Meditation and emotional processing in the brain:

An ERP study on the influence of long term Sudarshan Kriya yoga and meditation practice

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Abstract

The present study examined differences in the event-related brain potentials (ERPs) of 24 long term Sudarshan Kriya meditators and 24 control subjects without prior experience in meditation, in their response to an emotional evocative task. The International Affective Picture System (IAPS) was used to examine emotional processing in the brain. Subjects also completed the Positive and Negative Affect Schedule (PANAS). In the 200-400 ms time window, group differences were found at central and parietooccipital brain regions, independent of ERP response to stimulus valence. The meditators showed higher overall ERP amplitude in these regions compared to the controls. In the 400-600 ms time window meditators showed greater ERP response to neutral pictures at prefrontal brain regions, compared to controls. A negativity bias was found in both groups and both time windows. Correlations between subjects' PANAS scores and ERP amplitudes were found. The meditation group showed correlations at left, middle and right brain areas, while the control group showed correlations at left and middle brain areas, but not right brain areas. The present findings indicate an effect of meditation on brain responses, but not on emotional processing.

Introduction

Meditation and yoga originate from Eastern culture and have been passed on to the West, where an increasing number of people practice variants of these techniques. Some people use meditation and/or yoga as a method for reducing stress, anxiety or against symptoms of depression (Pilkington, Kirkwood, Rampes & Richardson, 2005; Brown & Gerbarg, 2005). In general, meditation can be divided into two types: mindfulness and concentrative. Mindfulness based meditation is allowing all your thoughts, feelings and sensations to arise while staying aware of yourself and your location (Cahn & Polich, 2006). Recent research has found that mindfulness meditation is associated with an increase in psychological well-being and a decrease in stress and mood disturbance (Brown & Ryan, 2003). An example of mindfulness based meditation is Zen meditation. Concentrative meditation forms include focusing on a specific mental or sensory activity, such as a repeating sound, a mental imagery or the breath. Yogic meditation is a form of concentrative meditation (Cahn & Polich, 2006). There are also techniques that include both forms of meditation. One of these techniques is Transcendental Meditation (TM), where practitioners focus on a repeated mantra and also try to get into a state of thought-free awareness (Cahn & Polich, 2006). Another technique that includes both mindfulness and concentrative aspects is Sudarshan Kriya (SK) yoga. In SK, yogic breathing, yoga postures and meditation are combined. SK consists of three preparatory stages where different types of inhaling and exhaling and chanting are practiced. After these breathing stages the SK cyclical breathing technique starts and is followed by meditation and rest (Brown & Gerbarg, 2005). SK meditation, the technique studied in the present research, is comparable with TM, where practitioners are guided into a state of thought-free awareness.

An increasing number of research has been done to study the beneficial effects of meditation techniques. Evidence for an influence of different meditation types on brain activity comes from electroencephalographic (EEG) studies. Overall, these studies report increased alpha and theta band power in long term meditators, compared to control subjects who did not have regular practice in meditation (reviewed in Cahn & Polich, 2006). Increased theta band power is associated with orientation, attention, memory and affective processing mechanisms, while increased alpha power is associated with calmness, relaxation and positive affect (Aftanas & Golocheikine, 2001; Cahn & Polich, 2006). An EEG frequency study comparing Short Term Sahaja Yoga Meditators (STM) to Long Term Sahaja Yoga Meditators (LTM) found that increased alpha and theta power and theta coherence are also important in experiencing emotionally positive feelings of bliss and internalized attention. A high-resolution EEG was recorded during an eyes closed condition and a meditation condition and subjects also completed a short questionnaire on 'blissful' experience and reported how many thoughts appeared during meditation. On the questionnaire, the LTM reported a more intense blissful experience and a lower thought appearance rate than the STM. EEG recordings showed that the LTM had increased theta (3.77-5.65 Hz) and alpha-1 power (5.65-7.54 Hz) in frontal regions and alpha-2 power (7.54-9.42 Hz) in anterior temporal and frontal regions, in comparison with STM, were theta ranged from 4.02-6.02 Hz, alpha-1 from 6.02-8.03 Hz, and alpha-2 from 8.03-10.04 Hz. Furthermore, STM showed alpha-2 desynchronization in parietotemporal, parietal and occipital regions and LTM showed increased theta synchronization in prefrontal and posterior association cortex. Correlation analysis between the EEG frequency results and the results on the questionnaire yielded a positive correlation between intensity of blissful experience and theta power in anterior frontal and frontal midline sites, and a negative correlation between thought appearance and theta power in anterior frontal, frontal midline, central frontal, and right central regions. These results indicate that positive experiences and concentration during meditating increase with long term regular practice (Aftanas & Golocheikine, 2001).

A reanalysis of this study was done to examine the complexity of neuronal computations in the brain, called dimensional complexity. Decrease of dimensional complexity over the midline anterior-frontal and centro-frontal regions was found during meditation, indicating that meditative experience elicits less complex EEG dynamics (Aftanas & Golocheikine, 2002). The authors discussed that these findings may suggest that meditators shut off information processing in frontal midline theta to maintain the focus on internalized attention and inhibiting useless information.

In a within-subject study with practitioners of TM, the EEG was recorded during TM practice. While meditating, the participants heard a bell ring at three different times. When the bell rang they gave a subjective report on their meditation experience at that time. Their experiences where categorized in 'transcending' and 'other experiences'. Higher alpha amplitude was found during the transcending phase compared to the other experiences, increasing from frontal to parietal sites. Also, higher alpha coherence was found during the transcending phase at bilateral-frontal locations (Travis, 2001). These results indicate that alpha power and coherence are associated with transcendental experience.

The influences of Zen meditation on EEG patterns have also been studied (Takahashi, Murata, Hamada, Omori, Kosaka, Kikuchi, Yoshida & Wada, 2005). Participants without prior experience learned and performed the Su-soku task, a Zen meditation task that involves counting one's own breaths. During the meditation task, an increase in alpha-1 power (8.20-9.77 Hz) was found at F3, F4, C3 and C4 electrode sites and in theta-2 power (6.25-7.81 Hz) at F3 and F4 electrode sites, indicating increased alpha and theta activity in frontal and central regions, compared to an EEG baseline control condition. This study also measured the correlations between change in EEG power (from baseline to meditation) and personality traits. Personality traits were assessed with the Cloninger's Temperament and Character Inventory which consists of four temperament dimensions: novelty seeking (NS), harm avoidance (HA), reward dependence (RD) and persistence (P). The NS score was positively correlated with alpha-1 power at F3, F4 and C3. HA score was positively correlated with theta-2 power at F3 and F4. The RD and P scores were not correlated with EEG power. The results of this study suggest that certain personality traits, such as the tendency to seek novelty and rewards and avoiding harmful situations and punishment, are beneficial for experiencing psychophysiological changes during meditation.

There are few studies on meditation that, besides examining EEG frequencies, also examined event-related potentials (ERPs), which are elicited during cognitive processing, or evoked potentials (EPs), which are elicited during sensory stimulation. A study by Bhatia et al. (2003) comparing SK teachers to controls, not only studied the EEG frequencies, but also P300. P300 is an ERP-component that is mostly found in stimulus discrimination tasks and is associated with attention and memory processing (Polich, in press). Brainstem Auditory Evoked Responses (BAER), which are evoked during auditory stimulation, were also tested. During EEG recording, participants had to lie down and relax with their eyes closed. P300 responses were elicited using a standard auditory oddball paradigm. Participants were instructed to count rare tones in a frequent tone presentation. For BAER measurement, brain activity was recorded while subjects passively received frequent tones in each ear. No significant differences were found between the groups in BAER and P300 latencies and amplitude. However, it has to be noted that the researchers measured the BAER and P300 using only a 2-channel recording with Cz as active electrode. Due to this limited number of channels, the results need to be addressed with caution. For recording the EEG the researchers used a 16-channel recording and they found significant differences in beta activity between the two groups. The SK teachers showed an increase in beta-1 (13-18 Hz) and beta-2 (19-30 Hz) activity at left fronto-occipital (electrodes F3 and O1) and midline areas (electrodes Fz and Pz). The authors state that beta activity is associated with a focus of attention and alertness and with increased awareness during meditation (Bhatia, Kumar, Kumar, Pandey & Kochupillai, 2003).

Banquet and Lesévre (1980), as described in Cahn & Polich (2006), examined the ERPs of a yogic meditation group and an inexperienced control group in their response to a visual oddball task, where subjects had to respond to frequent visual stimuli and withhold their response to odd visual stimuli. The meditation group performed the task before and after a 30-minute meditation practice, while the control group performed the task before and after 30-minutes of supine rest. The meditation group showed increased P300 amplitude after meditation practice, while the control group showed decreased P300 amplitude after the resting period. The meditation group also showed increased P200 and N120 amplitudes, had shorter response times to the stimuli and made fewer mistakes during the oddball task, compared to the control group. It is suggested that meditators show increased selective attention as a result of long term practice (in Cahn & Polich, 2006).

Another ERP study examined the effects of TM practice on the contingent negative variation (CNV) (Travis, Tecce, & Guttman, 2000), a component that is associated with attention and stimulus expectancy (Stadler, Klimesch, Pouthas, & Ragot, 2006). Travis et al. (2000) compared Long Term TM practitioners (LTM), Short Term TM practitioners (STM), and inexperienced controls in their performance on two stimulus sequence tasks. The first task was detecting a target tone which was cued by an asterisk. In the second task, a distractor (string of letters) was added between the cue presentation and the tone presentation. In response to the first task, the LTM group had the highest mean CNV amplitude, the STM group medium mean CNV amplitude, and the control group the lowest CNV amplitude. These differences were mostly found at the midline central site. Group differences were also found in the second task, with the distractor. Distraction effects were measured by subtracting the CNV amplitudes of the second task from the CNV amplitudes of the first task. At the midline frontal site, the control group showed high distraction effects compared to the STM and LTM group. The LTM showed low distraction effects. The CNV findings imply that long term meditation practice reduces distraction and therefore is associated with attentional allocation, which is beneficial for experiencing transcending during meditation practice (Travis et al., 2000).

Relatively few studies have examined the effects of meditation on emotional processing. Aftanas and Golocheikine (2005) studied the influence of meditation practice on EEG activity during non-emotional and emotional arousal. A Sahaja Yoga meditation group was compared to an inexperienced control group. EEG was recorded during a rest condition (eyes open/eyes closed), during presentation of neutral video clips (neutral landscape scenes), and during presentation of negative video clips (abusing people). In the rest condition, meditators showed increased theta-1 (4-6 Hz), theta-2 (6-8 Hz) and alpha-1 (8-10 Hz) band power compared to controls. In the emotionally neutral condition, both groups demonstrated a decrease in alpha-1 and alpha-2 (10-12 Hz) power, but the meditation group still showed larger power values, indicating a lower level of tonic arousal and more internal attentional allocation in meditators. These results are supported by previous studies that showed increased alpha and theta power in meditators. In the negative emotion condition, controls showed increased gamma (25-45 Hz) power at prefrontal, frontal, and anterior temporal regions compared to the rest and neutral condition, but meditators did not show any power changes. Gamma activity is associated with arousal and processing of affective stimuli. Specifically, increased right hemispheric gamma activity is found during negative picture processing (Müller, Keil, Gruber, & Elbert, 1999). In addition to the EEG measures, subjective measures were also examined. Subjective emotionality ratings of the negative video clip showed that the meditation group had lower scores on negative emotional feelings than the control group, indicating lower emotional reactivity to negative stimuli in meditators. The differences in gamma activity and subjective ratings indicate that the meditators are less aroused by negative aversive video clips, than the controls. Laterality differences were also examined and were found in the control group, but not in the meditation group. Controls showed increased alpha-2 power at parieto-temporal regions in the right hemisphere compared to the left hemisphere, only in the rest condition. The authors suggest that hemispheric asymmetry reflects ‘inner dialogue’ and meditators seem to be less distracted by this inner dialogue. A possible outcome is that meditators are better at reducing intense emotional arousal.

In sum, it seems that EEG studies on different forms of meditation using different paradigms find somewhat consistent results in alpha and theta frequency bands (also beta and gamma) with increased power in prefrontal, anterior frontal, frontal midline, left frontal, central and occipital areas. Some studies have found correlations between EEG frequency power and subjective reports of emotionally positive feelings, a novelty seeking tendency and harm avoidance. The ERP studies demonstrate increased amplitude of different ERP-components, such as P300 and CNV, in meditators. Furthermore, during evoked negative emotions, meditators show less arousal than controls. The results suggest that on the long term, meditation can give practitioners a positive feeling of bliss and relaxation and an increase in attentional focus.

Besides studies that have shown an influence of meditation practice on brain activity, several health studies found that meditation and yoga interventions can be beneficial for both mental and physical health. Pilkington et al. (2005) reviewed a number of studies that examined the effects of different forms of yoga on depression. The authors concluded that yoga has a positive effect on reducing stress, anxiety, and depressive disorders (Pilkington, Kirkwood, Rampes, & Richardson, 2005). In a study with patients who suffered from melancholic depression, it was found that SK yoga, used as a form of therapy, had similar outcomes as drug therapy (Janakiramaiah, Gangadhar, Naga Venkatesha Murthy, Harish, Subbakrishna & Vedamurthachar, 2000). Forty-five untreated patients were divided into three equal groups. The first group received training in SK yoga as treatment, the second group was treated with electroconvulsive therapy, and the third group was treated with the drug imipramine. The patients completed the Beck Depression Inventory (BDI) and the Hamilton Rating Scale for Depression (HRSD) before treatment and once a week during treatment. After four weeks of treatment, all three groups showed lower scores on the BDI and HRSD. The scores on the questionnaires in the SK yoga group did not differ from the scores of the imipramine group. The authors suggest that the results of SK yoga and imipramine treatment are comparable. Electroconvulsive therapy showed better results against the disorder than SK yoga and imipramine, but the advantage of yoga practice is that it has minimal unwanted side effects (Janakiramaiah et al., 2000).

Another study that has investigated the effect of SK yoga as treatment for depressive disorder, examined whether P300 can predict positive outcome of SK intervention. Patients suffering from dysthymic or melancholic depressive disorder received only SK yoga as treatment for a period of three months. P300 amplitude was recorded before and after SK yoga treatment, with an auditory oddball task. HRSD and BDI scores were also obtained before and after SK treatment. The two groups did not differ in P300 amplitude before and after treatment. However, SK practice did produce positive outcomes. The melancholia patients had higher scores on the two depression scales (HRSD and BDI) than the dysthymia patients before treatment, but the two groups had significantly lower HRSD and BDI scores after one month of SK treatment. P300 amplitude could not predict this positive outcome of the SK intervention (Naga Venkatesha Murthy, Janakiramaiah, Gangadhar, & Subbakrishna, 1998).

Davidson et al. (2003) investigated the effect of an 8-week training program in meditation on brain activity and immune function of healthy subjects. Half of the subjects received mindfulness meditation training. The other half of the subjects received no training and served as control group. EEG was recorded before, immediately after, and four months after the training period, during rest and during emotion induction. Baseline EEG activity during rest was significantly higher in the meditation group compared to the control group immediately after and after four months of training. The increased baseline activity was found at central sites in the left hemisphere. For emotion induction, participants had to describe their most positive and negative experiences and after each description their EEG was recorded. There was no difference in brain activity between the groups in their response to positive or negative emotion induction at any recording moment. However, immediately after the training period, the meditation group showed increased brain activity in the left anterior-temporal region after positive emotion induction, and at left-central sites after negative emotion induction, compared to their brain activity before the training. The controls showed no increased brain activity after emotion induction. The subjects' immune function was also tested. Both groups received an influenza vaccine after the training period. Four to eight weeks after the vaccination, blood samples of the subjects revealed that the meditators had produced more antibody titers in response to the vaccine, than the controls. A positive correlation between EEG activity and the antibody titers demonstrated that in the meditation group (after training) increased left hemisphere activity was associated with a higher level of antibody titers. This relation was not found in the control group. The authors claimed that even a short training program in mindfulness meditation can show significant changes in brain and immune function (Davidson, Kabat-Zinn, Schumacher, Rosenkranz, Muller, Santorelli, Urbanowski, Harrington, Bonus, & Sheridan, 2003).

The studies that were described have examined the influences of meditation and yoga on brain activity, mental and physical health and most studies have found beneficial results of meditative practices. Although meditation practice seems to be associated with increased emotionally positive feelings and decreased emotionally negative feelings, only a few studies have examined the relation between meditation and emotional processing.

The International Affective Picture System (IAPS) is a frequently used stimulus set to study emotional processing. The pictures used in the IAPS task are internationally standardized, emotionally evocative, color photographs that are divided into three valence categories: pleasant, neutral, and unpleasant (Lang, Bradley, & Cuthbert, 2005). Several studies have used the IAPS stimulus set to examine the ERPs of healthy subjects during emotional picture processing. These studies have revealed differences in emotional processing on two dimensions: arousal (separating affective from neutral pictures) and valence (separating pleasant from unpleasant pictures). Dolcos and Cabeza (2002) recorded ERPs of 15 healthy right-handed students in their response to IAPS pictures. An emotion effect was found in the 500-800 ms time window and was different at parietal and frontocentral sites. At parietal sites, the pleasant and unpleasant pictures both elicited higher mean positive amplitudes than neutral pictures, but there was no significant difference between the ERP responses to pleasant and unpleasant pictures. At frontocentral sites, the ERP amplitudes elicited by the pleasant pictures were significantly higher than the amplitudes of unpleasant and neutral pictures, but amplitudes elicited by the unpleasant pictures were not different from amplitudes elicited by neutral pictures. It was concluded that parietal locations are involved in processing emotional arousal, but not emotional valence differences, while frontocentral locations do seem to reflect emotional valence differences (Dolcos & Cabeza, 2002).

In another study investigating ERPs during affective picture processing, subjects were instructed to passively view each picture (Amrhein, Mühlberger, Pauli, & Wiedemann, 2004). ERP differences were found at the P300 amplitude and in time windows 200-300, 300-400, and 400-700 ms, reflecting higher mean positive amplitudes during affective picture viewing compared to neutral picture viewing. Differences between ERP responses to the pleasant and unpleasant pictures were found only in the 200-300 time window, where pleasant pictures elicited greater positive amplitude than unpleasant pictures. ERP positive amplitudes increased from frontal (F3, F4, and Fz) to central (C3, C4, and Cz) to parietal (P3, P4, and Pz) electrode sites. The results indicate that emotional arousal discrimination is found at 200 to 700 ms after stimulus onset, while emotional valence discrimination is found 200 to 300 ms after stimulus onset, but not 400 to 700 ms after stimulus onset.

Emotional valence and arousal effects during the IAPS task were also found at the P2 component (160-220 ms), N2 component (220-300 ms), P3 component (300-450 ms), early slow wave (550-700 ms), and late slow wave (700-850 ms) (Olofsson & Polich, 2007). At P2, the unpleasant pictures elicited higher positive amplitudes than pleasant and neutral pictures. At N2, the unpleasant pictures elicited greater negative amplitudes than pleasant and neutral pictures. At P3, unpleasant and pleasant pictures elicited greater positive amplitudes than neutral pictures. At these three components, mean amplitude was highest at the Pz electrode site. In the early and late slow wave, more positive voltages were elicited by unpleasant and pleasant pictures compared to neutral pictures, and increased from frontal to parietal sites.

A number of studies have examined hemispheric differences during emotional processing. According to the approach-withdrawal theory of emotion the left hemisphere processes positive emotions related to approach while the right hemisphere processes negative emotions related to withdrawal (Davidson, Ekman, Saron, Senulis, & Friesen, 1990). In their study, Davidson et al. (1990) found that emotions associated with approach related behavior (i.e. happiness) elicited greater left sided activity, while emotions associated with withdrawal behavior (i.e. fear and disgust) showed more right sided activity in the brain. This cerebral asymmetry was only found in frontal and anterior temporal regions.

In the present study, the goal was to examine whether long term practice of meditation would have a positive effect on emotional processing. ERPs were measured from long term SK yoga meditators and controls without meditation experience in their response to the IAPS task. Based on the approach-withdrawal theory of emotion, it was expected that the meditators would show higher ERP amplitudes in the left hemisphere in response to affective stimuli than the control group, indicating more left hemispheric activity, which is associated with positive emotions related to approach. Previous findings regarding emotionality and meditation have shown increased positive feelings of bliss in long term meditators compared to short term meditators and lower tonic arousal during evoked negative emotions in meditators compared to controls (Aftanas & Golocheikine, 2001, 2002, 2005). Also, a number of studies have demonstrated an increase in left hemispheric activity in meditators, especially at frontal and anterior temporal regions (Bhatia et al., 2003; Davidson et al., 2003), which corresponds to the locations of hemispheric differences found in approach and withdrawal related emotions

(Davidson et al., 1990). To the author's best knowledge, no research has used the IAPS paradigm to study emotional processing in meditators.

Methods

Subjects

Forty-eight subjects with ages ranging from 22 to 65 years (mean age ± SD was 46.8 ± 10.7 years) participated in this study. Of this total sample, 24 long term practitioners of meditation and SK were recruited from the Art of Living Foundation in the Netherlands. In addition, 24 controls were recruited amongst acquaintances of the researcher. The controls had never or not more than two times practiced meditation and yoga, but were interested in the techniques. Table 1 summarizes the subjects' characteristics as well as statistically significant differences. Education was measured on six levels: 1. primary education, 2. junior secondary education, 3. senior secondary education, 4. higher education, 5. university education, 6. other education. The meditation group was significantly higher educated than the control group, but no other differences between the groups were found. All participants completed a health-questionnaire and reported no history of psychiatric disorders and no history of neurological or neurovascular disorders (such as epilepsy or stroke) or use of drugs that are known to affect the central nervous system. Some participants did report depression or burn-out in the past, but were fully recovered and had no complaints at the present. Informed written consent was asked and received from all participants.

Table 1

Subjects' characteristics and significant differences between groups

	Mean ± SD (range)	
	Meditators	Controls
Age in years	45.2 ± 10.6 (22-60)	48.3 ± 10.9 (25-65)
Gender (male/female)	12/12	12/12
Handedness (right/left/both)	18/6/0	20/2/2
Educational level	4.1 ± 0.8 (1-6) *	3.5 ± 1.0 (1-6) *
Ethnicity (Dutch/not Dutch)	19/5	15/9

* $p < 0.05$.

Stimuli

The test stimuli included 77 pleasant, 74 pleasant, and 32 neutral pictures from the IAPS (Lang et al., 2005). Ten additional pictures were used as practice stimuli and eight other pictures were used as initial stimuli, prior to the test stimuli (see Appendix for numbers of used IAPS pictures). There were two different versions of the IAPS task, a male version and a female version. The two versions contained different pleasant pictures (erotic pictures of the opposite sex) and different unpleasant pictures. These differences are based on comparable ratings from men and women on three dimensions of the IAPS pictures: valence, arousal and dominance (Lang et al., 2005). For both versions, the button distribution was counterbalanced. Half of the subjects had to press the right button and the other half had to press the left button if they regarded a picture as pleasant. For pictures regarded as unpleasant they had to press the opposite button. There was no response button for neutral pictures. When regarding a picture as neutral, subjects had to press either the pleasant or the unpleasant button.

PANAS

The Dutch version of the Positive and Negative Affect Schedule (PANAS) was used to examine mood congruency effects (Watson, Clark & Tellegen, 1988; Peeters, Ponds, Boon-Vermeeren, Hoorweg, Kraan & Meertens, 1999). The PANAS contains two 10-item scales about one's own mood and can be assessed at seven different time frames: present moment, today, past few days, past week, past few weeks, past year, and in general. In this study the general time frame was used. The PANAS measures positive and negative affect. Positive affect (PA) measures how enthusiastic, active and alert someone is. A high score on PA stands for a lot of energy and complete concentration, while a low score on PA reflects sadness and apathetic state. Negative affect (NA) generally measures subjective pain and unpleasantness. A low score on NA reflects calmness and serenity.

Procedure

One to three weeks before EEG recording in the lab, participants completed the PANAS. Upon entering the lab they first did two relaxation exercises, which consisted of meditating and listening to narrated stories. The participants were seated in an upright, comfortable chair in a sound-attenuated room with dimmed lights. After the relaxation exercises, the participants started with the IAPS task. Participants were asked to try not to blink when a picture or fixation cross appeared on the screen. After a practice phase with ten pictures, the participants started the test phase and completed this phase in two blocks, with a break in between. They could take the break as long as needed.

Each experimental trial was built up as follows: a fixation cross for 400, 450, 500, 550 or 600 ms (randomized), followed by a picture for 500 ms, then a fixation cross for 1000 ms, and then a black screen for 2000 ms. After the black screen, a fixation cross appeared again, initiating a new trial. During the black screen the participants could give their response. The order of the pictures was randomized prior to the test, so that every participant received the same picture order.

EEG recording

Brain activity was recorded with the electroencephalogram (EEG) using a Biosemi ActiveTwo System amplifier from 64 scalp sites. Silver chloride active (Ag/AgCl) electrodes were placed upon the scalp according to the 10-20 International System. The electrodes were clicked into an elastic head cap for 64 electrodes. There were two reference electrodes on the head cap, the CMS (common mode sense) and DRL (driven right leg) electrodes. Four external electrodes were used to measure vertical electro-oculogram (VEOG) and horizontal electro-oculogram (HEOG) and were placed above and below the left eye (VEOG) and at the outer canthi of both eyes (HEOG). Two external electrodes were used for recording reference activity. These were placed on the left and right earlobes. All signals were digitized with a sampling rate of 500 Hz and 24-bit A/D conversion, and were filtered off-line.

During off-line processing, not more than two bad channels per subject were removed from the EEG signal. Because the earlobe references failed to record a useful signal, an average signal reference was applied. The data were filtered using a low cutoff of 1 Hz and high cutoff of 30 Hz (24 dB/octave slope). Data were segmented in epochs from 100 ms pre-stimulus to 2000 ms post-stimulus. HEOG and VEOG artifacts were corrected using the Gratton & Coles algorithm (Gratton, Coles, & Donchin, 1983). The mean 100 ms pre-stimulus period served as baseline. Artifact rejection was done semi-automatically. The criteria were a maximum allowed voltage step (gradient) of 50 μV, minimum and maximum allowed amplitude -200 to +200 μV and lowest allowed activity per interval of 100 ms was 0.10 μV. For subject data with more than 30 artifacts minimum and maximum allowed amplitude of -100 to +100 μV was used. Finally, epochs were averaged according to picture valence (unpleasant, neutral, pleasant).

Statistical analyses

The ERP waveforms were quantified by mean amplitude measures in two time windows: 200-400 ms, and 400-600 ms. The selection of these time windows was based on previous research and observation of the difference waves of the meditation and control group. The following electrode channels were selected for further analysis: AF7, AF8, Fpz, F3, F4, Fz, C3, C4, Cz, P7, P8, Pz, PO7, PO8, and Oz. The mean amplitudes in the selected time windows and electrode channels were examined with a repeated measures analysis of variance (RM-ANOVA) or repeated measures multivariate analysis of variance (RM-MANOVA), including three within-subject factors and one between-subject factor. The within-subject factors were: Caudality (prefrontal, including AF and Fp channels; frontal, including all F channels; central, including all C channels; parietal, including all P channels; parietooccipital, including PO and O channels), Laterality (left, including all uneven channels; midline, including all z channels; right, including all even channels) and Valence (unpleasant, neutral, pleasant). The between-subject factor was Group (meditation, control).

The assumption of sphericity was tested for each within-subject factor with Mauchly's Test of Sphericity. Significance and epsilon values (ε) were taken into account. If sphericity was assumed ($p > .05$, $\varepsilon > 0.90$) the RM-ANOVA was used for testing significance. If sphericity was not assumed ($p < .05$) either the Greenhouse-Geisser correction ($0.75 < \varepsilon < 0.90$) was applied or the RM-MANOVA was used ($\varepsilon < 0.75$). Significant interaction effects in the between-subject factor were further clarified with one-way ANOVAs, while significant interaction effects in the within-subject factors were clarified using contrast tests. Pearsons correlation was used to test the associations between the two scales of the PANAS and ERP means of the two groups. For all statistical analyses, a significance level of 0.05 (two-tailed) was selected.

Results

PANAS

Mean score ± SD on PA in the meditation group was 36.3 ± 3.9 and in the control group 36.7 ± 3.8. A one-way ANOVA yielded no significant difference between the groups on PA score. Mean score ± SD on NA in the meditation group was 16.9 ± 6.3 and in the control group 18.0 ± 5.9. No significant differences between the groups were found on NA score.

Time window 200-400 ms

RM-ANOVA yielded a significant main effect for Group, $F(1,46) = 4.64$, $p < .05$, with the meditation group having an overall higher mean positive amplitude than the control group. A significant main effect for Caudality, $F(4,43) = 47.23$, $p < .001$, $\varepsilon = 0.320$ was observed. Prefrontal, frontal and central areas demonstrated negative mean amplitudes, while parietal and parietooccipital areas showed more positive mean amplitudes. In addition to the Group effect and Caudality effect, a significant interaction effect was found for Caudality × Group, $F(4,43) = 2.62$, $p < .05$. One-way ANOVAs regarding the Caudality × Group effect yielded group differences at central and parietooccipital sites, but not at the other sites. At the central site, the meditation group demonstrated higher mean negative amplitudes than the control group. In the parietooccipital area the meditation group showed higher positive amplitudes than the control group. The difference waves for the control group and meditation group at the Cz and Oz electrode site are displayed in Fig. 1A and B. The topographical distribution of the difference between the groups is depicted in Fig. 2.

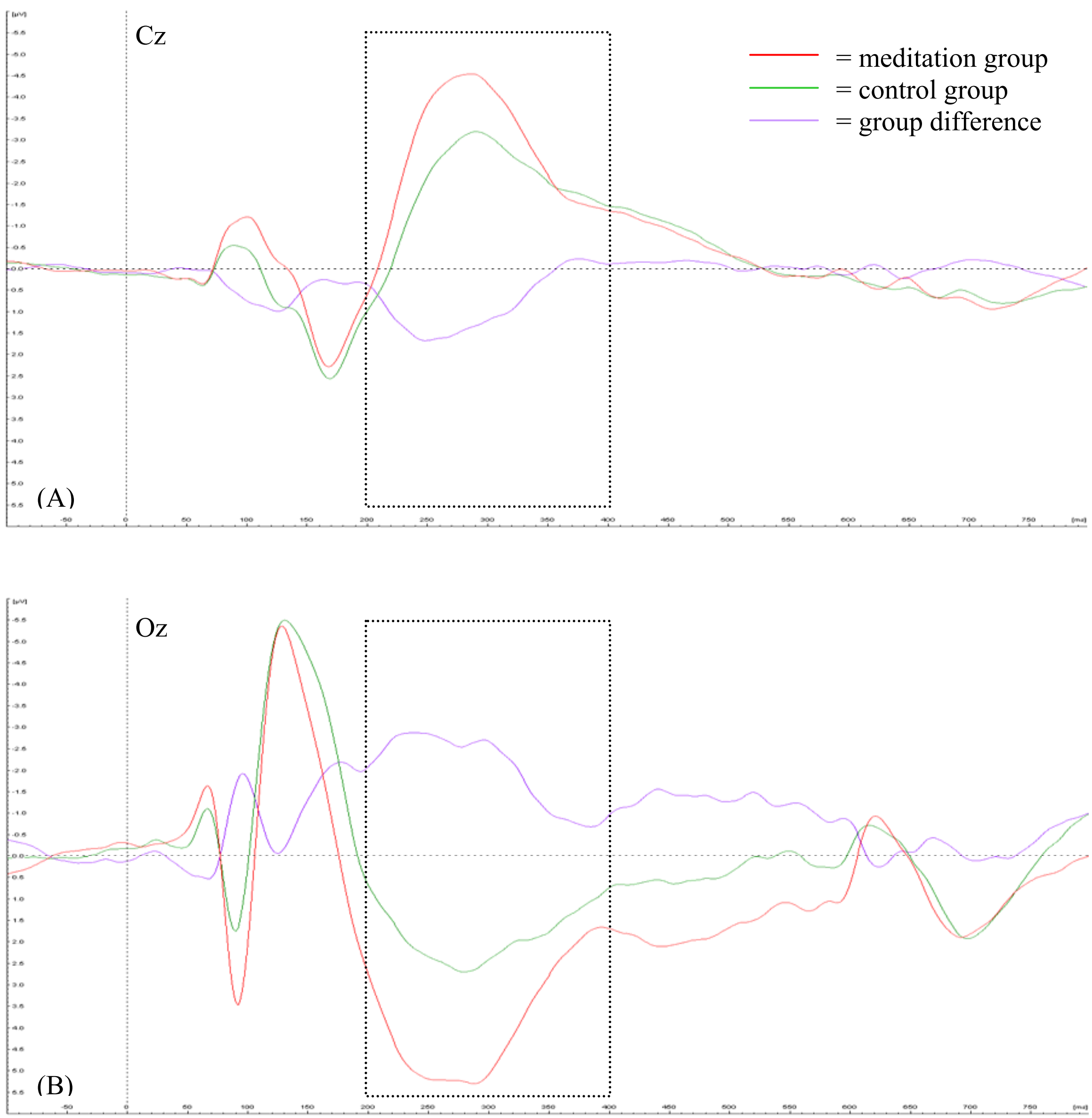


Fig. 1. Difference ERP waves of the meditation and control group from Cz (A) and Oz (B).

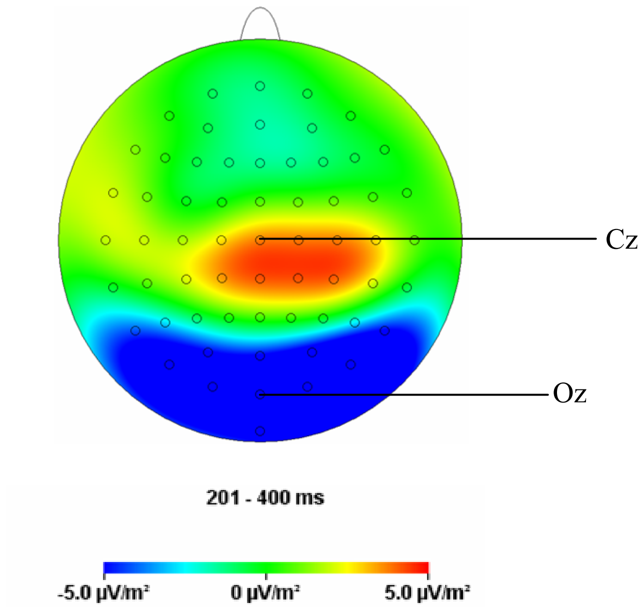
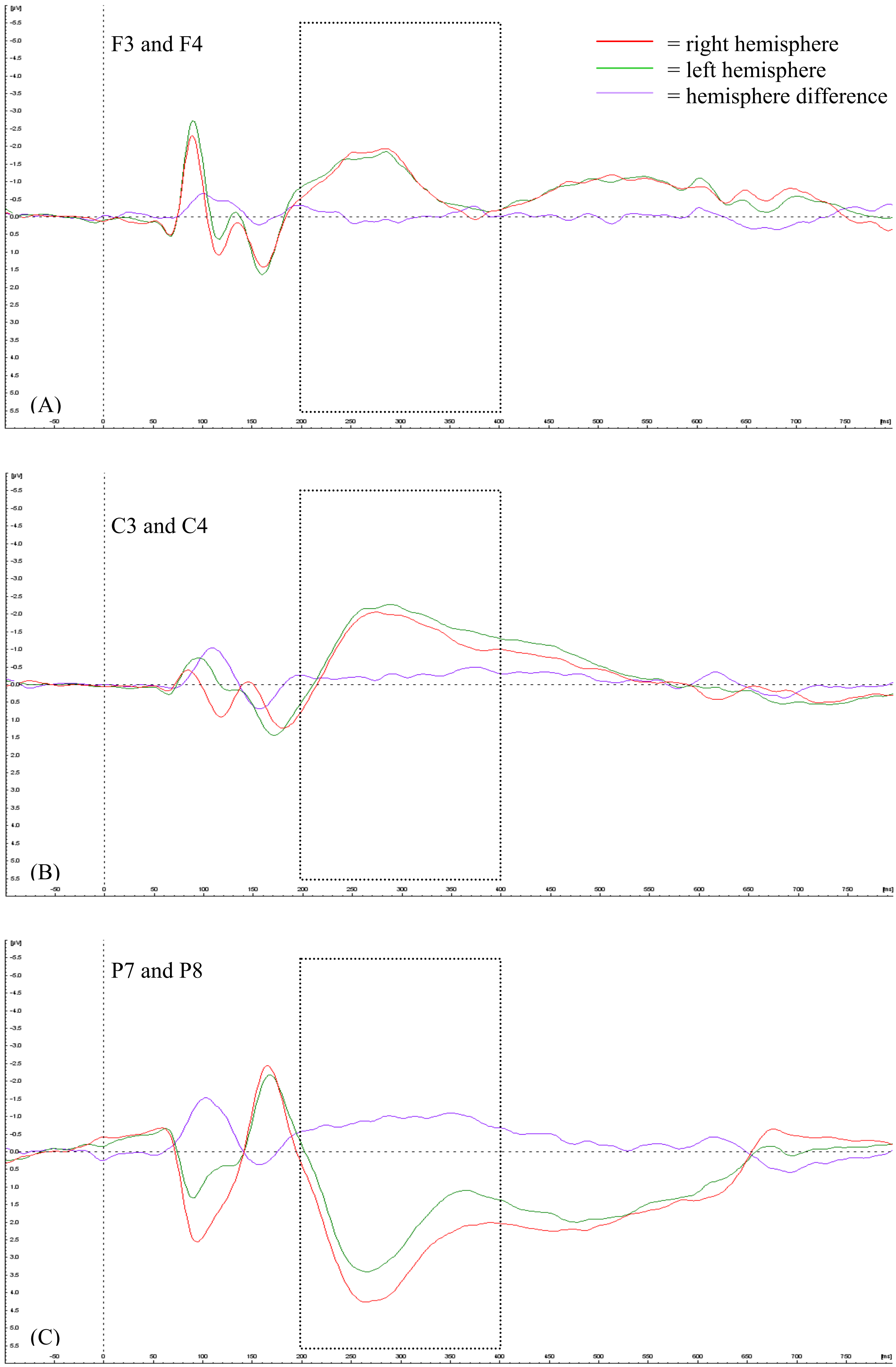


Fig. 2. Scalp distribution of the difference between ERPs of the meditation and control group in the 200-400 ms time window.

A significant main effect for Laterality, $F(2,92) = 50.83$, $p < .001$, $\varepsilon = 0.437$ was also found, showing more positive amplitudes in the left and right hemisphere and more negative amplitudes at the midline. In addition a significant Caudality × Laterality effect, $F(8,39) = 11.95$, $p < .001$, $\varepsilon = 0.539$ was found. A RM-ANOVA regarding the Caudality × Laterality effect yielded significant differences in laterality in frontal $F(2,94) = 28.83$, $p < .001$, $\varepsilon = 0.944$, central $F(2,94) = 28.69$, $p < .001$, $\varepsilon = 0.992$, parietal $F(2,94) = 49.94$, $p < .001$, $\varepsilon = 0.970$, and parietooccipital $F(2,94) = 33.78$, $p < .001$, $\varepsilon = 0.931$ areas, but not in the prefrontal area. Contrasts test demonstrated a significant difference between the left and the right hemisphere at parietal ($p < .001$) and parietooccipital ($p < .05$) areas, with the right hemisphere showing greater amplitudes than the left hemisphere. At these locations, the midline differed from both hemispheres ($p < .001$). In frontal and central areas, the left hemisphere was not significantly different from the right hemisphere, but the midline did differ significantly from the left as well as the right hemisphere, both $p < .001$. The difference between amplitudes in the left and right hemisphere for frontal, central, parietal and parietooccipital areas are displayed in Fig. 3.


F3 and F4
= right hemisphere
= left hemisphere
= hemisphere difference
(A)
C3 and C4
(B)
P7 and P8
(C)

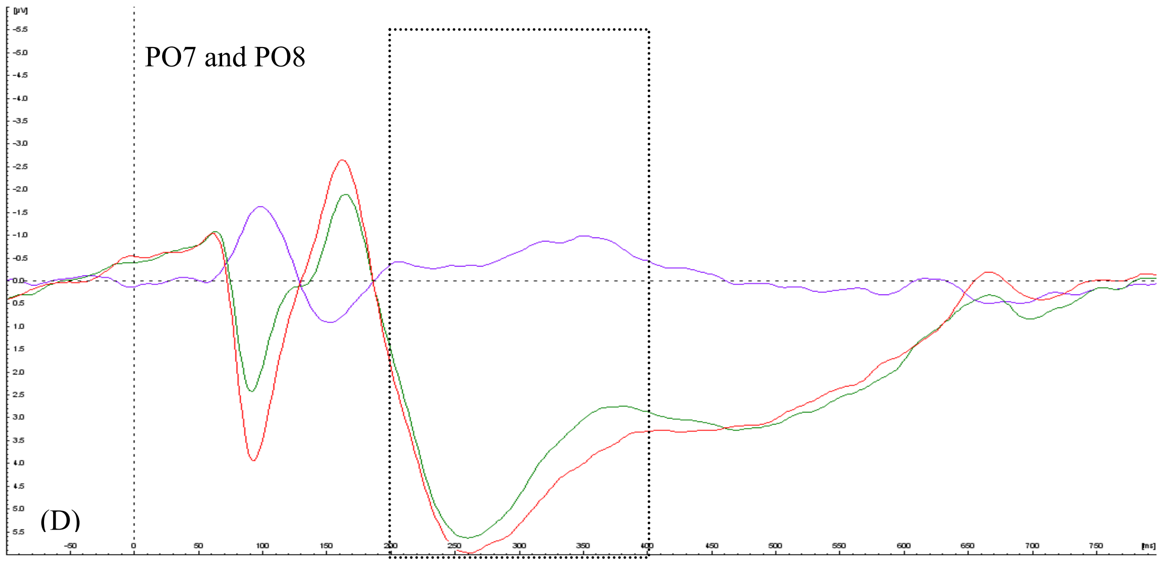


Fig. 3. Difference ERP waves of the left and right hemisphere at frontal (A), central (B), parietal (C) and parietooccipital (D) sites, averaged over both groups.

Finally, a Caudality × Valence effect was found, $F(8,39) = 3.26$, $p < .01$, $\varepsilon = 0.412$. Contrasts test showed a significant difference between response to pleasant and unpleasant pictures at frontal ($p < .01$), central ($p < .01$), parietal ($p < .001$) and parietooccipital ($p < .001$) sites, but not at the prefrontal site. Response to neutral pictures had no significant difference with both pleasant and unpleasant pictures responses at frontal and parietal sites, but responses to neutral pictures did differ significant from responses to unpleasant pictures at central ($p < .05$) and parietooccipital ($p < .05$) sites. In all cases, responses to unpleasant pictures elicited highest mean amplitudes, neutral picture responses elicited medium mean amplitudes, and pleasant pictures responses elicited lowest mean amplitudes. The ERP amplitudes of the pictures at electrode Fz are depicted in Fig. 4.

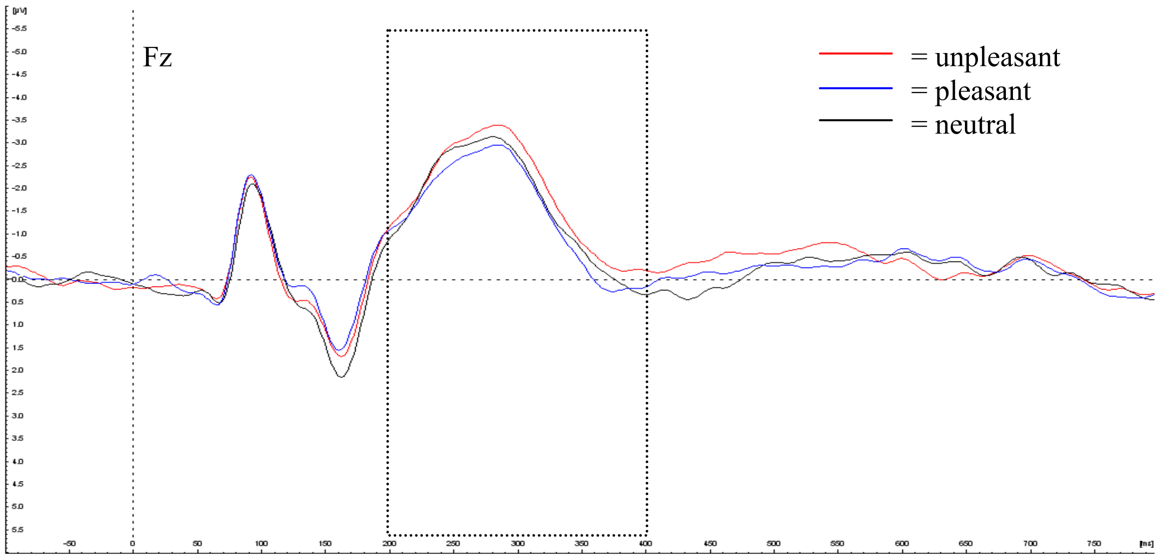


Fig. 4. Grand average ERPs from Fz of unpleasant, pleasant and neutral pictures, averaged over both groups.

Time window 400-600 ms

A significant main effect occurred for Caudality, $F(4,43) = 61.39$, $p < .001$, $\varepsilon = 0.354$. In addition, a significant three-way interaction for Caudality × Valence × Group, $F(8,39) = 2.24$, $p < .05$ was found. At the between-group level, one-way ANOVAs regarding the three-way interaction demonstrated a significant difference between the two groups only at the prefrontal site in response to neutral pictures. At this site the meditation group had stronger negative amplitudes in response to the neutral pictures than the control group. The prefrontal difference between the groups is depicted in Fig. 5A. Fig. 5B displays the difference waves for the control group and meditation group in response to neutral pictures at the Fpz electrode site. At the within-group level, contrast tests regarding the Caudality × Valence effect per group yielded that the control group had no significant differences in valence at any caudality, while the meditation group did show significant differences at the central site ($p < .001$) and parietooccipital ($p < .001$). At the central site, the meditation group showed a significant difference between unpleasant and pleasant pictures responses ($p < .001$), and between unpleasant and neutral pictures responses ($p < .001$), with response to unpleasant pictures eliciting greater negative amplitudes than response to pleasant and neutral pictures. Responses to the pleasant and neutral pictures were not significantly different from each other.

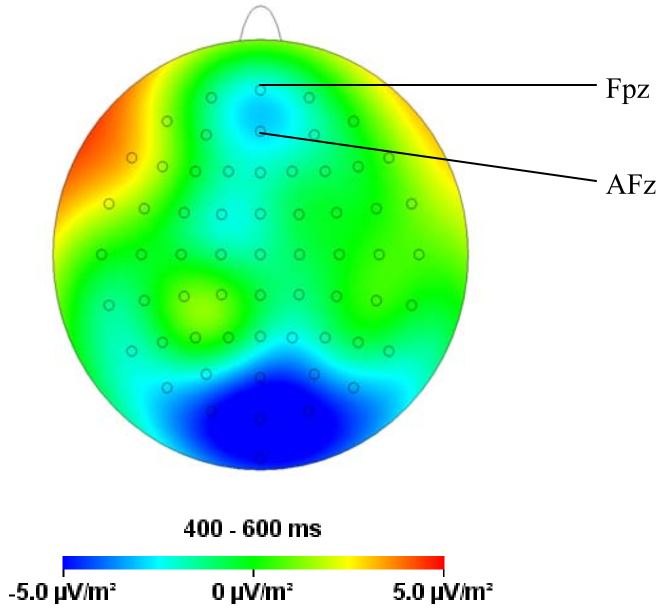


Fig. 5A. Scalp distribution of the difference between ERPs of the meditation and control group in response to neutral pictures for the 400-600 ms time window.

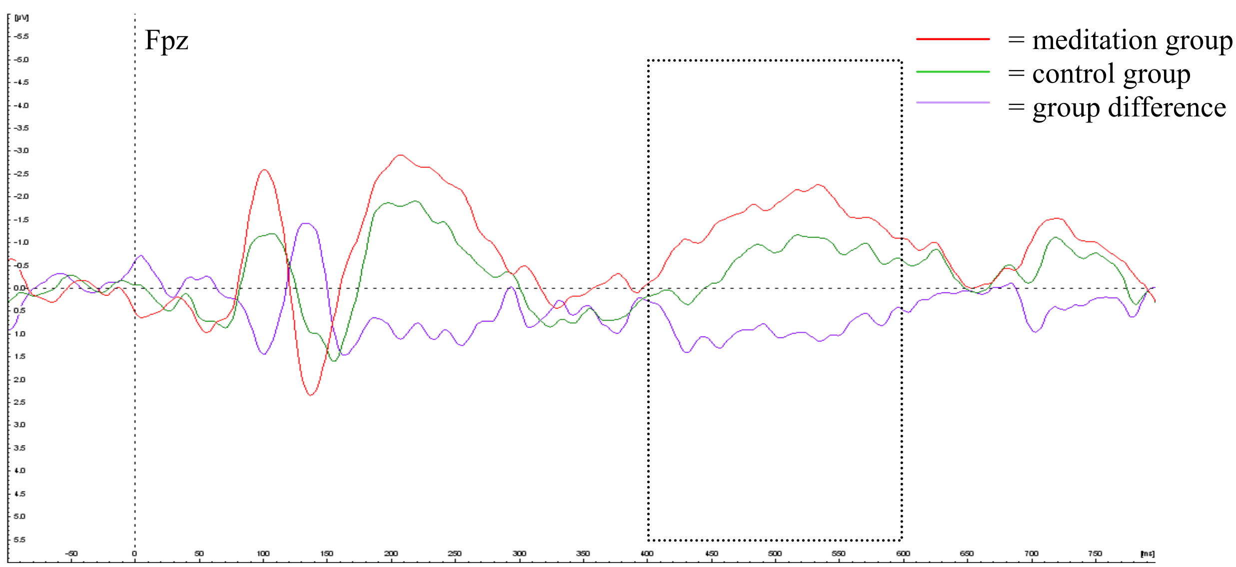


Fig. 5B. Difference ERP waves of the meditation and control group in response to neutral pictures from Fpz.

Fig. 6 illustrates ERP response differences between the pictures at electrode C3 for the meditation group and the control group. At the parietooccipital site, the meditation group showed a significant difference between response to unpleasant and pleasant pictures ($p < .05$), and between response to unpleasant and neutral pictures ($p < .001$), with unpleasant picture responses eliciting greater positive amplitudes than pleasant and neutral picture responses. Responses to the pleasant and the neutral pictures were not significantly different from each other.

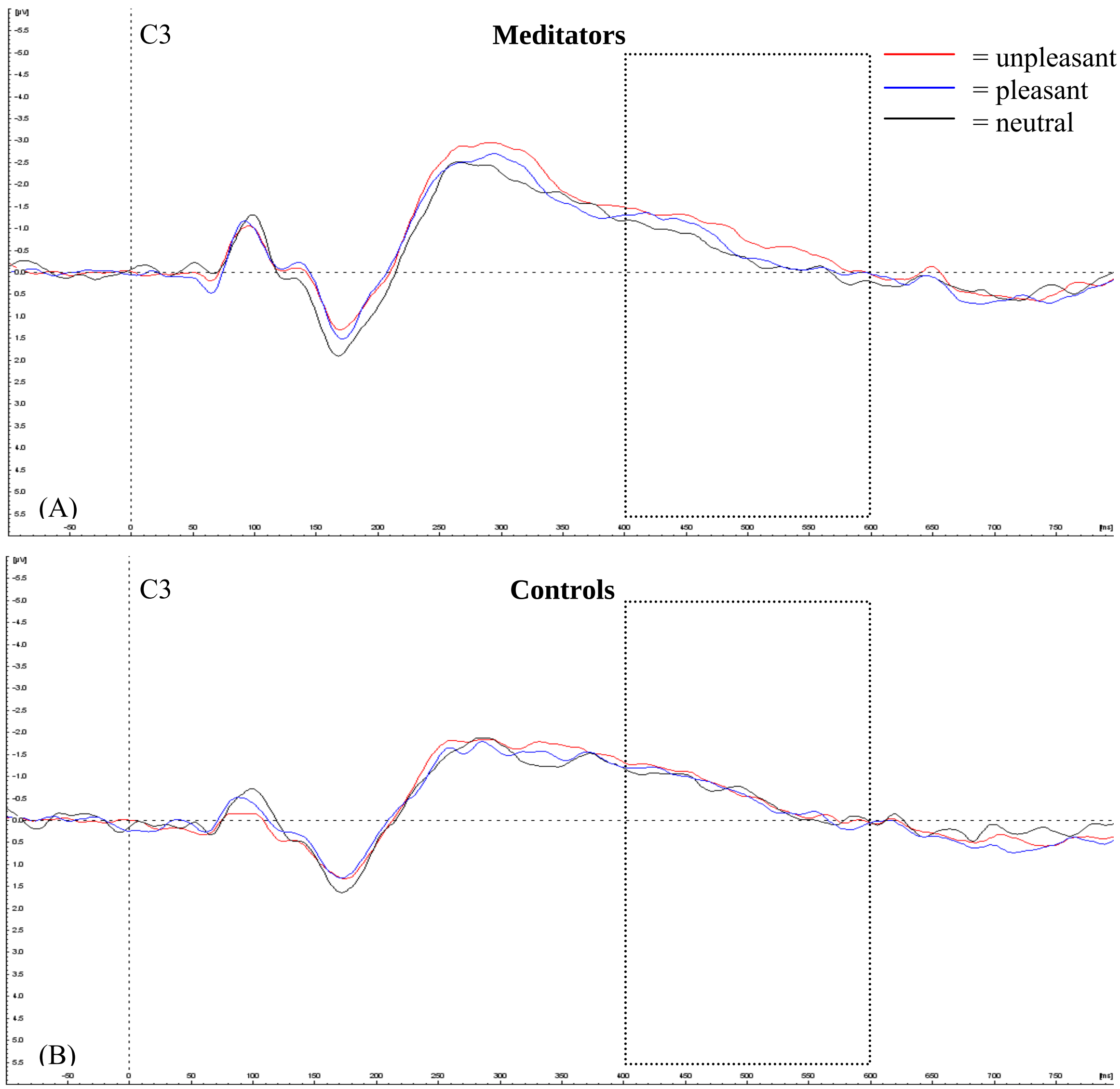


Fig. 6. Grand average ERPs from C3 of unpleasant, pleasant and neutral pictures in the meditation (A) and control (B) group.

A significant main effect for Laterality, $F(2,92) = 6.12$, $p < .01$, ε = 0.981, was found. In addition to the Laterality effect, a significant Caudality × Laterality effect, $F(8,39) = 32.73$, $p < .001$, ε = 0.623 showed differences in laterality at prefrontal $F(2,94) = 28.74$, $p < .001$, ε = 0.932, frontal $F(2,94) = 16.67$, $p < .001$, ε = 0.904, parietal $F(2,94) = 14.25$, $p < .001$, ε = 0.868, and parietooccipital $F(2,94) = 75.34$, $p < .001$, ε = 0.990, locations. Contrast tests yielded no significant differences between the left and right hemisphere at any location, but the midline was significantly different from the left and the right hemisphere at all locations ($p < .01$). The midline showed lower amplitudes than the left and right hemisphere.

An interaction effect for Caudality × Valence, $F(8,39) = 4.99$, $p < .001$, ε = 0.440 was found at frontal $F(2,94) = 3.83$, $p < .05$, ε = 0.988, central $F(2,94) = 7.97$, $p < .001$, ε = 0.928, and parietooccipital $F(2,94) = 10.05$, $p < .001$, ε = 0.819, sites. At all three sites, responses to pleasant and neutral pictures both were significantly different from responses to unpleasant pictures (both $p < .05$). There was no significant difference between responses to pleasant and neutral pictures. At the frontal and central site, responses to the unpleasant pictures elicited greater negative amplitudes than responses to the pleasant and neutral pictures, and at the parietooccipital site responses to unpleasant pictures reflected higher positive amplitudes than responses to pleasant and neutral pictures. The ERP grand averages are comparable with the grand averages depicted in Fig. 6A.

Finally, a trend was found for the Laterality × Group interaction, $F(2,92) = 2.38$, $p < .10$. Between-group differences were tested with a one-way ANOVA. This yielded a significant difference between the groups at the midline location $F(1,46) = 7.47$, $p < .01$, but not in the left or right hemisphere. Within-group differences were tested with a RM-ANOVA. A significant laterality difference was found in the control group $F(2,46) = 7.94$, $p < .001$, but not in the meditation group. In the control group, the midline differed significant from both left and right hemisphere ($p < .01$), but there was no significant difference between the left and right hemisphere. The midline showed more negative amplitudes, while the left and right hemisphere showed more positive amplitudes.

Correlation PANAS and ERP means

Table 2 and 3 show the significant correlations ERP means for pleasant, unpleasant and neutral pictures and scores on the PA and NA scale, respectively. In the meditation group, PA scores were negatively correlated with ERP mean amplitude at the right central site (C4) during processing of unpleasant and neutral pictures, and positively correlated with ERP amplitude at the left parietal site (P7) during pleasant picture processing. In the control group, PA scores were positively correlated with ERP means at left and central frontal sites (F3 and Fz) during processing of unpleasant pictures.

Correlations between NA score and ERP means in the control group were found at middle frontal and central sites (Fz and Cz), showing positive correlations during pleasant, unpleasant, and neutral picture processing, and at the left parietal site (P7) showing negative correlations during unpleasant picture processing. In the meditation group, positive correlations between NA score and ERP means were found at right prefrontal and all frontal sites (AF8, F3, Fz, F4), and negative correlations were found at left parietal and parietooccipital sites (P7 and PO7) during pleasant, unpleasant, and neutral picture processing. Negative correlations were also found at middle parietal and occipital sites (Pz and Oz) during unpleasant picture processing.

Table 2

Significant correlation coefficients between PA score and ERP mean responses for pleasant, unpleasant, and neutral pictures of the meditation and control group

		Meditators			Controls		
		Pleasant	Unpleasant	Neutral	Pleasant	Unpleasant	Neutral
Left	AF7	-	-	-	-	-	-
	F3	-	-	-	-	0.412*	-
	C3	-	-	-	-	-	-
	P7	0.457*	-	-	-	-	-
	PO7	-	-	-	-	-	-
Middle	Fpz	-	-	-	-	-	-
	Fz	-	-	-	-	0.424*	-
	Cz	-	-	-	-	-	-
	Pz	-	-	-	-	-	-
	Oz	-	-	-	-	-	-
Right	AF8	-	-	-	-	-	-
	F4	-	-	-	-	-	-
	C4	-	-0.435*	-0.433*	-	-	-
	P8	-	-	-	-	-	-
	PO8	-	-	-	-	-	-

* $p < 0.05$.

** $p < 0.01$.

Table 3

Significant correlation coefficients between NA score and ERP mean responses for pleasant, unpleasant, and neutral pictures of the meditation and control group

		Meditators			Controls		
		Pleasant	Unpleasant	Neutral	Pleasant	Unpleasant	Neutral
Left	AF7	-	-	-	-	-	-
	F3	0.425*	0.429*	0.430*	-	-	-
	C3	-	-	-	-	-	-
	P7	-0.495*	-0.476*	-0.429*	-	-0.426*	-
	PO7	-0.580**	-0.497*	-0.426*	-	-	-
Middle	Fpz	-	-	-	-	-	-
	Fz	0.460*	0.597**	0.454*	0.442*	0.444*	0.480*
	Cz	-	-	-	0.427*	0.446*	-
	Pz	-	-0.508*	-	-	-	-
	Oz	-	-0.497*	-	-	-	-
Right	AF8	-	0.538**	0.454*	-	-	-
	F4	0.542**	0.613**	0.423*	-	-	-
	C4	-	-	-	-	-	-
	P8	-	-	-	-	-	-
	PO8	-	-	-	-	-	-

* $p < 0.05$.

** $p < 0.01$.

Discussion

In the present study, the ERPs in response to affective pictures of long term SK meditators were compared to the ERP responses of non-experienced controls. EEG data was processed into ERP waveforms and based on observation and previous research, two time windows were selected for further analysis. The early time window (200-400 ms) was selected because of previous studies that examined the effects of meditation and yoga practice on the P300 component (Bhatia et al., 2003; Naga Venkatesha Murthy et al., 1998; Banquet & Lesévre, 1980). The later time window (400-600 ms) was selected because previous IAPS studies have shown significant ERP differences on picture valence at 200 to 800 ms after stimulus onset, but not in later time windows (Dolcos & Cabeza, 2002; Amrhein et al., 2004).

Contrary to the expectations, no significant left hemisphere differences in emotional processing were found between the groups. However, in the early time window (200-400 ms) a significant difference between the two groups was found, demonstrating a stronger ERP response to pictures in the meditation group compared to the control group, regardless of picture valence. In addition, a significant Caudality × Group interaction showed that this difference between the groups occurred specifically at central and parietooccipital locations, and not at other locations. It is possible that the increased ERP amplitude in response to pictures (but not valence) found in the meditators versus controls, reflect increased attention rather than a difference in emotional processing and that attention is more pronounced in central and parietooccipital brain areas.

Support for these findings comes from studies that showed increased focus of attention in meditators and increased brain activity at posterior brain regions. In a study with TM practitioners, group differences were also found at the central site in the CNV component, an ERP component associated with attention and stimulus expectancy (Travis et al., 2000). CNV is a slow negative waveform that is elicited when stimulus sequences are presented where a probe stimulus indicates the presentation of a certain target (Stadler et al., 2006). In the study by Travis et al. (2000), long term meditators were compared to short term meditators and controls in their response to a stimulus sequence task. During a simple stimulus sequence task, long term meditators showed higher CNV mean amplitude than short term meditators and controls, and this difference was more pronounced at the midline central site. Also, ERP responses on a divided-attention-task revealed that long term meditators were less distracted during the task than short term meditators and controls. Travis et al. (2000) suggest that long term meditation practice is associated with reduced distraction and increased attentional focus and that this is reflected specifically in the central brain area. Increased selective attention in meditators was also found in a study by Banquet and Lesévre (1980), as described in Cahn & Polich (2006), where meditators showed increased P300 amplitude compared to controls in response to a visual oddball task. Recent research has suggested that P300 reflects attentional processing of a target, and that increased P300 amplitude is related to increased task difficulties, where more focus of attention is required (Polich, in press). Group differences at central and occipital brain regions were also found in EEG frequency studies. These studies found increased frequency power in meditators when compared to controls at central (Davidson et al., 2003; Takahashi et al., 2005) and occipital locations (Bhatia et al., 2003). Although it is difficult to compare the results of EEG frequency studies to the ERP results of the present study, both show differences at posterior brain regions, especially central regions, which may indicate that the influence of long term meditation practice is mostly reflected in these brain regions.

Two other interaction effects were found in the early time window: Caudality × Valence and Caudality × Laterality. Regarding the Caudality × Valence effect, a difference between unpleasant and pleasant pictures responses was found at frontal, central, parietal and parietooccipital locations, with unpleasant pictures eliciting stronger ERP amplitudes than pleasant pictures. ERPs in response to neutral pictures were not different from the affective pictures at frontal and parietal sites. However, at central and parietooccipital regions the neutral pictures elicited lower ERP amplitudes than the unpleasant pictures and similar amplitudes as the pleasant pictures. The present study failed to find any differential activation due to stimulus valence in prefrontal areas.

Surprisingly, these present findings suggest that frontal to occipital brain areas are more involved in valence discrimination (distinguishing pleasant from unpleasant pictures) than prefrontal brain areas. This is somewhat different from previous findings of emotion studies using the IAPS task. Dolcos and Cabeza (2002) have found valence differences at frontocentral locations, but not at parietal locations. At parietal locations, the IAPS pictures were distinguished at the arousal level (distinguishing affective pictures from neutral pictures), but not at the valence level, whereas in the present study valence effects, but not arousal effects were found in parietal and parietooccipital regions. The differences between the findings of Dolcos and Cabeza (2002) and the present study, may be due to the fact that they found emotional effects in a later time window, 500 to 800 ms after stimulus onset, while the present results are found in the 200-400 ms time window.

Several IAPS studies have found an arousal effect in ERP responses, where response to affective pictures elicited greater amplitudes than response to neutral pictures (Amrhein et al., 2004; Olofsson & Polich, 2007). In contrast to these studies, the present results have not shown differences in responses to pleasant (affective) and neutral pictures. Amrhein et al. (2004) have also found that in the 200-300 ms time window, pleasant picture processing elicited greater amplitudes than unpleasant picture processing, increasing from frontal over central to parietal sites. In contrast, the present results show that unpleasant pictures elicited greater amplitudes than pleasant and neutral pictures, at frontal to occipital regions. Support for the findings in the present study comes from studies regarding the negativity bias. According to the negativity bias, people are more sensitive to emotionally negative information than positive information. The negativity bias was found in IAPS studies that have examined the late positive potential (LPP), an ERP component often found in the 300 to 900 ms time window. At the LPP component, amplitudes were larger for unpleasant pictures than for pleasant pictures (Ito, Larsen, Smith, & Cacioppo, 1998; Huang & Luo, 2006). The present results have found a negativity bias at an earlier component, 200 to 400 ms after stimulus onset. It is possible that an attentional bias towards negative information occurs very early in affective picture processing. It has to be noted that the three stimulus types (pleasant, unpleasant, neutral) used in the present study were not controlled for potential differences in arousal. It is therefore possible that the negativity bias was found due to differences in arousal.

For the Caudality × Laterality effect, it was found that at frontal and central sites, the left and right hemisphere had no difference in ERP amplitude, but the midline showed significant greater negative amplitudes than both hemispheres, indicating more brain activity at midline locations. At parietal and parietooccipital sites the right hemisphere showed high activation, the left hemisphere medium activation, and the midline low activation, when compared to each other. These results indicate that hemispheric activity is lower than midline brain activity at frontal and central regions, but increases at parietal and occipital regions. This is inconsistent with the cerebral asymmetry findings in the study of Davidson et al. (1990). In that study hemispheric differences were found at frontal and anterior temporal regions, but not at central and parietal locations. However, in the study by Davidson et al. (1990), the hemispheric differences were related to approach and withdrawal stimuli, whereas the present study failed to find a cerebral asymmetry effect due to stimulus valence. Also, it has to be noted that Davidson et al. (1990) used emotion-arousing films as affective stimuli, whereas the present study used IAPS pictures as affective stimuli. Due to the difference in test stimuli the results of these studies are difficult to compare.

In the later time window (400-600 ms) no main group differences were found. However, a significant three-way interaction effect for Caudality × Valence × Group showed that at the prefrontal sites, the meditation group had greater negative amplitudes in response to neutral pictures than the control group. Within the groups, the control groups showed no differences at any location in response to affective pictures, but in the meditation group response to unpleasant pictures elicited higher amplitudes than response to pleasant and neutral pictures at central and parietooccipital locations, but not at other locations.

It was expected that the meditation group would show more left hemisphere activity in response to positive stimuli, indicating higher response to approach related emotions in meditators. This expectation was not supported by the present findings. However, the between group analysis showed that the meditators had higher ERP responses to neutral pictures at the prefrontal location, compared to the controls. This result can be explained by putting the picture valences in an approach-withdrawal context (Davidson et al., 1990), in a sense that both neutral and pleasant pictures might be associated with approach and unpleasant pictures with withdrawal. Taking this perspective, it is possible that meditators, but not controls, regard neutral pictures as approachable situations.

A problem with this suggestion is that in the IAPS task, only the pleasant and unpleasant pictures are regarded as emotional stimuli, and the neutral pictures are used as control stimuli (Lang et al., 2005). However, the affective ratings of IAPS pictures are based on subjective ratings, and differences between the ratings of men and women have been found (Lang et al., 2005). It is possible that meditators would also show different ratings on IAPS pictures than controls, but these ratings were not obtained in the present study. Another problem with interpreting the results is the significant Caudality × Valence effect, which showed no valence effect at the prefrontal site, but only at the frontal, central and parietooccipital sites, whereas the three-way interaction was found at the prefrontal site. Furthermore, the significant Caudality × Valence × Group interaction needs to be interpreted with caution. Due to the low epsilon values for sphericity the interaction was tested with the RM-MANOVA, but with the RM-ANOVA the three-way interaction was not significant.

The Caudality × Valence interaction yielded somewhat similar results as in the earlier time window, with responses to unpleasant pictures eliciting greater amplitudes than pleasant and neutral pictures at frontal, central, and parietooccipital sites. Again, a negativity bias was found, also in the later time window. The negativity bias was found in the 200-600 ms time window, but in contrast with other studies that have found a negativity bias in the LPP (Ito et al., 1998; Huang & Luo, 2006), the ERP amplitudes in response to unpleasant pictures in this study were negative at the frontal and central sites, and positive at parietooccipital sites.

A significant Caudality × Laterality effect was found and both hemispheres showed more activity than the midline in prefrontal, frontal, parietal and parietooccipital areas. Thus, increased hemispheric activity is found in the later time window almost throughout the whole scalp, whereas in the earlier time window increased hemispheric activity was only found in parietal and parietooccipital areas. Regarding temporal distribution, it is suggested that hemispheric differences can be found in later components during cognitive processing, but that in earlier components the midline brain areas are more involved.

Finally, a trend was found for the Laterality × Group effect, indicating that the groups only differed at the midline location, but not at the left and right hemisphere. Taken from the baseline, the meditation group showed greater amplitudes than the controls, indicating more brain activity at the midline location in meditators than in controls. Aftanas and Golocheikine (2001) found that in meditators theta activity at frontal midline locations is associated with emotionally positive feelings of bliss and internalized attention. Within the groups, the meditators showed no laterality differences. The control group showed less activation in the midline than in both hemispheres. Support for these findings comes from the Aftanas & Golocheikine (2005) study, where laterality differences were found in the control group, but not in the meditation group, during rest EEG recording. It was suggested that meditators are better at regulating emotional arousal and are less distracted by the 'inner dialogue' reflected by laterality differences. However, as noted earlier it is difficult to compare EEG frequency studies with ERP research as performed in the present study.

In the present study, subjects' PANAS scores were also assessed. No group differences were found on PANAS scores. Correlation analysis between the two scales of the PANAS (PA and NA) and ERP mean amplitudes yielded significant correlations.

The PA scale of the PANAS measures enthusiasm and alertness (positive affect) and high scores on this scale reflect high energy and concentration (Watson et al., 1988). In the control group, PA score was positively correlated with ERP responses to unpleasant pictures at left and middle frontal areas. In the meditation group, a positive correlation was found between PA score and ERP responses to pleasant pictures at the left parietal site and negative correlations in response to unpleasant and neutral pictures at the right central site.

Subjects' score on the NA scale showed more significant correlations with ERP means than PA score. The NA scale measures subjective pain and unpleasantness (negative affect) (Watson et al., 1988). In the meditation group, positive correlations between NA score and ERP responses to pleasant, unpleasant and neutral pictures were found at right prefrontal and left, right and central frontal areas. Negative correlations were found at left and central parietal, left parietooccipital and central occipital areas. Similar results were found in the control group, but only at central frontal, central and left parietal sites.

Interestingly, the meditation group showed correlations at left, middle and right brain areas, while the control group showed correlations at left and middle brain areas, but not right brain areas. From the present study it is difficult to draw conclusions about the association between subjects' PANAS scores and cognitive functioning. The correlation results show that subjective responses on positive and negative affect can possibly be associated with cognitive responses to affective stimuli.

Takahashi et al. (2005) have also examined the correlation between questionnaire measures of personality traits and EEG power of novice Zen meditators. They found that novelty seeking and harm avoidance traits were positively correlated to left and right frontal and central alpha and theta power and that these traits are beneficial for experiencing positive mental and physical changes during meditation. Aftanas and Golocheikine (2001) found that intensity of blissful experience was positively correlated with theta power in anterior frontal and frontal midline areas, while thought appearance was negatively correlated with theta power in anterior frontal, frontal midline, central frontal, and right central regions.

In conclusion, limited differences between the meditation group and control group were found. In the early time window, the meditation group experienced more brain activity than the control group, specifically at central and parietooccipital brain areas, but this difference was found regardless of emotional processing. This indicates that meditation practice has an effect on brain responses to cognitive stimuli, but not on emotional processing. In the later time window, group differences were found in response to neutral stimuli at prefrontal brain areas. Valence effects were found in both groups, indicating that the IAPS task is useful for measuring affective processing. In both groups, an attentional negativity bias was found in the early and later time window, suggesting that negative information produces more brain activity. No group differences in subjective measures of positive and negative affect were obtained, but positive and negative affect did correlate with brainwaves differently in both groups, indicating that subjective reports are associated with brain responses to affective stimuli.

Further research in meditation effects is important to asses the potential clinical utility of meditation practice. Future studies should examine the longitudinal effects of meditation, for example by providing meditation training to inexperienced subjects and measuring the mental and physical changes by means of questionnaires and physiological assessments. When studying emotional processing in meditators with IAPS, the stimuli should be controlled for differences in arousal. Also, differences in brain functioning and spatial distribution could be measured more accurately with other neuroimaging techniques than EEG, such as PET or fMRI.

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APPENDIX

Numbers of the IAPS pictures used:

Pleasant: 1450, 1460, 1510, 1601, 1610, 1670, 1710, 1750, 1920, 2030, 2050, 2070, 2170, 2260, 2341, 2370, 2500, 2501, 2540, 2620, 4002, 4005, 4150, 4220, 4520, 4250, 4531, 4532, 4533, 4572, 4599, 4608, 4641, 4660, 5000, 5010, 5200, 5250, 5270, 5390, 5410, 5594, 5621, 5623, 5626, 5629, 5700, 5720, 5750, 5760, 5780, 5800, 5830, 5831, 5870, 5910, 7200, 7325, 7330, 7340, 7502, 7900, 8030, 8130, 8161, 8170, 8190, 8200, 8210, 8300, 8320, 8370, 8400, 8470, 8497, 8500, 8501, 8510

Unpleasant: 1040, 1050, 1090, 1220, 1300, 1302, 1310, 1390, 1931, 2205, 2206, 2221, 2490, 2520, 2590, 2682, 2691, 2700, 2722, 2750, 2752, 2753, 2900, 3010, 3071, 3170, 3210, 3250, 3500, 3530, 3550, 5130, 5940, 6010, 6200, 6212, 6300, 6312, 6313, 6350, 6570, 7224, 7234, 7700, 8230, 8480, 9000, 9001, 9007, 9010, 9050, 9090, 9101, 9110, 9190, 9210, 9220, 9230, 9280, 9290, 9320, 9330, 9331, 9360, 9390, 9410, 9421, 9490, 9520, 9560, 9570, 9622, 9830, 9910.

For men: 1460, 1670, 1750, 2050, 2260, 2341, 2501, 2700, 2900, 3530, 4002, 4005, 4150, 4220, 4250, 6313, 6350, 8497, 8510, 9007, 9320, 9410, 9421, 9570
For women: 1310, 1390, 1450, 1931, 2030, 2221, 2500, 2620, 2682, 2752, 3210, 4520, 4531, 4532, 4533, 4572, 5130, 5250, 5390, 5410, 5940, 7234, 7330, 8320

Neutral: 2190, 2200, 2220, 2410, 2480, 2580, 2840, 2880, 5510, 5532, 5534, 5740, 6150, 7002, 7009, 7020, 7038, 7050, 7090, 7130, 7140, 7190, 7205, 7207, 7233, 7235, 7490, 7491, 7500, 7590, 9070, 9700.

Practice: 1275, 1740, 2165, 2751, 5030, 7170, 7180, 7360, 8041, 9300.

Initial: 1463, 1620, 2720, 6930, 7006, 7080, 7430, 9080.