipsilateral power in group 2 compared to group 1, thus an increase of ipsilateral power in the  $\theta_3$  band after the MBSR training. The same is visible at the P3/P4 electrode pair (from 850 to 1000, F(1,32) > 5.66,  $\rho < .05$ ) with the mean of group 2 higher (M > .06, SD < .07) than group 1 (M < .02, SD < .05), as well as at the P5/P6 electrode pair (from 900 to 1000 ms, F(1,32)) > 6.46,  $\rho < .05$ ) with the mean of group 2 (M > .06, SD < .08) higher as the mean of group 1(M < .02, SD < .05). Next, in the lower  $\alpha_1$  band the same increased ipsilateral power after the MBSR training is found at parietal- and occipito-parietal sites. At the P5/P6 electrode pair an effect was visible (from 700 to 750 ms,  $F(1,32) = 4,18, \rho < .05$ ) with the mean of group 2 (M = .08, SD = .08) higher than the mean of group 1 (M = .03, SD = .09). Similarly, an increased ipsilateral power after the MBSR training was revealed at the PO3/PO4 electrode pairs (from 850 to 900 ms and from 950 to 1000 ms, F(1,32) > 4.41,  $\rho < .05$ ) with the mean of group 2 (M = .08, SD = .10) higher than the mean of group 1 (M < .02, SD = .07). At last, in the upper  $\alpha_2$  band increased ipsilateral power after the MBSR training is found as well at parietal sites. At the P5/P6 electrode pair (from 650 to 750 ms, F(1,32) > 4.17,  $\rho < 100$ .05) with the mean of group 2 (M > .09, SD < .09) higher than the mean of group 1 (M = .01, SD < .09). Similarly, at the P7/P8 electrode pair an effect was visible from 700 to 700 ms after cue onset (F (1,32) = 4.43,  $\rho < .05$ ) with a mean of group 2 (M = .08, SD = .10) higher than the mean of group 1 (M = .01, SD = .09).

LPS band	Time window	Maxima	M <sub>pre</sub>	M <sub>post</sub>	F(32)
	(ms)				
$\theta_2$	650 - 750	P4	.06	.01	4.34* - 4.86*
	750 - 800	P6	.07	.03	4.24*
	750 - 950	02	.0405	.01	4.49* - 6.00*
$\theta_3$	850 - 1000	CP6	.02	.07	4.94* - 7.63**
	850 - 1000	P4	.0102	.0607	5.66* - 7.85**
	900 - 1000	P6	.0102	.0607	6.46* - 8.67**
$\alpha_1$	700 - 750	P6	.03	.09	4.18*
	850 - 900	PO4	.01	.08	4.41*
	950 - 1000	PO4	.02	.08	4.49*
$\alpha_2$	650 - 750	P6	.03	.0911	4.17* - 6.19*
	700 - 750	P8	.01	.08	4.43*

Table 3: Between Group Differences for Electrode Pairs When the Significant Criterion was Crossed.

\*  $\rho < .05$ . \*\*  $\rho < .01$ . \*\*\*  $\rho < .005$  \*\*\*\*  $\rho < .001$  (two tailed). LPS = the lateralized power spectra.

## 3.3.3. Overall effects for the within group analyses

The overall LPS results for the within group analyses revealed significant deviation from zero in all four frequency bands ( $\theta_2$ ,  $\theta_3$ ,  $\alpha_1$  and  $\alpha_2$ ) indicating higher ipsilateral power compared to contralateral power (see Table 4). For the  $\theta_2$  band a significant deviation from zero was visible at parietal, occipito-parietal, occipital and central sites from 350 – 1000 ms after cue onset. The longest, most pronounced and most significant effect were at the PO7/PO8 electrode pair (from 650 to 1000 ms, t(33) > 3.15,  $\rho < .004$ ). For the higher  $\theta_3$  band a significant deviation from zero was visible at central and parito-central sites from 350 to 600 ms after cue onset. The longest, most pronounced and most significant effect were at the C3/C4 electrode pair (from 350 to 600 ms, t(33) > 3.90,  $\rho < .001$ ). For the lower  $\alpha_1$  band a significant deviation from zero was visible at parietal, occipital and parito-central sites from 400 to 1000 ms after cue onset. The longest, most pronounced and most significant effects were at the P7/P8 electrode pair (from 400 to 750 ms, t(33) > 3.07,  $\rho < .003$ ). For the upper  $\alpha_2$  band a significant deviation from zero was visible at parietal, occipito-parietal, occipital, central and parito-central sites from 350 to 1000 ms after cue onset. The longest, most pronounced and most significant effects were at the P7/P8 electrode pair (from 400 to 750 ms, t(33) > 3.07,  $\rho < .003$ ). For the upper  $\alpha_2$  band a significant deviation from zero was visible at parietal, occipito-parietal, occipital, central and parito-central sites from 350 to 1000 ms after cue onset. The most pronounced and most significant effect were at the P7/P8 electrode pair (from 350 to 600 ms, t(33) > 3.07,  $\rho < .003$ ). For the upper  $\alpha_2$  band a significant deviation from zero was visible at parietal, occipito-parietal, occipital, central and parito-central sites from 350 to 1000 ms after cue onset. The most pronounced and most significant effect were at the P7/P8 electrode pair (from 350 to 600

Wavelets		LPS	
Band	Windows (ms)	Maxima	<i>t</i> (33)
$\theta_2$	300 - 500	C4	3.03* - 3.99**
	650 - 1000	P6	3.13* - 4.53***
	650 - 1000	PO8	3.15* - 5.04***
	700 - 1000	P8	3.01* - 4.37**
	700 - 950	P4	3.15* - 3.50*
	700 - 950	O2	3.05* - 5.93***
	750 - 1000	PO4	3.29* - 3.50*
$\theta_3$	350 - 600	C4	3.90* - 6.24***
	450 - 600	CP6	3.06* - 3.59*
$\alpha_1$	400 - 700	CP6	3.05* - 4.32**
	400 - 750	P8	3.07* - 4.94***
	400 - 750	P6	3.20* - 3.94**
	400 - 600	PO8	3.35* - 3.98**
	400 - 600	02	3.10* - 4.37**
	900 - 1000	P4	3.12* - 3.21*
$\alpha_2$	350 - 1000	CP6	2.99* - 4.84***
	350 - 600	P8	3.85* - 5.69***
	400 - 700	P6	327* - 4.65***
	400 - 600	PO4	3.40* - 4.33**
	400 - 600	02	3.27* - 3.60*
	650 - 1000	CP4	3.20* - 4.38**
	700 - 950	C4	3.01* - 3.56*

Table 4: Overall Within Group Effects for Electrode Pairs When the Significant Criterion wasCrossed for at Least Four Successive Time Windows.

Note: Effects are described in terms of ipsi-contralateral differences (therefore P4, PO4 etc.). Positive outcomes = ipsilateral power higher than the contralateral power; negative outcomes = contralateral power higher than the ipsilateral power. \*  $\rho < .005$ . \*\*  $\rho < .001$ . \*\*\*  $\rho < .0005$  (one tailed).



Figure 4: Topographical maps of the within group results for the relevant  $\theta$ -band before and after the MBSR training. For further description, see figure 2.



Figure 5: Topographical maps of the within group results for the α-bands before and after the MBSR training. For further description, see figure 2.

#### 3.3.4. Within group differences

Separate analyses of the group differences showed significant lateral differences in the bands  $\theta_2$ ,  $\alpha_1$ and  $\alpha_2$  (see Table 5). For the  $\theta_3$  band no significant differences were obtained. For the  $\theta_2$  band effects were visible at central sites from 300 to 400 ms after cue onset. At the C3/C4 electrode pair (from 300 to 400 ms, t(15) > 2.16,  $\rho < .05$ ) the mean of group 1 (M > .04, SD = .05) is significantly higher than the mean of group 2 (M = -.00, SD = .06). This difference between groups is indicating more ipsilateral power in group 1 compared to group 2, thus a decrease of ipsilateral power in the  $\theta_2$  band after receiving a MBSR training. This is equivalent to the result in the between group analyses, where a decrease of ipsilateral power in the  $\theta_2$  band was found. As for the higher  $\theta_3$  band no effect is found. Next, in the lower  $\alpha_1$  band comparable results as in the between group analyses on the  $\alpha_1$  band are visible. An increased ipsilateral power after the MBSR training is found at parietal-, occipito-parietal and occipital sites from 450 to 950 ms after cue onset. At the PO7/PO8 electrode pair an effect was visible (from 450 to 600 ms, t(15) = -2.78,  $\rho < .05$ ) with the mean of group 2 (M = .08, SD < .09) higher than the mean of group 1 (M = .03, SD < .08). Similar an increased ipsilateral power after the MBSR training was revealed at the O1/O2 electrode pairs (from 450 to 600 ms, t(15) > -3.63,  $\rho < .01$ ) with the mean of group 2 (M < .05, SD < .07) higher than the mean of group 1 (M < .02, SD < .06). Similar effects are found at the electrode pair P5/P6 (from 450 to 650 ms, t(15) > -2.15,  $\rho < .05$ ) with the mean of group 2 (M < .08, SD < .09) higher than the mean of group 1 (M < .05, SD = .07). Also at the P7/P8 electrode pair this increased ipsilateral power was found (from 450 to 700 ms, t(15) > -2.29,  $\rho < .05$ ) with the mean of group 2 (M < .06, SD = .08) higher than the mean of group 1 (M < .04, SD = .08). As well as at the P3/P4 electrode pair (from 900 to 950, t(15) = -2.24,  $\rho < .05$ ) with the mean of group 2 (M = .08, SD < .10) higher than the mean of group 1 (M = .05, SD = .09). At last, in the upper  $\alpha_2$  band increased ipsilateral power after the MBSR training is found as well, at parietal and parito-central sites from 350 to 500 ms after cue onset. At the P7/P8 electrode pair (from 350 to 500 ms, t(15) > -2.18,  $\rho < .05$ ) with the mean of group 2 (M > .07, SD < .07) higher than the mean of group 1 (M = .05, SD < .09). Similar at the P5/P6 electrode pair an effect was visible from 400 to 500 ms after cue onset (t(15) > -2.63,  $\rho < .05$ ) with a mean of group 2 (M = .09, SD = .08) higher than the mean of group 1 (M < .05, SD < .10). As well as at the CP5/CP6 electrode pair an effect of ipsilateral increased power was visible (from 400 to 500 ms, t(15) > -2.54,  $\rho < .05$ ) with a mean of group 2 (M > .09, SD = .08) higher than the mean of group 1 (M < .05, SD = .07).

LPS	Time window (ms)	Site	M <sub>pre</sub>	M <sub>post</sub>	<i>t</i> (15)
$\theta_2$	300 - 400	C4	.0405	00	2.16* - 2.18*
$\alpha_1$	450 - 600	PO8	.03	.08	-2.78*2.98**
	450 - 600	O2	.0002	.0506	-3.63**5.00****
	450 - 650	P6	.0405	.0809	-2.15*2.91*
	450 - 700	P8	.0104	.0609	-2.29*2.87*
	900 - 950	P4	.05	.08	-2.42*
$\alpha_2$	350 - 500	P8	.0205	.07011	-2.18*3.44***
	400 - 500	P6	.0405	.09	-2.63*2.69*
	400 - 500	CP6	.0405	.0910	-2.54*2.72*
* $\rho < .05$ . ** $\rho < .01$ . *** $\rho < .005$ **** $\rho < .0001$ (two tailed). LPS = the lateralized power spectra.					

Table 5: Within Group Differences for Electrode Pairs When the Significant Criterion was Crossed.

Positive outcomes = power higher prior the training than after the training; negative outcomes = power higher after the training than before the training.

## 4. Discussion

Mindfulness seems to have a positive effect on mental- and physical health (Baer, 2003; Bohlmeijer et al., 2010; Carlson et al., 2007; Miller et al., 1995). However, as was argued in the introduction more research on the efficiency of mindfulness is needed. As mindfulness is suggested to increase the efficiency of attentional processes (Bishop et al., 2004; Chiesa et al., 2013) this study focused on the modulation of attentional processing after an 8-weeks MBSR training. This has been examined with an endogenous transient Posner task by analyzing and comparing between- and within group results. It was expected that participating in the MBSR program would result in enhanced efficiency of endogenous transient attention, and that this would be visible in an increase of ipsilateral  $\alpha$ -power and an similar increase of  $\theta$ -power.

#### 4.1. Within- and between group results

The subjective effects found showed that the MBSR training had the intended effect. Increased selfreported mindfulness was present after the training both between groups and within the same group. This is replicating results of previous studies that are showing enhanced mindfulness on self-reports (e.g. Cohen-Katz, Wiley. Capuano, Baker & Shapiro, 2005; Shapiro, Brown & Biegel, 2007). Furthermore, both the between- and within group LPS results provided support for the claim that mindfulness is enhancing attentional processing. The between group results revealed the expected increase of ipsilateral power compared to contralateral power in the lower  $\alpha_1$  and in the upper  $\alpha_2$  band after the MBSR training. This is comparable with previous reports on attentional processing in which increased ipsilateral  $\alpha$ -power in task-irrelevant locations were revealed (Handel et al., 2011; Kelly et al., 2009; Rihs et al., 2007; Thut et al., 2006; Van Gerven & Jensen, 2009; Worden et al., 2000). In this study on the lower  $\alpha_1$  band increased ipsilateral power compared to contralateral power was visible from 700 to 100 ms after cue onset on parietal and occipito-parietal sites. On the upper  $\alpha_2$  band similar results were found from 650 to 750 ms after cue onset on parietal sites. Also the within group results revealed increased ipsilateral compared to contralateral  $\alpha$ -power after the MBSR training. These effects were visible both in the lower  $\alpha_1$  as in the upper  $\alpha_2$  band. On the lower  $\alpha_1$  band effects were present from 450 to 700 ms after cue onset at occipito-parietal, occipital and parietal sites, and from 900 to 950 ms at parietal sites. In the upper  $\alpha_2$  band these effects were present from 350 to 500 ms after cue onset at parietal and parito-central sites. These results reflect an increase of  $\alpha$ -power for the participants after they have received the MBSR training, compared to before the training. Van der Lubbe and Utzerath (2013; see also Van der Lubbe et al., 2014) have found higher ipsilateral power compared to contralateral power on the  $\alpha_1$  band in comparable sites and time windows, during an attention demanding task. The effects on the  $\alpha$ -bands are assumed by Van der Lubbe et al. (2014) to reflect the inhibition of task-irrelevant sites and enhanced modulation of attentional processing. This supports the hypothesis that mindfulness is modulating attentional processing, and this modulation might take place through more effectively noise inhibition.

On the  $\theta_3$  bands similar expected effects are found on the  $\theta_3$  band. After the training increased ipsilateral  $\theta$ -power compared to contralateral power was found from 850 to 1000 ms after cue onset at parietal sites and parito-central sites. This effect on the  $\theta_3$  band was only visible in the between group analysis, but not in the within group analysis. Similar to the results on the  $\alpha$ -bands this may reflect the enhanced attentional processing due to increased mindfulness. On the  $\theta_2$  band an unexpected effect of decreased ipsilateral power compared to contralateral power after participating in the training was found. In other words: before the training the ipsilateral  $\theta$ -power on this band was higher compared to contralateral power, and this effect was no longer present after the training. This effect was found in both the between- as in the within group analyses before the training. In the between group analysis this effect was visible from 650 to 800 ms after cue onset at parietal sites, and at posterior sites from 750 to 950 ms after cue onset. In the within group analysis this effect was visible from 300 to 400 ms after cue onset at central sites. This higher ipsilateral  $\theta_2$  power before the training may reflect that participants find it more difficult to focus their attention before the MBSR training than after. Before the training participants might need more effort to focus their attention on the cued hand. This effort could be reflected as the higher ipsilateral power compared to contralateral power. At last, the effects in the within group analyses were slightly more early visible than effects found in the between group analyses. Both analyses revealed effects on parietal and occipito-parietal sites.

#### 4.2. Top down modulation

In this study it was aimed to provide objective support for the modulation of attentional processing through the practice of mindfulness. The presented results of increased ipsilateral  $\alpha_1$ ,  $\alpha_2$  and  $\theta_3$  power are suggested to reflect the inhibition of task-irrelevant sides. This may give more insight into how mindfulness training in sensory attention to the breath and body sensations used in the MBSR program elicit positive changes in mental- and physical health. Learning to focus on somatosensory stimuli,

such as the breath, seems to enhance the ability to suppress irrelevant sensory inputs in an endogenous manner. Self-regulation of the focus of attention seems to be enhanced as participants are better to suppress irrelevant input and attend to relevant input. This idea is also suggested by Kerr and his colleagues (2013). These authors based on findings of enhanced  $\alpha$ -power in previous studies (Kerr et al., 2011b; Kerr, Josyula & Littenberg, 2011a). They argue that mindfulness results in top-down modulation of  $\alpha$ -power which facilitates enhanced sensitive filtering of sensory information. More specifically they suggest that: "Learning to control alpha oscillations in the primary somatosensory cortex may be a key gateway mechanism for learning to use thalamocortical alpha regulation to suppress irrelevant sensory inputs across sensory neocortex in an internally directed, top down manner, for forms of regulation such as selective attention and working memory" (Kerr et al., 2013, p 12). This study provides of even more thorough evidence for the modulation of attentional processing visible in changes in the  $\alpha$ -power. The effects of increased ipsilateral  $\alpha$ -power is strong support for the idea that mindfulness results in better regulation of suppressing irrelevant information, thereby enhancing the efficacy of the focus of attention.

#### 4.3. Supramodal attention control

Previous results of changes in the primary somatosensory cortex (Kerr et al., 2011a; Kerr et al., 2011b; Kerr et al., 2013) have been partly replicated in this study. In this study some effects have been revealed at central and parito-central sites, which can be assumed to reflect the endogenous attending to a part of the body. However, it was argued in the introduction that supramodal attention control would result in more than one modality to be involved. In this study most of the effects have been revealed on the occipito-parietal cortex, which is strongly related to visuospatial attentional processing (Foxe et al., 1998; Van der Lubbe & Utzerath, 2013; Van der Lubbe et al., 2014). These results can be understood as supramodal attention control, in which a spatial presentation related to the visual modality is involved in processing information of other modalities. Previous results of supramodal attention control found in attentional processing supports this idea (Eimer et al., 2002; Seiss et al., 2007)

Although in this study ERLs were not examined, these results may be similar to findings of studies comparing the LPS and ERL effects in a similar 1-s cue target interval (see Van der Lubbe & Utzerath, 2013; and Van der Lubbe et al., 2014). In these studies comparable ipsilateral  $\alpha$ -power have been related to the ERL components: the late directing attention positivity (LDAP) and the biasing related positivity (BRP). These components are thought to reflect the final stage in which modulation along the ventral processing stream takes place (Hopf & Mangun, 2000; Van der Lubbe & Utzerath, 2013). Furthermore, the LDAP have been visible in auditory spatial attention tasks as well and is suggested to be related to cross-modal interaction in attentional processes (Seiss et al, 2007). Therefore, the results of this study seem to indicate that the modulation of attentional processing is enhanced in which cross-modal interaction is involved.

#### 4.4. Critical notes

There are several points that need to be addressed on further understanding the significance, but also the limitations of the results of this study. First, it is possible that some of the effects in the between group analyses are missed because of the choice in criteria. It was chosen to further analyze only those effects that already revealed significant deviation from zero on the overall results (indicating lateral differences). In the overall within group analyses the means before and after the training were analyzed separately. This means that any effects of lateral differences before the training and after the training were further analyzed. However, in the overall between group results the means before and after the training were different groups, this way effects of both groups were taken into account together. It is possible that by averaging over the groups, some effects that were only present in one of the groups have been missed. Yet, the between group analyses revealed more effects compared to the within group analyses. Also most of the effects that are found on both analysis are comparable. Therefore it is assumed that the main effects are revealed. However, it cannot be ruled out that some effects might have been missed.

Second, it could be argued that the effects as described above are reflecting the expectancy of pain, as nociceptive stimuli have been given right after the cue-target interval. Previous research have given many support that nociceptive cortical areas are more active not only during the experience of pain, but also during the expectancy of pain stimuli (e.g. see Petrovic, Petersson, Ghatan, Stone-Elander & Ingvar, 2000). It may be assumed that in this study the expectancy of pain is also influencing the neural activity. However, as the cue has no predictable value for the location in which the nociceptive stimuli is given, this activity would not be visible in the hemispherical differences. Therefore, the lateralization results as been presented in this paper are not related to the expectancy of pain, but to the more specific lateral differences in attentional processes as measured with the LPS. As many results of the between- and within analyses are quite similar, it seems like the expectancy of nociceptive stimuli is of no influence on the results. It is expected that replicating this study without the nociceptive stimuli would reveal comparable results.

Finally, it could be argued that the results of this study are not the specific effects of mindfulness. In this study only a waitlist control group has been used, but not a no-treatment control group such as a relaxation training. Therefore it is possible that the results of this study are not specific for mindfulness. Previous studies have revealed that some of the effects of mindfulness are found in no-treatment control groups as well. A randomized control trial using subjective outcomes on mindfulness (self-reports i.e. on daily emotions) compared both a mindfulness- and a relaxation group with a control group (Jain et al., 2007). Both in the mindfulness- and in the relaxation group increased positive mood stated and decrease in distress have been found, compared to a control group. Specific for the mindfulness group was a decrease in distractive and ruminative thoughts and behaviors. The authors suggest that the mechanism of reducing distractive and ruminative thoughts and behavior may be how mindfulness reduces distress. Similar research has compared results of a mindfulness group, physical exercise of a wait-list control group (McMillan, Robertson, Brock & Chorlton, 2002). In this research with 145 participants with traumatic brain injuries no significant differences were found between the two active groups. These results are replicated in another research testing mindfulness as an active ingredient while using an active control group, who perceived a Health Enhancement Program (HEP; MacCoon et al., 2012). This active control matched with MBSR in non-specific factors such as structure, but without the training of mindfulness. This research found MBSR, but not HEP, to result in a decrease in the participant's pain rating, suggesting a specific effect for mindfulness in the regulation of pain. Furthermore, self-reports on mental- and physical effects revealed a reduction of symptoms for both MBSR as HEP, therefore no specific effect of mindfulness is shown. Surprisingly, mental distress and depression decreased with HEP, but increased with MBSR. These three studies (Jain et al., 2007; McMillan et al., 2002; MacCoon et al., 2012) replicate previous findings on the positive influence on mental- and physical health of mindfulness, but shows that some of these effects are found in an active control group as well (or even more). This indicates that not all effects as revealed in self-reports are specific for mindfulness. Similarly, this might be relevant for objective support of the modulation in brain activity through the practice of mindfulness. In this study it therefore cannot be ruled out that the objective effects found are not specific for mindfulness. Further research on objective support for the modulation of attentional processing through the practice of mindfulness is needed that uses both a waiting-list control group and an active control group. As the HEP is specifically designed to control for non-specific factors of MBSR this program could be recommended for a follow-up study. Details on this program and additional recommendations can be found in MacCoon and colleagues (2012).

#### 4.5. Conclusion

The results reveal increased ipsilateral power compared to contralateral power in the lower  $\alpha_1$ ,  $\alpha_2$  and  $\theta_3$  bands after participating in an 8-weeks MBSR training. This is strong support that practicing mindfulness improves attentional processing. Specifically, the efficiency of endogenous spatial attention. Together with results of previous studies, these effects found in this study are suggested to reflect the inhibition of noise in task irrelevant locations. Furthermore, this study gives support for the involvement of supramodal attention control and improved top-down modulation.

Practicing mindfulness seems to improve the ability to focus one's attention. This enhanced attentional processing is likely related to the mental- and physical health that is improved through mindfulness training.

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