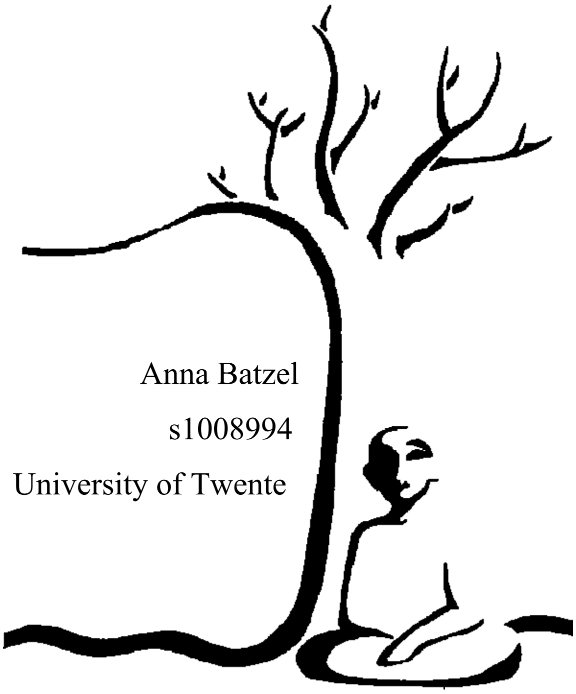
The influence of mindfulness training on the processing of painful stimuli in a transient spatial attention paradigm.

Bachelor thesis



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Abstract

The aim of the current study was to determine the influence of mindfulness training on the processing of painful stimuli in a transient spatial attention paradigm. We examined the processing of intracutaneous stimulation by focusing on the N1 and P3a ERP components, which were assumed to indicate early sensory processing and the orienting response towards painful stimuli respectively.

A separate-sample pretest-posttest design was adopted, where the treatment consisted of a mindfulness based stress reduction (MBSR) training. The control group took part in an EEG experiment prior to the MBSR training and the experimental group participated after attending the MBSR training. During the EEG experiment the participants performed a modified Posner task, where the to-be-attended side changed randomly. Intracutaneous electrical stimuli were administered to the forearms with high or low intensities. Participants had to press a foot pedal when a stimulus of relevant intensity appeared at the to-be-attended arm.

Analysis of the ERP components indicated no group differences on the N1 component amplitudes and latencies. Peak amplitudes of the P3a component for unattended stimuli were significantly higher for the control group as compared to the experimental group on the electrode FCz.

Early sensory stimulus processing was not affected by mindfulness training since no group differences were found in N1 component amplitudes or latencies. However, mindfulness indeed facilitated the ability to successfully orient attention as indicated by a decreased orientation response towards unattended pain stimuli.

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1. Introduction

The most intense experience of all sensory modalities is the sensation of pain. Pain tends to occupy attention and to drive it away from other sensations. Imagine yourself bumping your toe against a table while trying to answer the phone. As soon as you experience the intense pain you forget all about the ringing phone and your attention is then completely occupied by the painful sensation. This example illustrates what Sanderson (2004) calls acute pain, which typically is intense but time-limited. Chronic pain which does not pass after a minimum of six months often begins as acute pain (Sanderson, 2004). Chronic pain is a major health care problem and has many negative effects on the affected individual's lives. Chronic pain of moderate to severe intensity bears on 19% of adult Europeans, thereby seriously impairing their daily activities and social as well as working lives (Breivik, Collett, Ventafridda, Cohen, & Gallacher, 2006).

Behavior therapy oriented approaches based on acceptance and mindfulness have been shown to be effective in the treatment of chronic pain conditions (Wicksell, Ahlqvist, Bring, Melin, & Olsson, 2008). The results of a review by Baer (2003) indicate that chronic pain patients show a statistically significant improvement in pain ratings after attending a mindfulness based stress reduction (MBSR) program (e.g. Kabat-Zinn, 1982). MBSR is a group program developed by Dr. Jon Kabat-Zinn and contains several exercises designed to give participants experiences of mindfulness by means of meditation, relaxation-techniques and yoga (Kabat-Zinn, 1982). The MBSR training used for the current study is discussed in more detail in the methods section of this paper. However, the results of Baer's (2003) reviewed studies were based on self-ratings and did not use control groups. Because of these methodological weaknesses of the reviewed studies it is difficult to infer strong conclusions about the effectiveness of mindfulness based approaches to the treatment of chronic pain (Baer, 2003).

The majority of research on mindfulness has focused on clinical studies to assess the effectiveness of mindfulness based interventions, but little is known about the underlying mechanisms (e.g. Shapiro, Carlson, Astin, & Freedman, 2006). The aim of the current study was to examine the underlying attentional mechanisms of mindfulness by means of electroencephalography (EEG), in particular the early event-related potential (ERP) components as discussed later on.

Mindfulness is characterized by attending to the present moment and the inner and/ or outer experiences in a non-judgmental way (Kabat-Zinn et al., 1992). The essence of mindfulness is not to escape the unpleasant experience of pain through distraction but to focus attention on that sensation in a detached manner (Kabat-Zinn, 1982). The central idea of mindfulness is thus learning to attend to a stimulus in a neutral way and orienting attention towards that stimulus. One core principle of MBSR is to free oneself of judgments and to open awareness to immediate experiences as they occur in the present moment (Brantley, 2005). This principle implies flexibility in the ability to allocate attention to a particular sensation and not letting your attention cling to one experience or sensation.

The perception of pain can be modulated by several cognitive and emotional factors as for example indicated by Arntz, Dreessen and Merckelbach (1991) whose results suggested that attention to a pain stimulus was related to a stronger pain impact. A series of studies have shown attention to be an important determinant in stimulus processing (e.g. Posner, Snyder, & Davidson, 1980). These studies consistently show that when participants are instructed to attend to a particular location, for example by means of a cue, the responses to a target stimulus in that location are faster and more accurate than responses to target stimuli which are not in the attended location. This enhancement in responses does not only occur when the cued location stays the same over many trials, so called sustained focused attention, but also when the cued location varies randomly over many trials, so called transient attention. The current study focuses on transient shifts of attention. As Van der Lubbe, Buitenweg, Boschker, Gerdes and Jongsma (2012) pointed out there are several reasons to study transient rather than sustained attentional manipulations. One of these advantages of a transient attention manipulation is that the efficacy of the instruction to orient to a specific side can be assessed by means of behavioral measures like accuracy of responses or reaction times (Van der Lubbe et al., 2012). In this study it was assumed that mindfulness enhances the ability to flexibly orient attention and to not letting attention cling to one particular stimulus. Therefore a transient paradigm was chosen to assess this claim of enhanced flexibility in that the participants had to change the allocation of their attention in each trial.

Several studies indicate that attention also affects the processing of painful stimuli. Van der Lubbe et al. (2012) showed that transient spatial attention has a clear effect on early ERP components which were produced by intracutaneous electrical stimuli. The current study employs a slightly different intracutaneous stimulation method as developed by Inui, Tran, Hoshiyama and Kakigi, (2002). This method uses a single small planar concentric electrode for the activation of Aδ fibers of the epidermis in a very small area (Inui et al., 2002). It selectively activates the Aδ fibers and causes no activation of the fast Aβ fibers (Mouraux, Iannetti, & Plaghki, 2010) which otherwise would interfere with cortical activity caused by the slower Aδ fibers. Only the Aδ fibers are involved in nociception and thus the transfer of (potential) tissue damage. The intensity of the electrical stimuli was manipulated by varying the number of electrical pulses rather than simply increasing the amplitude of the stimuli. This method has the advantage that the same fibers will be activated for both intensities (high vs. low) because the increasing number of pulses only leads to an increase in action potentials along the same fibers (Van der Heide, Buitenweg, Marani, & Rutten, 2009).

In the current study the participants had to respond only to relevant intracutaneous stimuli that appeared on the attended arm and never to unattended stimuli. This method was also used by Van der Lubbe et al. (2012) and was suggested to have several advantages. First of all the cues are necessary to perform the task properly so that the participants inevitably have to switch their attention. Therefore the probability of finding attentional effects increases (Van der Lubbe et al., 2012). Secondly, because the stimuli at the unattended side were never task relevant, they might give information about to-be-ignored painful stimuli and about possible attention capture effects. Especially, this method makes it possible to investigate the influence of MBSR on unattended painful stimuli.

The main objectives of this study were the ERP components that are known to play a major role in attention and pain perception. To investigate the influence of mindfulness on these components a separate-sample pretest-posttest design was chosen as described by Campbell and Stanley (1963). This design incorporates a pretest at which the control group takes part, thereafter the control group and the experimental group both participate in a treatment, in this case a MBSR training. After the treatment only the experimental group takes part in a posttest. The five facets and the degree of mindfulness were assessed by means of the Five Facet Mindfulness Questionnaire Short Form (FFMQ-SF). This questionnaire was shown to have good psychometric properties (Bohlmeijer, ten Klooster, Fledderus, Veehof, & Baer, 2011) and was therefore chosen for the current study.

The current study was based on a recent research by Ströfer (2012) who used the same experimental design and examined the effects of mindfulness on spatial attention and pain perception. Ströfer's (2012) findings showed no effects of mindfulness on early sensory processing but a decreased orientation response towards painful stimuli. The aim of the current study was to support the findings of Ströfer (2012). However, some adaptations were made in the current study. First, Ströfer (2012) included a transient and a sustained version of the Posner task. Because in the current study we assumed that mindfulness enhances the ability to flexibly orient attention, we chose exclusively for a transient Posner task version.

Second, in the current study we adopted another data analysis approach. Sröfer (2012) examined the EEG data by means of a mean activity approach based on the assessment of topographic maps and grand averages. This approach yields information about the mean activity in a particular time window but does not give any indications regarding peak latencies. However a peak detection approach gives information about peak amplitudes as well as peak latencies. One of Ströfer's (2012) findings suggested that the orientation response (P3a component) was shifted in time as a function of attention, but this finding could not be verified by a mean activity approach. Therefore a peak detection approach was chosen to not only obtain information about peak amplitudes but to additionally gain information about peak latencies.

One of the attentional mechanisms measured in this study was the N1 ERP component, which is known to peak at about 100 ms after stimulus onset on the C5/C6 electrode contralateral to the stimulated side (Desmedt & Robertson, 1977). N1 was found to be reduced when attention was not directed at the stimulated finger (Van der Lubbe et al., 2012) and is thought to reflect an early selection of stimulus processing (Legrain, Guérit, Bruyer, & Plaghki, 2002). If the mindfulness training results in a better ability in attention allocation, it was expected to find an increase in the peak amplitude of the N1 component for attended stimuli in the group that received mindfulness training as compared to the group that did not receive that training. Such an effect would indicate an enhanced early sensory stimulus processing.

Furthermore the P3a component was included in the analysis. This component is known to peak at about 300 ms after stimulus onset at the Cz electrode and is thought to elicit an attentional capture effect for salient stimuli (Van der Lubbe et al., 2012). Because mindfulness is based on learning to effectively focus attention it was expected to find a decreased amplitude of the P3a for unattended stimuli and thereby a reduced P3a capture effect in the group that received MBSR training. So if mindfulness indeed facilitates the ability to successfully orient attention, the orientation response towards unattended pain stimuli should be repressed.

Moreover behavioral measures were included to give an indication of how well the task was performed. While the EEG was recorded the participants were instructed to only respond, by pressing a foot pedal, when the stimulus appeared on the attended side and had the relevant intensity. Half of the participants were asked to respond to high intensity stimuli while the other half had to respond to low intensity stimuli. Reaction times and accuracy rates were chosen as indicators of task performance. It was expected that both groups would achieve low reaction times and high accuracy rates as indicated by low false alarm rates and high hit rates.

2. Methods

2.1 Participants

Thirty-four students from the Faculty of behavioral science of the University of Twente took part in this study with a mean age of 23.74 (ranging from 20 to 34). Five were male and 29 were female. Handedness of the participants was assessed by means of Annet's handedness inventory (Annet, 1970). All except of two participants were right handed. One participant was left handed and one ambidextrous. Additionally, one participant had a weak form of red-green color blindness but reported to be well able to make a difference between the colored cues that were presented in the Posner task version. Another participant had dyslexia. Prior to their participation the students signed an informed consent. All participants received an eight week long MBSR training. The participants agreed to take part in one EEG experiment in which they received nociceptive stimulations implemented in an attentional Posner task. The medical ethical commission of the 'Medisch Spectrum Twente' approved this study.

2.2 Inclusion and exclusion criteria

For participation the students had to be aged between 18 and 65 years. The participants were instructed beforehand to avoid caffeine and nicotine one hour before the experiment. Also they were asked to avoid alcohol and drugs 24 hours before the experiment because all these substances were shown to influence both attention and the perception of pain (Moore, Keogh, & Eccleston, 2009). Further exclusion criteria were physical or mental disorders, physical pain complaints or poor visual capacity.

2.3 Mindfulness based stress reduction (MBSR) training

All participants took part in an eight week long MBSR training. This training consisted of one session of two hours each week. Furthermore the participants were asked to carry out 20-40 minutes mindfulness exercises every day outside the training sessions. The training was given by an experienced meditator who does daily meditation and/or yoga exercises.

The training covered informal and formal exercises. The informal exercises served to develop attentiveness in daily activities. The formal exercises were composed of body-scan, sitting mindfulness meditation, meditative walking and Hatha-yoga exercises (Hulsbergen, 2009). The formal exercises conduced to become more present in each moment in everyday life.

While performing the body-scan the participants were asked to direct their attention to physical experiences and to consecutively attend to different body parts. As the participants focused their attention to a specific body part they had to ascertain what they felt at that moment in the specific body part. Here the assignment was to notice the feelings without judging them. If the participants' attention flew away they had to redirect their attention to the particular body part. The body-scan exercise anchors the participant in the present moment, increases body consciousness and reinforces concentration.

While exercising the sitting mindfulness meditation the participants were asked to attend to their breath, especially to the movement of their breathing. Here again the goal was to notice feelings that were currently present without judging them. The sitting mindfulness meditation can also be directed to other objects, such as sounds, feelings or thoughts. During the MBSR training the participants also exercised free-choice sitting mindfulness meditation. This form of sitting mindfulness meditation does not require to direct attention to one point, but the idea is to direct open attention to anything that appears in consciousness. Here again if attention flew away the participants had to direct it back.

The object of meditation in meditative walking was the movement of the feet or legs. The participants exercised different ways of meditative walking, from alert fast walking to slow walking. During all forms of meditative walking, walking had to be done in silence. Again as attention flew away it had to be redirected to the object of meditation.

In Hatha-yoga exercises physical postures were combined with breathing and meditation. By performing the Hatha-yoga exercises concentrated and calmly the participants learned to listen to the signals of their bodies. As in all other exercises if attention flew away the participants had to direct it back. The goal of the Hatha-yoga exercises was to achieve a balance between body, mind and soul.

2.4 Experimental design

For the current study a separate-sample pretest-posttest design was chosen as described by Campbell and Stanley (1963). The 34 participants were randomly assigned to a control or an experimental group, so that each group consisted of 17 participants. The control group took part in the EEG experiment prior to the MBSR training. Thereafter both groups, control and experimental group, took part in the MBSR training concurrently. After the MBSR training only the experimental group participated in the second EEG experiment. Through comparing the data of both groups this design makes it possible to assess the effect of the MBSR training.

2.5 Procedure

The EEG experiments were carried out at the University of Twente. One experimental session lasted three hours and was carried out individually with one participant at a time. Before the experiment started the participants filled out several questionnaires. First the participants filled out the Annet-handedness questionnaire to indicate their hand preference (Annet, 1970).

Second, they had to fill in the Thayler's mood scale (Thayler, 1989) to assess the current mood state of the individual participants. Finally the participants were presented with the Five Facet Mindfulness Questionnaire Short Form (FFMQ-SF) to assess the different aspects of mindfulness (Bohlmeijer et al., 2011). Additionally we checked for neurobiological illnesses and motorical problems because both could influence task performance.

Having completed the questionnaires the participants were seated approximately 60 cm in front of a CRT monitor (75 Hz, 17 inch, controlled by a Pentium IV computer). Thereafter the EEG electrodes were applied on the head surface and the stimulation electrodes were attached on the right and left dorsal surface of the participants forearms. The administered stimuli intensities were individually determined by a pre-test. This procedure is explained in more detail in the following section of this paper. After all that the room was darkened and the experiment with a duration of one hour started. At the end of the experiment the participants once again filled in the Thayler's mood scale to assess possible changes in the current mood of the participants.

2.6 Stimuli

The intracutaneous stimulation method, as developed by Inui et al. (2002), was used to inflict the nociceptive sensations. Two stainless steel concentric bipolar needle electrodes were used with a ring of 1.2 mm in diameter as anode and a needle as cathode. The cathode was located exactly in the middle of the anode and stuck 0.1 mm out from the anode. By gently pushing the electrodes to the skin the needle cathode was placed in the epidermis where the nociceptors are seated. The outer ring anode only made contact with the skin. The intensity of the electrical stimuli was manipulated by 'pulse train modulation'. Here the number of electrical pulses was varied rather than simply increasing the amplitude of the stimuli.

Before the stimulus intensities were set for the experiment by varying the impulses, the individual current that should be employed for each participant was ascertained. By individually determining the particular currents, it was possible to account for recruited skin fibers and for subjective differences in pain perception.

The to-be-used current was determined by a pre-test. Here the participants had to indicate three intensity thresholds. A series of stimuli with ascending intensities were presented which started at 0 mA and subsequently rose with steps of 0.1 mA. The stimuli consisted of five pulses with a pulse interval of 5 ms and a pulse duration of 1 ms. When the participants reached a particular subjective intensity threshold they indicated that by pushing a key. The first threshold was called the 'pain threshold' (PT), where the participants had to indicate when a stimulation sensation shifted into a painful sensation. The second threshold was the 'detection threshold' (DT) which indicated the point at which the participants first sensed something. The third and last threshold was the 'pain-tolerance threshold' (TT), where the participant had to indicate the maximal intensity that he or she was willing to accept during the experiment. Thereafter the intensity of the current was not heightened anymore. Each of these thresholds was determined three times at each arm to attain an average for each threshold and each arm separately.

The obtained average TT gave the current for all stimuli in the experiment. The high and low intensity stimuli were generated by varying the number of pulses without changing the individually defined current. High intensity stimuli were composed of five pulses and thereby resembled the TT. Low intensity stimuli consisted of two pulses and caused a pain perception below the TT.

2.7 Task

In the current study a modified Posner task design was used as shown in Figure 1. The participants were instructed to hold their gaze at the screen center during the whole task and only to direct their attention but not to look at the cued location. The beginning of a trial was indicated by a white fixation cross that was displayed on a black background in the center of the monitor for 1200 ms. Thereafter the cue followed for 400 ms. The cue consisted of a red and a green triangle which pointed to the left and the right. The cue was exchanged by a fixation cross and after 600 ms an intracutaneous stimulus was presented at the left or right forearm. The stimulus was of either low or high intensity (two or five pulses). In total, 192 intracutaneous electrical stimuli (two or five pulses) were presented, either to the left or the right forearm. Participants had to attend to the cued forearm indicated by the green (or the red) side of the cue, which varied from trial to trial.

The experiment consisted of two blocks each containing 96 trials. During the first block half the participants had to attend to the green side of the cue and the other half to the red side of the cue. In the second block the color dependent instructions were reversed. The cue predicted for 50% the side on which the stimulus appeared.

Participants were divided into a low intensity group, for which the two pulse intracutaneous electrical stimuli were task relevant, and a high intensity group, for which the five pulse intracutaneous electrical stimuli were task relevant. The participants were instructed to respond by pressing a foot pedal with their right foot when the relevant stimulus occurred on the to-be-attended side (so called ‘Go’ trials) but not in any of the other conditions (so called ‘Nogo’ trials). Each stimulus combination (left/ right, attended/ unattended, two/ five pulses) was equally likely and varied pseudo randomly from trial to trial.

Prior to the first block the agreement between subjective pain perception and computed stimuli intensities (two and five pulses) were assessed by means of a digital continuous visual analogue scale (VAS). The pain rating VAS ranged from ‘0’ (no perceived stimulus) to ‘10’ (extreme painful stimulus). The participants consecutively received eight stimuli in a random order (two or five pulses on the left or right arm). The participants rated each stimulus combination twice. It was assumed that the differences of two and five pulse stimuli were reflected in the pain perception VAS ratings. Therefore, it was expected to find higher pain perception VAS ratings for five pulse stimuli as compared to two pulse stimuli.

At the beginning of each block, the participants received a low (two pulses) and a high (five pulses) stimulus on each arm which served as examples. At the end of each block participants had to rate again the eight stimuli on the pain rating VAS to control for habituation effects on pain perception.

For further details about the used apparatus and recordings see Ströfer (2012). She used the same methods as applied in the current study.

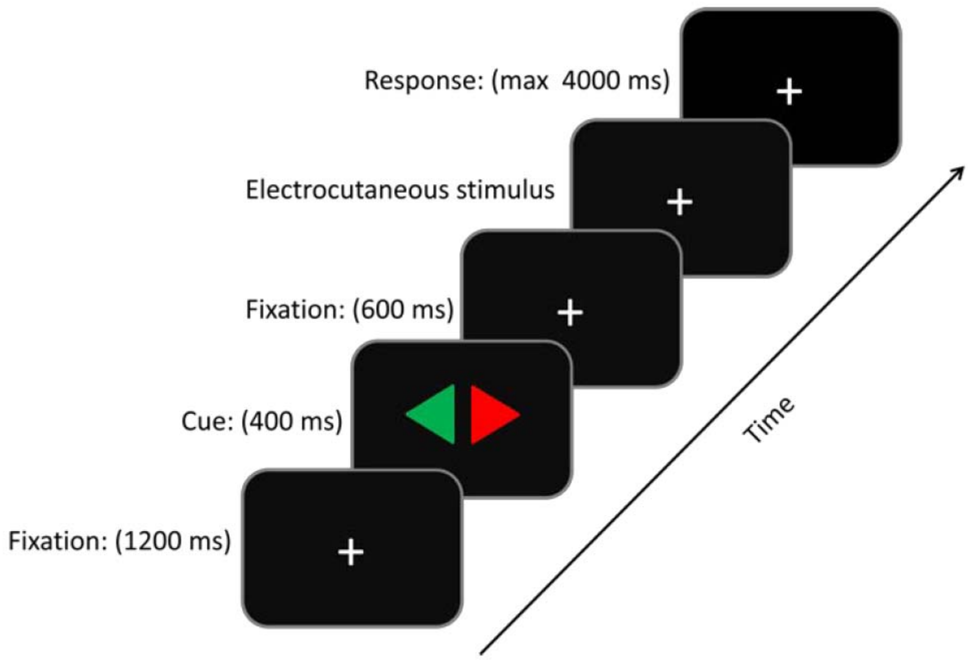

Figure 1. Posner task design. At the start of a trial a fixation cross was shown for 1200 ms. Thereafter a cue was presented for 400 ms. After the cue the fixation cross was shown again. The electrocutaneous stimulus followed 600 ms after the cue and could be of either low or high intensity and on either the cued or uncued location. Participants had 4000 ms time to give a response by pressing a foot pedal. They only had to react when the presented stimulus was on the cued location and of the relevant intensity (half the participants had to respond to high and the other half to low intensity stimuli).

2.8 Data analysis

2.8.1 Questionnaire measures

Thayer's mood scale was administered to the participants before and immediately after the EEG experiment to check for changes in mood during the experiment. On a 110 mm long visual analogue scale the participants indicated how tired, indifferent, anxious, happy, energetic, tense, positive, irritable, agitated and relaxed they felt at that moment. Changes in these mood states could give an indication about the complexity of the experiment and the task load. The scores for each emotion (0-110) corresponded with the distance between the set marker (in mm) and the start of the visual line. High scores indicate a high presence of the corresponding emotion. To check for differences in mood before and after the experiment paired sample *t*-tests were used.

The FFMQ-SF consists of 24 items. Participants had to indicate on a five point Likert scale (never or nearly never true, seldom true, sometimes true, often true, very often or always true) to what extent a proposition applied to them. The scores were respectively 1,2,3,4 or 5 for each item. The scores for some items had to be reversed because they were negatively formulated. The total score of the FFMQ-SF ranges from 24 to 120. A higher score indicates a higher degree of mindfulness. The FFMQ-SF has five subscales. The five facets of mindfulness that are measured by the FFMQ-SF are observing (noticing internal/external experiences), describing (labeling internal experiences with words), acting with awareness (attending to one's activities of the moment), being nonjudgmental (being neutral towards thoughts and feelings) and being nonreactive to inner experience (allow them to come and go) (Baer, 2008). Independent sample *t*-tests were used to assess the different degrees of mindfulness between the control group and the MBSR group. It was expected to find significantly higher scores in the degree of mindfulness in the MBSR group as compared to the control group.

To assess the degree of pain habituation during the task, pain rating VAS scores were recorded. We used a repeated measures ANOVA with the within subject factors block (pre-experimental block, first block, second block), hand (right/ left), stimulus (two/ five pulses) and the between subject factor group (control/ MBSR). In the case of the factor block, which had more than two levels, a Greenhouse-Geisser Epsilon correction was used if the Sphericity assumption showed a significant effect.

2.8.2 Behavioral measures

To assess the task performance of both groups the average response time on correct hit trials was determined. Furthermore the individual false alarm rate (*P*(F)) was computed by dividing the number of false alarms, thus every time the participant gave a reaction while no target was presented, by the total number of 'Nogo' trials. Also the individual hit rate (*P*(H)) was determined by dividing the number of correct hits by the total number of 'Go' trials.

2.8.3 EEG measures

For the analysis of the EEG data we used Brain Vision Analyzer (version 2.0.1). First the data was segmented in a -100 to 1700 ms interval relative to the onset of the cue and a -100 to 0 ms baseline was set. Horizontal eye movements (criterion: vEOG ± 120 µV) were marked and excluded to make sure that horizontal eye movements greater than 3° were removed. For the proper execution of the modified Posner task it was essential that the participants only allocated their attention to a particular side and did not move their eyes to the cued location. That is why the exclusion of horizontal eye movements relative to the cue was indispensable. For further analysis the -100 to 600 ms interval relative to the onset of the intracutaneous electrical stimulus was examined. Again a -100 to 0 ms baseline was set. EEG artifacts with a voltage step higher than 100 µV/ms and out of range values ± 250 µV for prefrontal electrodes, ± 200 µV for frontal electrodes, ± 150 µV for central electrodes, and ± 100 µV for parietal electrodes that occurred within 200 ms before and 200ms after the intracutaneous electrical stimulus were removed. Furthermore an ocular correction after the method of Gratton and Coles (Gratton, Coles, & Donchin, 1983) was carried out. This procedure left on average 98.7% of the trials, with a maximum of 100% and a minimum of 92.7%. Across all participants a total of 83 trials were removed. This was 1.3% of all trials (n=6528).

ERPs were rendered per individual as a function of electrode, attention, stimulation side, stimulus intensity and group. After examination of the grand means and the topographic maps, suitable electrodes and time intervals for further ERP analysis were determined (see figures 2-4). The following electrodes and time intervals were selected for peak detection: N1: 100-200 ms on C5 and C6; P3a: 270-370 ms on FCz and Cz. Repeated measure ANOVAs with the within subject factors electrode, stimulus intensity, stimulation side, attention and the between subject factor group were used for additional analysis of the acquired average peak amplitudes and latencies per individual. The between subject factor instructed intensity (high/low) was not included in the repeated measures ANOVA since it was assumed to be no main objective of this study. Additionally, by excluding this factor the number of degrees of freedom increased and thereby the power of the statistical analysis could be enhanced. For more information about possible effects of the factor instructed intensity examined by means of a mean activity analysis see Ströfer (2012).

3. Results

3.1 Questionnaire data

3.1.1 Thayer's mood scale

The paired sample *t*-test for the scores on Thayer's mood scale revealed changes in certain emotions during the experiment. The participants felt significantly more tired (t=-5.04, p<0.001), indifferent (t=-2.7, p=0.01), and relaxed (t=-2.08, p=0.046) after the experiment. They also felt less happy (t=4.14, p<0.001), energetic (t=5.27, p<0.001), tense (t=2.29, p=0.03), positive (t=2.54, p=0.02), and agitated (t=3.54, p=0.001) after the experiment.

3.1.2 FFMQ-SF

The independent sample *t*-test of the FFMQ-SF total scores showed a significant difference (t=-3.21, p=0.003) in the degree of mindfulness between the control and the MBSR group. As expected, the MBSR group did (M=87.88, SD=9.16) achieve significantly higher total scores on the FFMQ-SF than the control group (M=76.88, SD=10.78), indicating an increased self-reported degree of mindfulness after the MBSR training. Considering the subscales of the FFMQ-SF three of the five subscale scores were found to be significantly higher in the MBSR group as compared to the control group. On the subscale observing the MBSR group (M=16.4, SD=2.0) scored significantly higher (t=-3.4, p<0.001) than the control group (M=13.7, SD=2.6). On the subscale acting with awareness the MBSR group (M=17.2, SD=2.1) also scored significantly higher (t=-4.1, p<0.001) than the control group (M=13.8, SD=2.5). The MBSR group (M=16.8, SD=2.7) did also score significantly higher (t=-2.6, p=0.01) on the subscale being nonreactive to inner experience as compared to the control group (M=14.1, SD=3.3). The scores on the subscales describing and being nonjudgmental to inner experience did not show a significant difference between the MBSR and the control group.

3.1.3 Pain perception VAS

The repeated measures ANOVA on the pain perception VAS scores showed significant main effects of block ($F(2, 64)=18.12$, $\varepsilon=0.84$, $p<0.001$) and of stimulus intensity ($F(1, 32)=125.33$, $p<0.001$). The two pulse stimuli showed significantly lower pain perception VAS ratings (*M*=3.6, *SD*=0.1) than the five pulse stimuli (*M*=5.0, *SD*=0.2). As expected, the participants did perceive the five pulse intracutaneous electrical stimuli as more painful than the two pulse stimuli. Furthermore a habituation effect was found. The pain perception VAS ratings significantly decreased between the pre experimental block (*M*=4.9, *SD*=0.1) and the first experimental block (*M*=4.1, *SD*=0.2). The ratings for two pulse stimuli decreased in 0.9 points (pre experimental block: *M*=4.3, *SD*=0.1; first experimental block: *M*=3.4, *SD*=0.2) and 0.8 points for five pulse stimuli (pre experimental block: *M*=5.6, *SD*=0.2; first experimental block: *M* 4.8, *SD*=0.2). Between the first and the second experimental block (*M*=3.9, *SD*=0.2) no significant decrease in pain ratings was found.

3.2 Behavioral data

The computed average response times on correct hit trials showed response times around 990 ms (*M*=989.8 ms, *SD*=237.6 ms). The computed false alarm rates (*P*(F)) showed relatively few false alarms throughout all participants (*M*=8.68%, *SD*=9.80). The computed hit rates (*P*(H)) showed many hits in all participants (*M*=79.41%, *SD*=16.90). All in all, the behavioral data did indicate a proper task performance among all participants.

3.3 EEG data

The topographic maps of the N1 ERP component in Figure 2 show that activity was maximal at C5 and C6 for right and left stimuli respectively. The grand averages shown in Figure 3 indicate that the N1 component peaked between 100 and 200 ms after stimulus onset on the contralateral side. Based on this time interval two repeated measures ANOVAs were executed for individual N1 component peak amplitudes and for peak latencies. Both ANOVAs made use of the within subject factors attention (attended/ unattended), stimulus intensity (high/ low), stimulation side (left/ right), electrode (C5/ C6) and the between subject factor group (control/ MBSR).

The inspection of the topographical maps of the P3a ERP component revealed that activity was maximal at the electrodes FCz and Cz (see Figure 2). The grand averages of the P3a component (see Figure 4) pointed out that the P3a component peaked between 270 and 370 ms after stimulus onset. Based on this time interval two repeated measure ANOVAs were executed for individual P3a component peak amplitudes and for peak latencies. Again, both ANOVAs made use of the within subject factors attention (attended/ unattended), stimulus intensity (high/ low), stimulation side (left/ right), electrode (FCz/ Cz) and the between subject factor group (control/ MBSR).

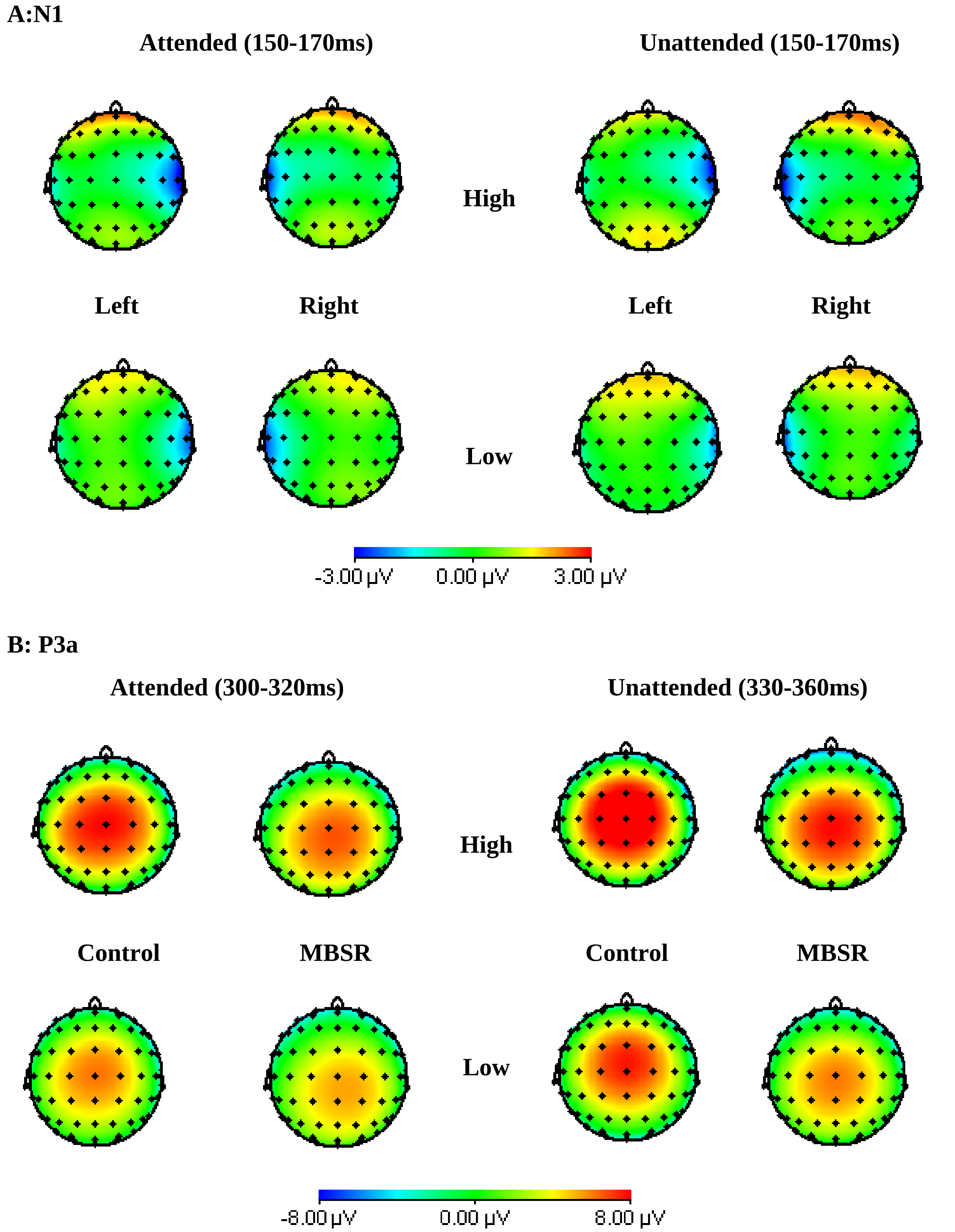

Figure 2. Topographic maps of P3a and N1 components (top view). Panel A shows topographic maps for the N1 component peaks as a function of attention (attended/ unattended), stimulation side (left/ right) and stimulus intensity (high/ low). Panel B shows topographic maps for the P3a component peaks as a function of group (MBSR/ control), attention (attended/ unattended) and stimulus intensity (high/ low).

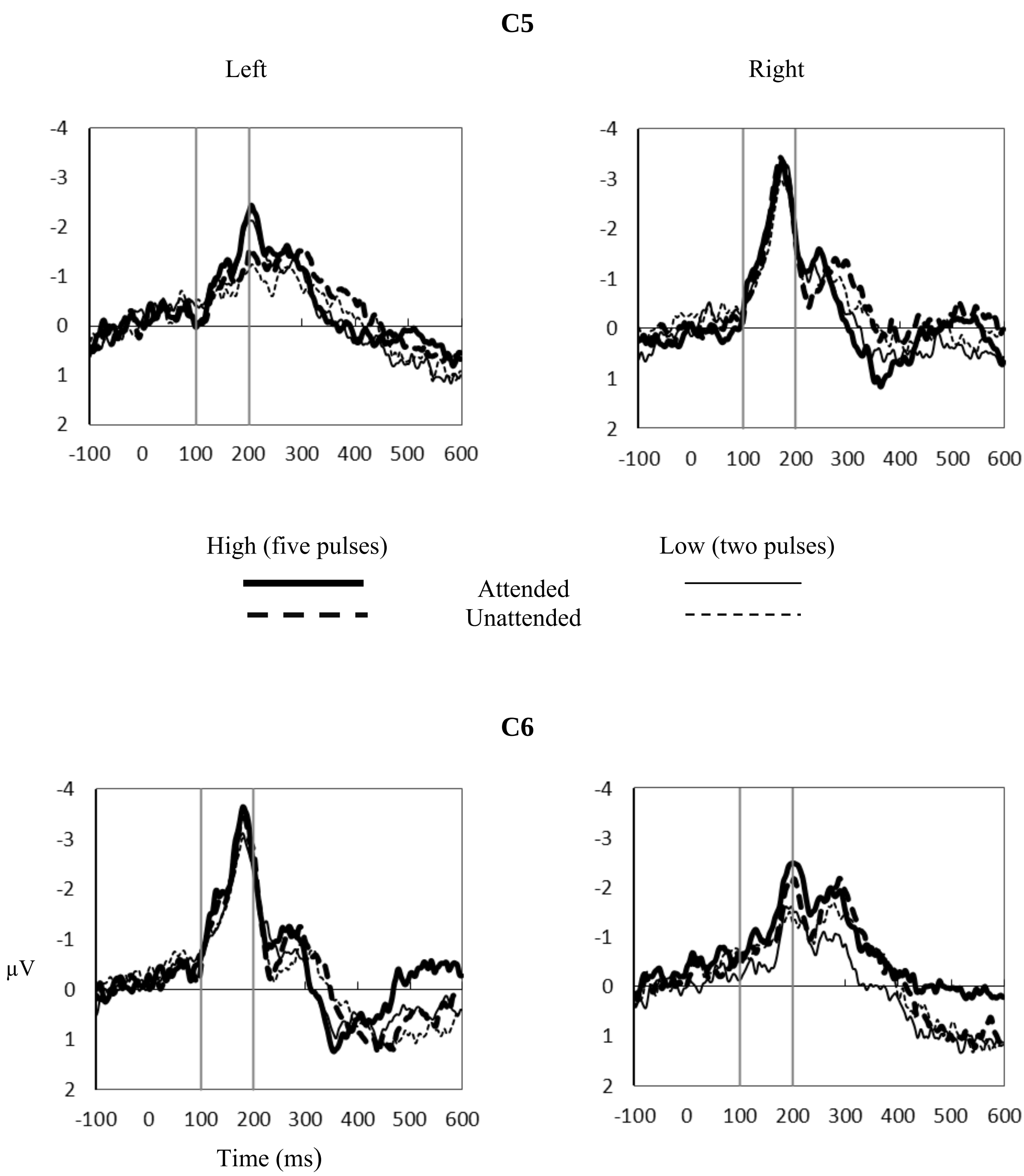

Figure 3. Grand averages of the N1 component at the electrodes C5 and C6. Grand means of the N1 component are displayed on the electrodes C5 (upper panel) and C6 (lower panel) with time in milliseconds (ms) along the x-axis and amplitude in microvolt (µV) along the y-axis. Stimulation on the left side is shown in the left panel and stimulation on the right side in the right panel. The selected time intervals for peak detection are indicated with solid vertical lines. For both, stimulation on the left side and on the right side, ERPs are presented as a function of attention (attended/ unattended) and intensity (high/ low).

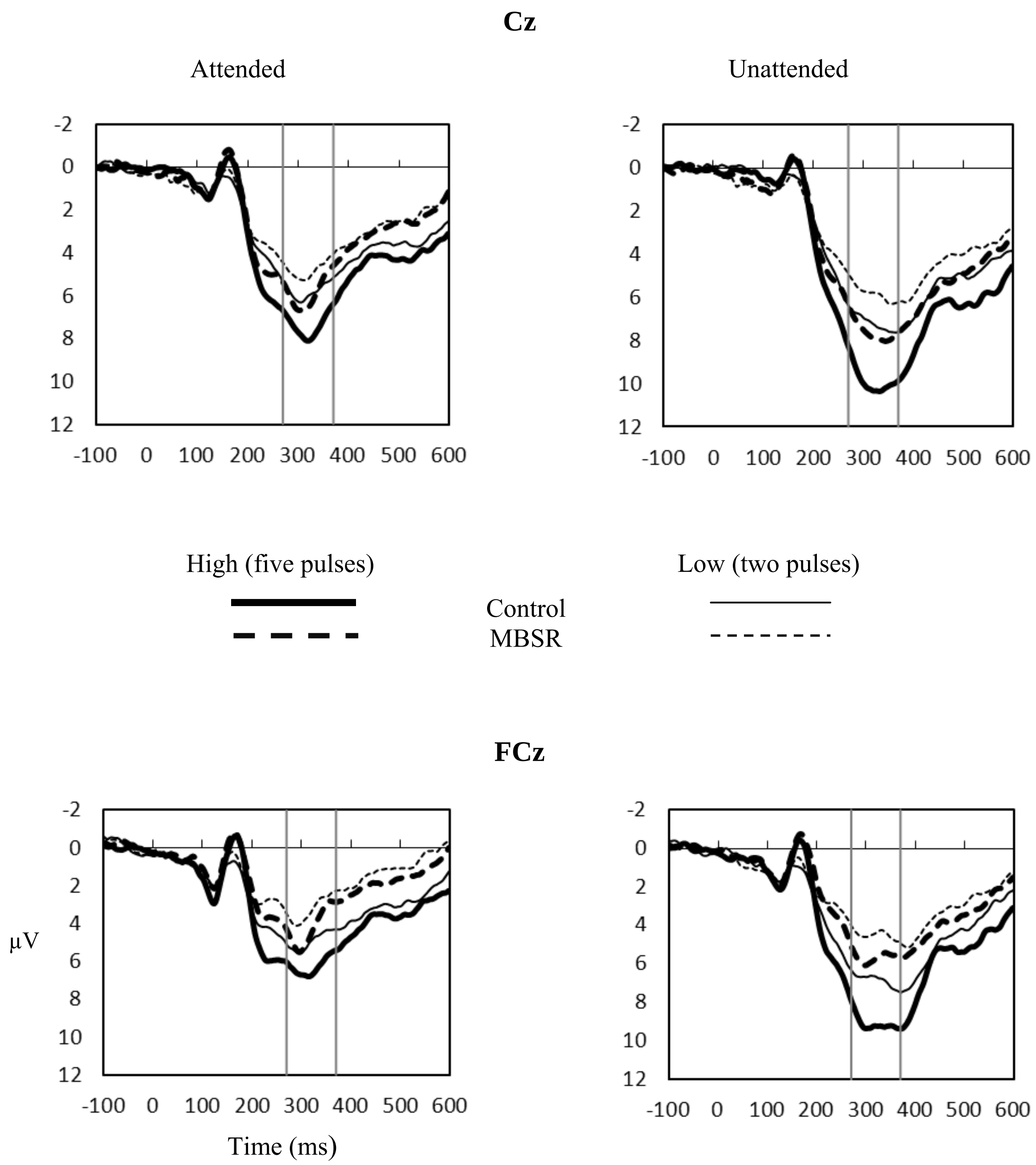

Figure 4. Grand averages of the P3a component at Cz and FCz. Grand means of the P3a component are displayed on the electrodes Cz (upper panel) and FCz (lower panel) with time in milliseconds (ms) along the x-axis and amplitude in microvolt (µV) along the y-axis. Attended stimuli are shown in the left panel and unattended stimuli in the right panel. The selected time intervals for peak detection are indicated with solid vertical lines. For both, attended and unattended stimuli, ERPs are presented as a function of group (control/ MBSR) and intensity (high/ low).

3.3.1 The N1 component

The control group and the MBSR group did not differ in N1 component peak amplitudes. No significant main effect of group ($F(1,32)=0.31$, $p=0.58$) was found. Also no significant interaction effect between attention and group ($F(1,32)=0.12$, $p=0.74$) could be detected. The hypothesis that the N1 component peak amplitude would be increased for attended stimuli in the MBSR group as compared to the control group could therefore not be confirmed.

A main effect of attention ($F(1,32)=8.17$, $p=0.007$) and a main effect of stimulus intensity ($F(1,32)=21.51$, $p<0.001$) were found in the N1 component peak amplitudes. Attended stimuli (M=-3.44 µV, SD=0.24 µV) resulted in a significantly higher N1 component amplitude than unattended stimuli (M=-3.16 µV, SD=0.24 µV). Five pulse stimuli (M=-3.50 µV, SD=0.25 µV) did also result in a significantly higher N1 component amplitude than two pulse stimuli (M=-3.11 µV, SD=0.23 µV).

Since it is known that the N1 component peaks contralateral to the stimulated side (Desmedt & Robertson, 1977), it was not surprising that we found a significant interaction effect between stimulated side and electrode ($F(1,32)=44.94$, $p<0.001$). Separate analysis for C5 revealed a significant main effect of stimulated side ($F(1,32)=27.20$, $p<0.001$) indicating that N1 component peak amplitudes were higher for stimuli on the right side (M=-4.01 µV, SD=0.37 µV) as compared to the left side (M=-2.46 µV, SD=0.18 µV). Similar results were found on C6, where stimulated side also led to a significant main effect ($F(1,32)=32.32$, $p<0.001$) pointing out that N1 component amplitudes were higher for stimuli on the left side (M=-4.10 µV, SD=0.34 µV) as compared to stimuli on the right side (M=-2.65 µV, SD=0.24 µV).

The analysis of N1 component latencies did not reveal any significant effects indicating that there was no time difference in N1 component peaks between the two groups.

3.3.2 The P3a component

Analysis of the P3a component amplitudes revealed a significant three way interaction effect between attention, electrode and group ($F(1,32)=6.46$, $p=0.016$) (see Figure 5). Separate analysis for attention revealed no significant differences between the groups on attended stimuli ($F(1,32)=1.90$, $p=0.18$). However, for unattended stimuli the separate analysis for attention did reveal a significant main effect of group ($F(1,32)=4.41$, $p=0.044$), indicating that the P3a component amplitudes were decreased in the MBSR group ($M=7.54$ μV, $SD=0.91$ μV) as compared to the control group ($M=10.25$ μV, $SD=0.91$ μV). Consequently, the hypothesis that P3a component amplitudes would be decreased for unattended stimuli in the MBSR group as compared to the control group was confirmed. Additional separation of the peak data of unattended stimuli for electrode revealed that the main effect of group was only discernible on the electrode FCz ($F(1,32)=6.80$, $p=0.01$), but not on Cz ($F(1,32)=2.23$, $p=0.15$). On FCz the P3a component amplitudes of the control group were significantly higher ($M=10.10$ μV, $SD=0.89$ μV) than those of the MBSR group ($M=6.80$ μV, $SD=0.89$ μV).

Additionally, main effects of attention ($F(1,32)=36.09$, $p<0.001$), stimulus intensity ($F(1,32)=72.12$, $p<0.001$) and electrode ($F(1,32)=6.74$, $p=0.01$) were found for P3a component amplitudes. Unattended stimuli evoked a higher P3a component amplitude ($M=8.90$ μV, $SD=0.65$ μV) as compared to attended stimuli ($M=7.05$ μV, $SD=0.59$ μV). P3a component amplitudes were higher for five pulse (high intensity) stimuli ($M=8.93$ μV, $SD=0.68$ μV) as compared to two pulse (low intensity) stimuli ($M=7.02$ μV, $SD=0.53$ μV). The P3a component reached higher amplitudes on the electrode Cz ($M=8.45$ μV, $SD=0.68$ μV) than on FCz ($M=7.50$ μV, $SD=0.57$ μV).

Analysis of P3a component latencies yielded main effects of attention ($F(1,32)=19.22$, $p<0.001$) and electrode ($F(1,32)=8.80$, $p=0.006$). Attended stimuli caused earlier P3a component peaks (*M*=314.43 ms, *SD*=3.36 ms) as compared to unattended stimuli (*M*=331.04 ms, *SD*=3.84 ms). Also did the P3a component peak earlier on the electrode FCz (*M*=319.05 ms, *SD*=3.50 ms) than on Cz (*M*=326.42 ms, *SD*=3.12 ms).

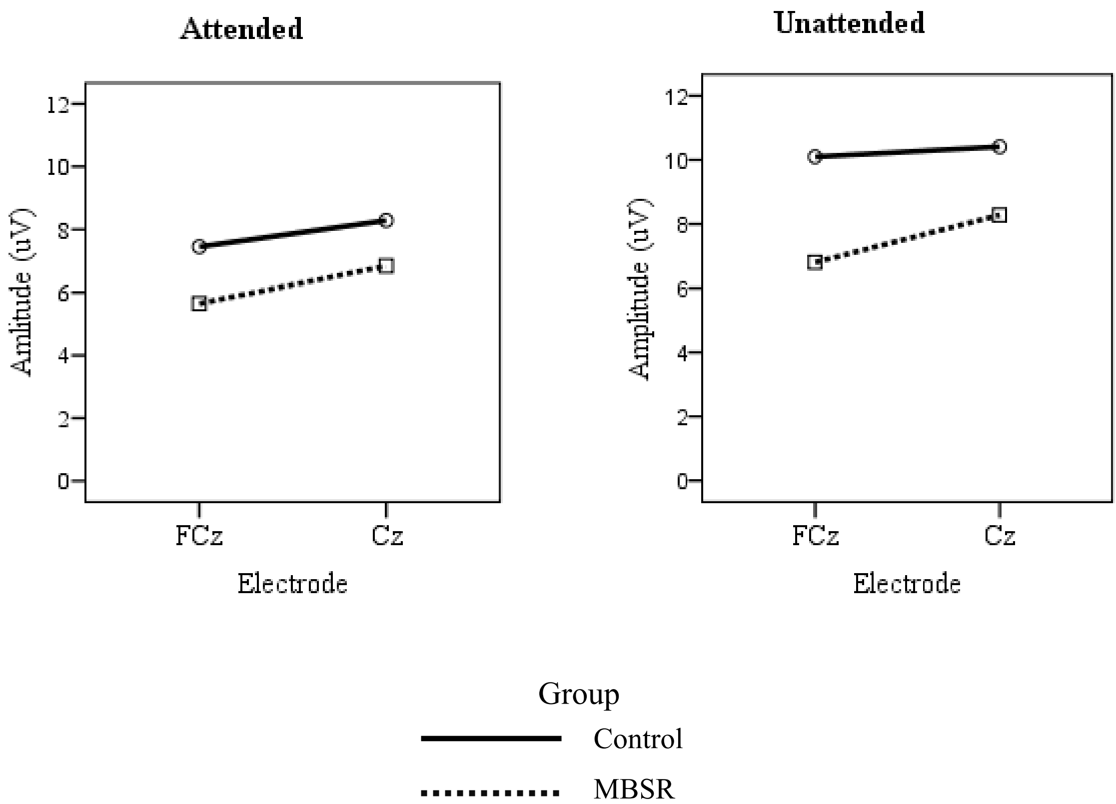

Figure 5. The P3a component peak data as a function of attention, electrode and group. P3a component peak amplitudes for attended stimuli (see left panel) on FCz and Cz did not differ significantly between the MBSR and the control group. For unattended stimuli (right panel) as well peak amplitudes did not differ significantly on Cz between the two groups. However, on FCz the difference in peak amplitudes for unattended stimuli was significantly lower for the MBSR group as compared to the control group.

4. Discussion

Several studies have shown that mindfulness based interventions can be effective in the treatment of chronic pain (e.g. Kabat-Zinn, 1982). However, these studies face several methodological weaknesses, like assessing the effect of mindfulness exclusively by means of self-ratings and the lack of control groups. Therefore it is difficult to infer strong conclusions about the effectiveness of mindfulness based approaches (Baer, 2003). These methodological weaknesses were overcome in the current study through the use of a randomly assigned treatment and control group and by assessing the effect of mindfulness by means of ERP data in addition to self-ratings. The majority of research on mindfulness has focused on clinical studies to assess the effectiveness of mindfulness based interventions, but little is known about the underlying mechanisms (e.g. Shapiro et al., 2006). The aim of the current study was to examine the underlying mechanisms of mindfulness on a neuropsychological basis. This was put into practice through examining the orientation towards pain, by means of the P3a ERP component, and the early sensory processing of painful stimuli, by means of the N1 ERP component.

In this study it was assumed that mindfulness implies flexibility in the ability to allocate attention to a particular sensation and not letting attention cling to one experience or sensation. Therefore a transient paradigm, rather than a sustained paradigm, was chosen to assess this claim of enhanced flexibility in that the participants had to change the allocation of their spatial attention in each trial. The intensity of the applied intracutaneous stimuli was manipulated by varying the number of electrical pulses rather than simply increasing the amplitude of the stimuli. This method had the advantage that the same fibers would be activated for both intensities (high vs. low) (Van der Heide et al., 2009).

The behavioral data indicated that the participants were well able to execute the modified Posner task. High hit rates and low false alarm rates show that they were well capable of discriminating between high and low intensity stimuli and to allocate their attention to the cued side. The analysis of the pain perception VAS scores additionally confirmed that the participants were well able to discriminate between stimulus intensities. Two pulse stimuli were perceived as less painful as compared to five pulse stimuli. This was indicated by lower VAS ratings for two pulse stimuli than for five pulse stimuli. The five pulse stimuli could be considered painful as indicated by the pain perception VAS ratings in the pre experimental block. Although the perceived pain intensities decreased in the first experimental block, indicating a habituation effect corresponding to earlier findings (see e.g. Ernst, Lee, Dworkin, & Zaretsky, 1986), the five pulse stimuli could still be considered painful. Altogether the data indicated that the attention manipulation was effective and that modifying the number of pulses resulted in differently perceived stimulus intensities. In the following section the effects of mindfulness on pain perception by means of the ERP components will be considered.

Since no group differences were found in N1 component amplitudes or latencies it seems that early sensory stimulus processing was not affected by the mindfulness training. There are some arguments validating that the detected negative deflection around 170 ms after stimulus onset truly was the N1 component as an indicator of early sensory processing. First we found the amplitudes of our ERP component to be maximal at the C5/ C6 electrode contralateral to the stimulated side (see figures 3 and 4), which is characteristic for the N1 component (Desmedt & Robertson, 1977). Into the bargain we found enhanced amplitudes of attended as compared to unattended stimuli and also enlarged amplitudes for high intensity stimuli as compared to low intensity stimuli, which is in accordance with previous findings using a transient spatial attention paradigm (Van der Lubbe et al., 2012). The relatively late latency of our negative deflection can be assumed to be due to the slower conduction times along Aδ fibers and is additionally in line with findings reported by Legrain, et al. (2002).

Supporting this assumption, we did not find a positive reflection around 60 ms after stimulus onset on C5 and C6, which was found to indicate cortical arrival of stimuli along Aβ fibers (Van der Lubbe et al., 2012). All in all, it can be assumed that the detected negative deflection around 170 ms is indeed the N1 component as an indicator of early sensory processing.

Mindfulness did in fact facilitate the ability to successfully orient attention as indicated by a repressed orientation response towards unattended pain stimuli. The P3a component amplitudes were decreased for unattended stimuli in the group that received the MBSR training as compared to the control group. These results showed that the attentional capture effect had a lessened impact on the MBSR group, suggesting that learning to open awareness to immediate experiences as they occur in the present moment (Brantley, 2005) could possibly reduce the involuntary orientation towards painful stimuli. This reduced automatic orientation towards pain stimuli could be the underlying mechanism for the effectiveness of mindfulness based approaches to the treatment of chronic pain.

Several findings of other researchers confirm that the positive deflection peaking at about 300 to 360 ms after stimulus onset found in the current study indeed represents the P3a component implying an automatic orientation response. The current findings showed a pronounced orientation effect towards high intensity stimuli as indicated by significantly higher amplitudes for high intensity stimuli as compared to low intensities. A study by Legrain, Guérit, Bruyer, and Plaghki (2003) on laser evoked potentials in a sustained attention manipulation attained comparable effects on the P3a component. They found a reallocation of attention indicated by high P3a component amplitudes for unattended high intensity stimuli, but not for low intensities. Moreover, the findings of the current study were in accordance with the results of Van der Lubbe et al. (2012) who as well found increased P3a component amplitudes for unattended and high intensity stimuli as compared to attended and low intensity stimuli respectively. Additionally, the current findings on peak latencies of the positive deflection around 300 to 360 ms after stimulus onset showed that attended stimuli caused an earlier peak than unattended stimuli. In line with that, Mageliero, Bashore, Coles, and Donchin (1984) showed P3 component latencies to be related to stimulus evaluation time, suggesting that painful stimuli could be faster evaluated when they were already attended to. This finding also confirms Ströfer's (2012) assertion that the P3a component peak was shifted in time as a function of attention. Furthermore, the positive deflection in the current study did reach a peak earlier on FCz than on Cz, suggesting that this component was generated in the anterior cingulated cortex (ACC). Bromm and Chen (1995) and Van der Lubbe et al. (2012) showed the source of the P3a component to be the ACC, therefore supporting the assumption that the positive deflection found in the current study indeed represents the P3a component. Additionally, these findings indicate a P3a instead of a P3b component because the P3b was shown to peak more posterior and to indicate target stimuli (Polich, 2003). All in all, the consonances between the findings of the current study and those of previous studies give reason to believe that the positive deflection peaking at about 300 to 360 ms after stimulus onset found in the current study indeed represents the P3a component implying an automatic orientation response.

In general the current study could support the findings of Ströfer (2012). Like Ströfer (2012) we did not find a difference in the N1 component between the MBSR and the control group. Also, the current study indicated higher N1 component amplitudes for attended and high intensity stimuli as compared to unattended and low intensity stimuli respectively, which is in accordance with Ströfer's (2012) findings. On the P3a component amplitude the same effects of attention and intensity were found as indicated by Ströfer (2012). Here unattended as well as high intensity stimuli caused higher P3a component amplitudes as compared to attended and low intensity stimuli respectively. Additionally, the P3a component latency analysis could verify Ströfer's (2012) assumption that attended stimuli elicited earlier P3a component peaks than unattended stimuli.

However, some results of the current study differed from those of Ströfer (2012). Ströfer (2012) presumed a later N1 component peak in the MBSR group as compared to the control group. This assumption could not be verified by the current study. No effects in N1 component latencies could be detected in the current study, indicating that Ströfer's (2012) finding could be a result of an artifact caused by the time window choice as Ströfer (2012) herself already suspected. Furthermore, the detected group difference in P3a component amplitude in the current study depended on attention. The P3a component amplitudes were reduced in the MBSR group only for unattended stimuli. Ströfer (2012) found this reduction in P3a component amplitudes in the MBSR group independent of attention. Taking a closer look at Figure 5 a trend of an overall decrease in P3a component amplitudes could also be suspected in the current study. However, this reduction did only reach significance for unattended stimuli. Additionally, Ströfer's (2012) findings of an overall decreased P3a component for the MBSR group were rather surprising. If mindfulness indeed facilitates the ability to successfully orient attention, a repressed automatic orientation response towards unattended pain stimuli, but not towards attended stimuli, would be expected. For attended stimuli yet an increased orientation response could be suspected. See Ströfer (2012) for possible explanations of this rather surprising finding.

In the following section some findings of the used questionnaires will be discuss. The scores on Thayer's mood scale revealed that participants felt less energetic, agitated, happy, positive and more tiered after the experiment. These results could point to a high task load. Additionally, the participants were sometimes confused and made some errors in the first trials. To take away some of these exertions future studies may add some practice trials, so that participants could familiarize themselves with the task and avoid confusion and errors

(Ströfer, 2012). For some further shortcomings of the current study design and possible improvements see Ströfer (2012).

The FFMQ-SF revealed an overall increased degree of mindfulness in the MBSR group as compared to the control group. Considering the subscales of the FFMQ-SF it is interesting that we found no group difference on two of the five facets of mindfulness. The MBSR group did not attain higher scores as compared to the control group on the subscales describing and being nonjudgmental. One possible explanation could be that participants in the MBSR group did not adhere to their daily mindfulness exercising and therefore obtained lower scores on those subscales. To investigate this claim the mindfulness exercising times of each participant should be assessed and evaluated with regard to instructed minimum exercising time. So conclusions could be drawn about training maintenance.

All in all, this study revealed some valuable information about underlying mechanisms of mindfulness on a neuropsychological basis and showed that mindfulness did not affect early sensory processing but indeed facilitated the ability to successfully orient attention as indicated by a repressed orientation response towards unattended pain stimuli[1]. The attentional capture effect had a lessened impact on the MBSR group suggesting that learning to open awareness to immediate experiences as they occur in the present moment (Brantley, 2005) could possibly reduce the involuntary orientation towards painful stimuli. This reduced automatic orientation towards pain stimuli could be the underlying mechanism for the effectiveness of mindfulness based approaches to the treatment of chronic pain.

[1]Additional analysis with instructed intensity as complementary between subjects factor revealed significant interaction effects between instructed intensity (high/ low) and group (MBSR/ control) in both N1 and P3a component amplitudes as well as latencies. The previous findings must therefore be viewed in a critical light. Further analysis with inclusion of the factor instructed intensity is needed to be able to draw strong conclusions about possible effects of mindfulness on a neuropsychological basis.

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