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Impact of meditation on emotional processing—A visual ERP study

Aleksander Sobolewski[a,*], Ewa Holt[b], Ewa Kublik[a], Andrzej Wróbel[a]

[a] Nencki Institute of Experimental Biology (Polish Academy of Sciences), Department of Neurophysiology, 3 Pasteur St., 02-093 Warsaw, Poland
[b] Warsaw School of Social Psychology (SWPS), 19/31 Chodakowska St., 03-815 Warsaw, Poland

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ABSTRACT

Impact of meditation on emotional processing, and its clinical applications, has recently drawn significant interest. In this visual event-related potential (ERP) study we investigated whether long-term meditation practitioners exhibit different ERP responses to the emotional load of stimuli (IAPS pictures) than control subjects with no experience in meditation. Differences were observed in the late positive potential (LPP). LPP amplitude is typically greater in ERPs evoked by emotionally arousing scenes, specifically negative images, compared to neutral scenes. This effect was also replicated in our study, but not in case of meditators' frontal scalp regions, who differed significantly in this respect from control subjects. Our findings provide support for different emotional processing in meditation practitioners: at high levels of processing meditators are less affected by stimuli with adverse emotional load, while processing of positive stimuli remains unaltered. To further confirm this observation, a long-term longitudinal random assignment study would be desirable.

1. Introduction

Traditional practices commonly referred to as "meditation", present in various cultures, are alleged to lead to heightened awareness, more balanced emotional behavior and other health benefits. The practices take different forms, however common features include detached observation of one's introspective phenomena ("open monitoring" or "mindfulness" meditation) and focus on a simple object ("focused attention" or "concentrative" meditation; Lutz et al., 2008). Recently a distinct category of meditation – "automatic self-transcending" – has been proposed (Travis and Shear, 2010; Josipovic, 2010).

The putative advantages of meditation have drawn increased clinical and scientific interest, such that it recently merited extensive reviews (including one commissioned by the U.S. Department of Health and Human Services; Ospina et al., 2007). The findings corroborate some effects of meditation, but, while encouraging further investigation, also criticize the frequent low quality of original research, precluding firmer conclusions (Chiesa and Serretti, 2009; Ospina et al., 2007; Cahn and Polich, 2006).

Original studies that do support the effects of meditation have shown, for example, that the practice of meditation has influence on the immune, endocrine and autonomic system, e.g. it causes a decrease in respiration rate, heart rate and spontaneous skin conductance response (Dillbeck and Orme-Johnson, 1987; Infante et al., 2001; Davidson et al., 2003). Aftanas and Golosheykin (2005) suggested that meditators have better capabilities to moderate intensity of emotional arousal. They argued that greater desynchronization in EEG alpha band combined with gamma band synchronization over anterior cortical sites in non-meditating control subjects during watching an emotionally adverse movie clip represented heavier emotional workload on the controls than on meditators. Effects of meditation were reported to include increased theta/alpha band activity (e.g. Travis et al., 2002), while individuals exhibiting greater theta activity tended to have lower state and trait anxiety scores (Inanaga, 1998).

Impact of meditation on emotional processing has not, however, to our knowledge, been a subject of visual event-related potential (ERP) study, while visual ERPs have been consistently shown to reflect emotional processes triggered by the emotional load of the stimulus (scene, picture), and thus provide a good research tool of the human brain's emotional responses. Particularly, the so-called late positive potential (LPP, a sustained positive component of the ERP waveform starting ca. 400–500 ms post-stimulus) was shown to increase with the emotional potency carried by the stimuli (Codispoti et al., 2007; Olofsson and Polich, 2007; Hajcak and Olvet, 2008; for review see Olofsson et al., 2008). It was also sensitive to regulation of emotions and top-down modulation related to evaluation of the affective stimuli (Hajcak et al., 2006; Moser et al., 2006; Carretié et al., 2006), diminished LPP being associated with suppression of emotional reaction (Moser et al., 2006).

The goal of the present experiment was therefore to investigate how meditation influences visual ERPs evoked by emotionally arousing stimuli. Rather than transient alterations

* Corresponding author. Tel.: +48 22 589 23 64.
E-mail address: a.sobolewski@nencki.gov.pl (A. Sobolewski).

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appearing during actual meditation sessions (i.e. states), we intended to capture long-term effects of meditation practice, revealing lasting reorganization of emotional processes (i.e. traits).

2. Materials and methods

2.1. Participants

Twenty six individuals were included in the study. Thirteen (7 men and 6 women; aged 38.7 ± 9.8 years, mean ± standard deviation), who have been practicing Buddhist meditation, formed a 'meditators' group. The 'control' group ($n = 13$, 5 men and 8 women; aged 34.6 ± 6.5 years) were recruited from healthy volunteers with no experience of meditation. There were no significant age differences between the groups ($p = 0.40$, Wilcoxon's rank sum test), nor did the gender ratios in the groups differ significantly from the 1:1 expected population ratio ($p = 0.41$ for control group and $p = 0.78$ for meditators, Pearson's chi-square test).

Meditators were required to have practiced for at least five previous years for minimum five hours a week. They were affiliated with different Buddhist institutions and the common directive of the meditation practices pursued by them can be summarized as remaining in a quiescent state, receptive to any thoughts, emotions or sensations, but without any lingering on them, or evaluating them, or allowing them to disrupt the meditative state, remaining within present experience, with no projecting into the future, or reflecting on the past (i.e. most resembling "mindfulness" meditation).

2.2. Psychological testing

The participants filled out questionnaires: a Courtauld Emotional Control Scale (CECS; Watson and Greer, 1983) and a Formal Characteristics of Behavior–Temperament Inventory (TI; Strelau and Zawadzki, 1993). CECS is a simple instrument containing questions surveying subject's typical reactions when experiencing three emotions: "Anger", "Unhappiness" and "Anxiety", with scores primarily registered on three corresponding scales, quantifying degree of control over emotional states. TI is a more sophisticated psychometric questionnaire designed to measure basic, inborn and stable temperamental personality traits identified by Regulative Theory of Temperament – an extension of pavlovian concepts (Strelau, 1996). Traits measured (on six corresponding scales) are: "briskness" (tendency to respond to stimuli promptly, and modulate responses easily), "perseveration" (tendency to continue response after cessation of stimuli), "sensory sensitivity" (strength of simulative value required to elicit response), "emotional reactivity" (tendency to react intensively to emotion-generating stimuli), "endurance" (ability to sustain adequate responses to prolonged/intensive stimuli), "activity" (tendency to elicit/seek strong stimulation).

The control and meditation groups did not differ significantly on any of the scales comprising both tests (two sample *t*-tests, CECS: anger ($p = 0.27$), depression ($p = 0.74$), anxiety ($p = 0.37$); TI: perseveration ($p = 0.27$), sensory sensitivity ($p = 0.63$), emotional reactivity ($p = 0.92$), endurance ($p = 0.15$), activity ($p = 0.45$), briskness ($p = 0.36$)).

2.3. Stimuli

Stimuli consisted of 120 pictures from the International Affective Picture System (IAPS; Lang et al., 1999). The pictures were grouped into three sets of 40 according to their scores on two 9-point IAPS scales: emotional valence (unpleasant to pleasant, 1–9) and level of arousal induced in the viewer (relaxed to aroused, 1–9). One set, "neutral" pictures, contained 40 images which scored 5.52 ± 0.97 (mean ± standard deviation) on the valence scale and 2.76 ± 0.36 on the arousal scale, the 40 "negative" pictures scored 2.48 ± 0.83 and 6.38 ± 0.64 respectively, and the 40 "positive" pictures scored 7.00 ± 0.95 and 5.81 ± 0.68. Each set differed significantly from the other ones on both scales (two sample *t*-tests, $p < 0.001$ in each). No set differed significantly from any other with regard to the average luminance of the images it contained (two sample *t*-tests, $p \geq 0.90$ in each).

2.4. EEG recording

EEG activity was recorded with eight electrodes (Fp1, F3, F4, Fz, Cz, Pz, O1, O2) of the 10/20 system held on the scalp with an elastic cap; two linked reference electrodes were attached to the earlobes. Two additional electrodes were attached with adhesive to the skin below and to the right of the right eye to allow bipolar electro-ocular activity recording. The signals were recorded through a Neurodata Acquisition System amplifier (Grass Technologies Product Group of Astro-Med, Inc., USA) with a 0.1–200 Hz band pass filter and 20 k amplification, and digitized on-line to a data file at 500 Hz sampling rate (Power1401 analog–digital interface, Spike 2 software, Cambridge Electronic Design, UK).

2.5. Experimental procedure

After entering the EEG laboratory, the participant received oral and written information on the experiment. After completion of the questionnaires the participant was seated in a comfortable recording chair, EEG electrodes were attached and the lights in the laboratory were dimmed. The participant was instructed to look at the pictures, without blinking or any movement, but otherwise let herself/himself naturally experience the pictures. The computer screen was positioned at eye level and at a distance of 130 cm so as to cover ca. 15° of horizontal visual angle. The set of 120 images (40 of each valence) was presented in a pseudorandom order. Each picture was displayed once for 1.5 s, followed by a 3–5 s (random) of empty grey screen, during which the participant was allowed to blink, and a 2–3 s (random) display of a fixation cross, which served as a fixation point for the next image, as well as a cue that the participant was to cease all blinking and eye movement until the upcoming image disappeared. After the 40th and 80th image, there was an additional 2 min rest break. The whole presentation lasted for ~20 min. Finally, the participants were paid for participation and debriefed (meditation practitioners finished with an additional meditation session with EEG recording, however the results are not a subject of this paper).

2.6. Data preparation

The recorded data were transferred for further analysis to Matlab software environment (The MathWorks, Inc., USA). Raw EEG signals were low-pass filtered with a direct-form FIR digital filter with a 30 Hz half-cutoff frequency and downsampled to 100 Hz. To reduce the data, for each subject we averaged the O1 and O2 recordings into one 'occipital' signal, Cz and Pz – into a 'centro-parietal' signal, and kept F3 and F4 as a 'left frontal' and 'right frontal' signal, respectively. Subsequently, 1.7 s (i.e. 170 sample long) ERP epochs were extracted from the signals, consisting of a 200 ms pre-stimulus reference period and 1.5 s after picture onset. The ERPs accompanied by the electro-ocular activity signal exceeding ±40 μV were rejected as contaminated with ocular artifacts. Of all ERP epochs 88.6% in control group, and 88.5% in the meditators group, remained in the dataset as artifact free. ERPs were corrected to zero baseline using the 200 ms pre-stimulus period as reference prior to any further averaging and analysis, i.e. we subtracted from each ERP waveform the mean value of EEG in the 200 ms preceding the stimulus. Finally, for each subject we averaged the traces evoked by the pictures from the same (negative, positive or neutral) set. Ultimately, our dataset used in further statistical analyses (see Tables 1 and 2) and averaging (Fig. 1) consisted of 78 ERP waveforms (i.e. two groups × three stimulus valences × the number of participants in each group $n = 13$).

3. Results

Fig. 1 illustrates group mean (i.e. grand average) ERPs registered in our study. There is, as expected (see Section 1), an evident increase of the LPP amplitude in response to stimulus negativity in control subjects (Fig. 1A). However, interestingly, there is no such effect, or only an inconspicuous increase, in meditators' group (Fig. 1B). On the other hand, stimulus positivity elicited only modest LPP variations in both groups, which were similar in both control (Fig. 1C) and meditators' (Fig. 1D) groups.

To analyze statistically these observations, we compared mean LPP amplitudes (i.e. mean ERP levels in a set window) the across groups and stimulus valences using two-way ANOVA on the dataset described in Section 2.6. We chose an LPP window of 500–1500 ms, i.e. starting on the last clear trough consistently appearing in the ERP shapes (see Fig. 1). The results – presented in Table 1 – show no main effects of either group or valence. The only significant effect is that of interaction between group and valence over frontal electrodes. To investigate this interaction, we tested mean LPP amplitudes between groups separately for different image valences. The results, provided in Table 2 and Fig. 2, clearly show that differences lie in the reaction to negative pictures: the control subjects' LPP is significantly increased in response to picture negativity as compared to meditators, while there are no differences between groups in response to neutral and positive pictures.

4. Discussion

The present visual ERP study provides evidence for a long-term effect of meditation practice on the brain's emotional processing. We found that – in contrast to the control subjects – meditators' ERPs, specifically over frontal regions, were not impacted by

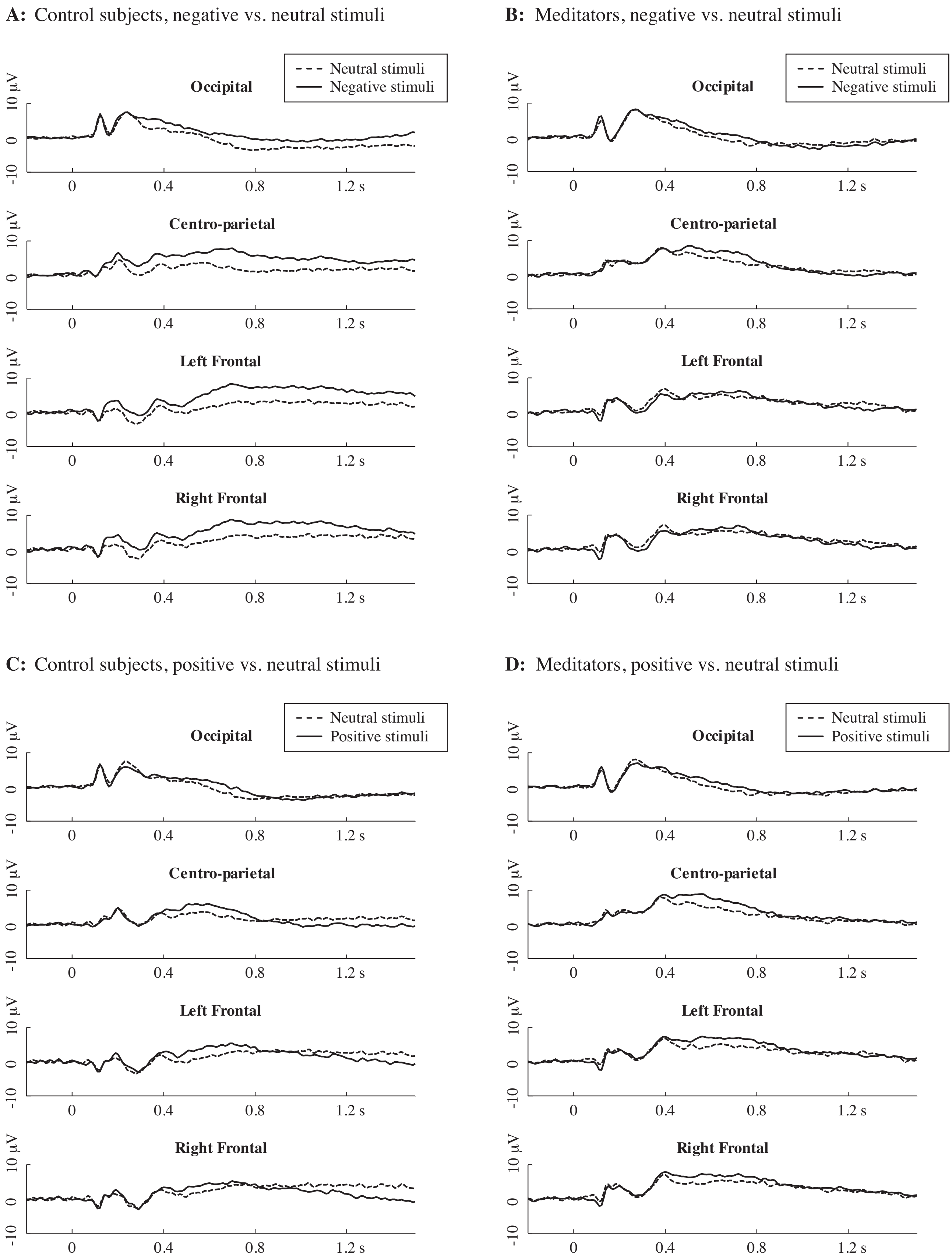

Fig. 1. (A) Group mean ERPs. Control subjects' ERPs evoked by neutral and negative stimuli. (B) Meditators' ERPs evoked by neutral and negative stimuli. (C) Control subjects' ERPs evoked by neutral and positive stimuli. (D) Meditators' ERPs evoked by neutral and positive stimuli.

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Table 1
ANOVA summary tables for comparisons of mean LPP amplitudes.

Occipital ERPs

Source	SS	df	MS	F	p
Group	1.46	1	1.46	0.07	0.8
Valence	19.19	2	9.60	0.44	0.65
Interaction	24.14	2	12.07	0.550	0.58
Error	1570.06	72	21.81		
Total	1614.84	77			

Centro-parietal ERPs

Source	SS	df	MS	F	p
Group	0.18	1	0.18	0.01	0.91
Valence	52.77	2	26.39	2.00	0.14
Interaction	69.87	2	34.94	2.65	0.08
Error	950.71	72	13.20		
Total	1073.54	77			

Left frontal ERPs

Source	SS	df	MS	F	p
Group	3.89	1	3.89	0.35	0.56
Valence	58.64	2	29.32	2.61	0.08
Interaction	94.53	2	47.26	4.21	0.02
Error	808.73	72	11.23		
Total	965.79	77			

Right frontal ERPs

Source	SS	df	MS	F	p
Group	8.85	1	8.85	0.67	0.42
Valence	46.76	2	23.38	1.77	0.18
Interaction	97.19	2	48.60	3.68	0.03
Error	950.81	72	13.21		
Total	1103.62	77			

Abbreviations: SS, sum of squares; df, degrees of freedom; MS, mean squares.

Table 2
LPP amplitude (μV) in control and meditators' group for different scalp regions and stimulus valences (the values are: mean ±standard error of the mean and significance of differences, i.e. Student's *t*-test *p*-values).

	Positive stimuli			Neutral stimuli			Negative stimuli		
	Controls	Meditators	p	Controls	Meditators	p	Controls	Meditators	p
Occipital	−1.75 ± 1.02	−0.63 ± 0.57	0.35	−2.26 ± 1.82	−1.26 ± 0.68	0.61	−0.11 ± 2.04	−1.19 ± 0.85	0.56
Centro-parietal	1.35 ± 1.18	3.30 ± 0.86	0.19	1.82 ± 0.73	2.20 ± 0.61	0.69	5.20 ± 1.62	2.58 ± 0.66	0.15
Left frontal	2.24 ± 1.11	3.86 ± 0.80	0.25	2.45 ± 0.64	2.97 ± 0.49	0.52	6.44 ± 1.49	2.95 ± 0.65	0.04
Right frontal	2.35 ± 1.09	4.16 ± 0.77	0.19	3.54 ± 1.28	3.32 ± 0.49	0.87	6.78 ± 1.43	3.18 ± 0.61	0.03

negative pictures (there was no increase in the LPP components of ERP). On the other hand, we found no difference in LPP response to emotional positivity of images between meditators and control participants. This allows us to posit that meditation practitioners either perceive adverse emotional stimuli in a different way from non-meditators or regulate (inhibit) the emotional reaction to negative stimuli – while processing of positive stimuli remains unaltered (uninhibited). Since main source of this difference seems to involve frontal cortical regions, we hypothesize that meditators are capable of hampering afferent emotional arousal triggered by negative visual stimulus.

There are two possible explanations of our result. Firstly, some dispositional emotional (temperamental) traits of the meditators could both: drive them towards engaging in special practices like meditation and – coincidentally – result in altered ERPs. To fully rule out this explanation a long-term longitudinal random assignment study would be necessary. We purported, however, to control the influence of dispositional temperamental traits through verifying that our experimental groups did not score differently in relevant psychological tests (CECS and TI; see Section 2).

The other possible explanation involves the plasticity effect of long-term meditation practice. One of the central features of Buddhist meditation tradition is a phenomenon referred to as 'mindfulness', which, in cognitive research, has been described as a process whereby the subject is highly aware and receptive of her/his present, transient experience (Creswell et al., 2007). A key aspect of this 'mindfulness' is enhanced cognitive categorization, or 'labeling', of experiences. In Buddhist tradition such 'mindfulness' is to produce certain emotional detachment from the experiences, thus regulating emotional processes. The other aspect of meditation, i.e. concentration of attention, may also facilitate emotional detachment. Possibly intensive training of concentration, 'mindfulness' and 'labeling', i.e. cognitive categorization of experiences and detachment mentalization during meditation sessions, transfers to a degree to daily functioning, which influence the underlying plastic changes of the neuronal network producing the results observed is this study.

Recent neuroimaging findings support the view that conscious and voluntary use of metacognition and cognitive recontextualization selectively alters the way the brain processes emotional stimuli (Beauregard, 2007). 'Mindfulness' as a disposition, and the cognitive categorization of emotional stimuli it implies, was postulated to modulate emotional processing (Creswell et al., 2007). This study showed association of 'mindfulness' with enhanced prefrontal cortical regulation of affect through 'labeling' of negative affective stimuli. Significant regulatory effect of cognitive categorization of emotional stimuli has also been confirmed in electrophysiological research (Hajcak et al., 2006) – however only if the categorization is such that it abstracts from emotional meaning of the stimuli. It has also been demonstrated that cognitive strategy of detachment as such can attenuate subjective and physiological measures of anxiety, with potential source of this modulation in various frontal cortices (Kalisch et al., 2005) – again, however, in the cited study detachment was understood somewhat differently, i.e. as directing one's attention away from the emotional stimuli instead of just mentalizing its emotional potency. Therefore, the nature of 'mindfulness', being a result of meditation, and its emotional regulatory function, although supported by research (also by this study) remains elusive. Possibly, the other central feature of meditation: trained concentrative abilities, granting enhanced attentional control (Lutz et al., 2009), plays a significant part in the effect observed by us.

Regardless of explanation, our study provides support to the notion that meditation practice might be an effective tool for emotional regulation. A possible alternative explanation, which, despite lack of differences in standard psychological tests, cannot be ruled out, is that altered emotional processing of the meditators is a result of some pre-existing temperamental trait, manifesting itself in individuals, inter alia, in the drive towards special practices like meditation.

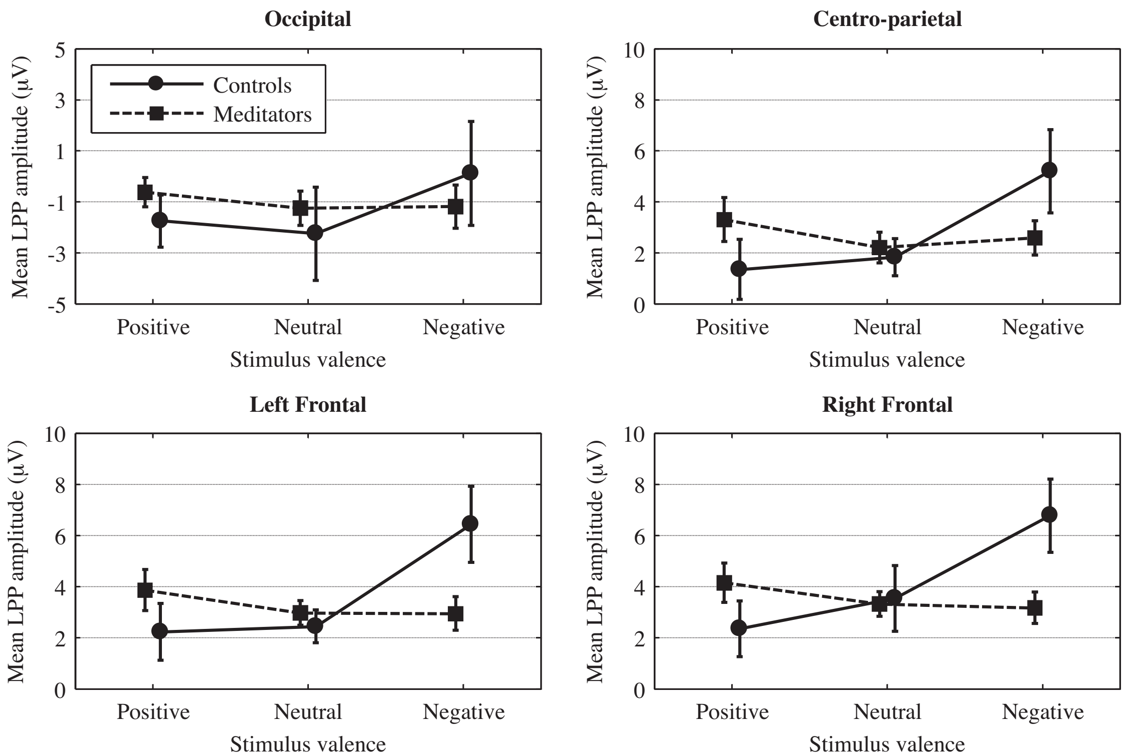

Fig. 2. Mean LPP (500–1500 ms post stimulus) amplitudes in control (solid line with round markers) and meditators' (dashed line with square markers) groups for three stimulus valences (on the horizontal axes) and four scalp regions (in the four panels). Error bars denote standard error of the mean (SEM). See Table 2 for values and statistics.

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