International Journal of Psychophysiology 90 (2013) 207–214

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Mindfulness (Vipassana) meditation: Effects on P3b event-related potential and heart rate variability

Luis Carlos Delgado-Pastor [a,*], Pandelis Perakakis [b,d], Pailoor Subramanya [c], Shirley Telles [c], Jaime Vila [b]

[a] University of Zaragoza, Spain
[b] University of Granada, Spain
[c] Vivekananda Research Foundation, Bangalore, India
[d] Laboratory of Experimental Economics, University Jaume I, Spain

ARTICLE INFO

Article history:
Received 22 February 2013
Received in revised form 30 May 2013
Accepted 15 July 2013
Available online 24 July 2013

Keywords:
Vipassana
Mindfulness
Event-related potential
Heart rate variability
Attention
Emotional regulation

ABSTRACT

The concept of mindfulness is based on Vipassana, a Buddhist meditation technique. The present study examines the physiological indices of attention and autonomic regulation in experienced Vipassana meditators to test the claim that mindfulness is an effective therapeutic tool due to its effects on increasing awareness of present experience and emotional self-regulation. Ten male experienced Vipassana meditators underwent two assessment sessions, one where they practiced Vipassana meditation and another where they rested with no meditation (*random thinking*). Each meditation/no-meditation session lasted 30 min and was preceded and followed by an auditory oddball task with two tones (*standard* and *target*). Event-related potentials to the tones were recorded at the Fz, Cz, and Pz locations. Heart rate variability, derived from an EKG, was recorded continuously during the meditation/no-meditation sessions and during a 5-minute baseline before the task. The Vipassana experts showed greater P3b amplitudes to the target tone after meditation than they did both before meditation and after the no-meditation session. They also showed a larger LF/HF ratio increase during specific Vipassana meditation. These results suggest that expert Vipassana meditators showed increased attentional engagement after meditation and increased autonomic regulation during meditation supporting, at least partially, the two claims concerning the clinical effectiveness of mindfulness.

1. Introduction

Mindfulness is a Buddhist-based meditation that current psychology has rediscovered and used as a therapeutic tool for various psychological disorders (Allen et al., 2006; Baer, 2003; Barnhofer et al., 2009; Carmody, 2009; Kuyken et al., 2010; Lazar, 2005; McCracken and Gutiérrez-Martínez, 2011; Toneatto and Nguyen, 2007; Zgierska et al., 2009). Two fundamental components of mindfulness have been distinguished in recent clinical applications: (a) self-regulation of attention (awareness) toward the present experience and (b) an attitude of curiosity, openness and acceptance of the present experience. Awareness and acceptance of internal and external aspects of the present experience are assumed to bring about emotional stability through a non-evaluative re-cognition of sensations, emotions, and thoughts without reactivity or over-involvement (Bishop et al., 2004; Hayes and Feldman, 2004; Chambers et al., 2009). These two components of mindfulness have been applied clinically as integral parts of different training programs: (a) *Mindfulness Based Stress Reduction* (Kabat Zinn, 1982), (b) *Dialectic Behavioral Therapy* (Linehan, 1993), (c) *Mindfulness-based Cognitive Therapy* (Segal et al., 2002), (d) *Acceptance and Commitment Therapy* (Hayes et al., 1999), (e) *Mindfulness-based Relapse Prevention* (Bowen et al., 2009) and (f) *Acceptance-based Behavior Therapy for Generalized Anxiety Disorder* (Roemer and Orsillo, 2007). Despite the popularity and widespread application of mindfulness, the psychological and neuropsychological mechanisms underlying its clinical effectiveness are still poorly understood.

Vipassana is the main Buddhist meditation technique on which mindfulness is based. Vipassana, which means *to see things as they really are*, is a method of training the mind through focused attention on bodily sensations, emotions, and thoughts without mental reactivity to the experience. It has been defined as a form of self-transformation through self-observation (Thera, 1962). The main focus of the Vipassana technique is training one's awareness of any mental experience as it arises from moment to moment, including breathing sensations, sensations from all parts of the body, and thoughts related to feelings of good will, love, and compassion. The final aim of this awareness training is to achieve emotional stability and happiness.

Consistent with the focus of Vipassana on attention training and interoceptive awareness to achieve emotional stability, recent psychophysiological research on the effects of Vipassana has specifically examined changes in the central and peripheral physiological indices of attention and autonomic regulation (Delgado et al., 2010). Event-related

* Corresponding author at: Facultad de Ciencias Humanas y de la Educación, University of Zaragoza, 22003 Huesca, Spain. Tel.: +34 974239341; fax: +34 974237384.
E-mail address: siulcar@hotmail.com (L.C. Delgado-Pastor).

0167-8760/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpsycho.2013.07.006

potentials (ERPs) and heart rate variability (HRV) are the two physiological indices most frequently investigated within the context of Vipassana and other meditation techniques.

ERPs are brain potentials recorded from the scalp that are elicited in association with the cognitive processing of specific events. N1, P2, P3a, and P3b are the main ERP components that are thought to reflect cognitive processes. They are commonly recorded using the auditory or visual *oddball task*, in which participants attend to a stimulus (target) embedded as rare occurrences among a series of a more frequent non-attended stimulus (standard). Greater amplitudes and shorter latencies of the ERP components are generally interpreted in terms of increased attention. P3a and P3b are two subcomponents of P300, the largest ERP component elicited by the target stimulus in the *oddball task*. P3a, with a frontal distribution, is thought to reflect stimulus-driven attention whereas P3b, with a temporal–parietal distribution, is thought to reflect the allocation of attentional resources for subsequent memory processing (Polich, 2007).

A number of studies have investigated changes in ERPs (N1, P2, P3a, P3b) to characterize differences in attentional processes in experienced meditators (see Cahn and Polich, 2006). Several studies have reported increases in the amplitude and/or decreases in the latency of P300 (P3b) to target stimuli *after* meditation (Banquet and Lesévre, 1980; Cranson et al., 1990; Goddard, 1989, 1992; Sarang and Tellles, 2006; Travis and Miskov, 1994) but a decrease in the P3a amplitude to distracting unexpected stimuli if the task was performed during meditation (Cahn and Polich, 2009). Both findings are interpreted in terms of attentional engagement/disengagement: after meditation, the attentive set to incoming external stimulation is expected to be augmented, leading to increased P300, whereas, during meditation, the attentive set to external distracting stimuli is expected to be diminished, leading to decreased P300. However, not all of these studies investigated Vipassana meditation, and none of the studies examined P300 using the *oddball task* after Vipassana meditation. Moreover, the significant differences among studies concerning the type of meditation, the amount of practice, the attentional task, and the moment of the physiological test (during versus after meditation) preclude firm conclusions on the effect of Vipassana on ERP indices of attention (Cahn and Polich, 2009).

HRV refers to the cyclic variations in the heart rate and is obtained by calculating the time interval between successive heartbeats. When heart rate variations are analyzed using spectral analysis, three frequency bands are usually identified: High Frequency (HF: between 0.5 and 0.15 Hz), Low Frequency (LF: between 0.15 and 0.04 Hz), and Very Low Frequency (VLF: between 0.00 and 0.04). The HF band coincides with cyclic changes in respiration; the heart rate increases during inhalation and decreases during exhalation. This cardio-respiratory synchrony, also called *respiratory sinus arrhythmia* (RSA), is mediated by parasympathetic (vagal) control. The LF band is mediated by both sympathetic and parasympathetic control as it is related to baroreflex control of the heart, whereas the VLF band is thought to be controlled by sympathetic influences mainly related to thermal-fluid regulation and the sleep–wake cycle (Berntson et al., 2007). Therefore, high HRV in the HF respiratory band, or in the transition between the HF and LF mediated by vagal influences, is generally interpreted in terms of good autonomic and emotional regulation (Malliani, 1999; Thayer and Lane, 2000).

A number of studies have investigated changes in HRV indices in experienced meditators (Cysarz and Bussing, 2005; Goshvarpour et al., 2011; Hoshiyama and Hoshiyama, 2008; Lehrer et al., 1999; Patra and Telles, 2010; Peng et al., 1999, 2004; Peressitti et al., 2010; Phongsuphap et al., 2008; Wu and Lo, 2008). Although the majority of these studies used spectral analysis techniques, some employed different procedures, such as the calculation of HRV indices in the time domain (Patra and Telles, 2010; Peng et al., 1999; Peressitti et al., 2010; Phongsuphap et al., 2008; Wu and Lo, 2008), non-linear HRV indices (Hoshiyama and Hoshiyama, 2008; RenuMadhavi and Ananth, 2010), and Poincaré plots (Goshvarpour et al., 2011). The results are far from consistent. One of the indices most frequently reported—the LF/HF ratio—shows conflicting findings, with some studies reporting increases (Cysarz and Bussing, 2005), others reporting decreases (Patra and Telles, 2010), and still others reporting no change (Peng et al., 2004) during meditation. The LF/HF ratio is usually interpreted in terms of sympathetic/parasympathetic balance, assuming that an increase in the ratio reflects increased sympathetic and decreased parasympathetic activation, whereas a decrease in the ratio reflects the opposite pattern of autonomic activation. This assumption has been challenged by evidence that LF oscillations are predominantly determined by vagal activity, rather than by sympathetic activity, linked to blood pressure control mechanisms (Reyes del Paso et al., 2013). Moreover, it has been argued that during meditation the respiratory pattern, which normally operates within the HF spectral range, tends to move towards the upper limit of the LF band (approximated at 0.1 Hz), which coincides with the so-called *resonance frequency* (Lehrer et al., 1999, 2000; Peng et al., 2004; Phongsuphap et al., 2008). This phenomenon reflects a synchronization of respiratory and baroreflex heart rate oscillations and is mediated by parasympathetic control. The inconsistent findings may also be due to differences in meditation types. Some meditations included specific yoga postures that are known to induce heart rate changes or focused on reducing breathing frequency, which inevitably moves the RSA from the HF toward the LF band. As in the case of ERPs, only a few studies examined HRV during or after Vipassana meditation, thus hindering firm conclusions on the effect of Vipassana on cardiac indices of autonomic regulation.

The aim of the present study was to examine both ERP and HRV indices of attention and autonomic regulation in experienced Vipassana meditators. The P3b component of the ERPs was investigated using the auditory *oddball task* just before and after a 30-minute period of Vipassana meditation. The HRV indices were investigated during the same meditation period by recording the electrocardiogram and applying spectral analysis to the heart rate time series. Both indices were compared to those obtained by the same participants in a similar period of no-meditation (*random thinking*). It was hypothesized that Vipassana experts would show (a) an increased amplitude of P3b after meditation than before meditation or after no meditation and (b) higher indices of HRV reflecting higher vagal control during meditation than before meditation or during no meditation.

2. Methods

2.1. Participants

Participants were 10 male experienced Vipassana meditators with an age range between 20 and 61 years. They had a minimum of 2 years of regular practice, an average experience of 7.5 years, and an average weekly practice of 15 h. They all belonged to the *Dhamma Paphulla Vipassana Center* at Bangalore (India) and participated voluntarily. No participant was undergoing psychological or pharmacological treatment or had auditory or cardiovascular problems. Due to artifacts in the physiological recordings, one participant was excluded from the ERP analysis and three participants from the HRV analysis.

2.2. Design

Participants underwent two assessment sessions on consecutive days and at the same daily time: one session practicing Vipassana meditation and another session resting with random thinking (Smallwood and Schooler, 2006; Telles et al., 2005). The order of the sessions was counterbalanced across participants. Each session consisted of the following sequence: (a) a 5-minute resting baseline, (b) a pre-intervention auditory *oddball task*, (c) a 30-minute meditation/random thinking with continuous HRV measurement, and (d) a post-intervention auditory *oddball task*.

2.3. Oddball task

The *oddball task* consisted of the discrimination between two tones: the *standard tone*, a 1000 Hz tone presented 240 times (80%), and the *target tone*, a 2000 Hz tone, presented 60 times (20%), in random order. Both tones were presented binaurally with an intensity of 70 dB and 100 ms duration using adjusted earphones (TDH-39, Amplivox, UK). The inter-stimulus interval was 1 s. The task of the subject was to mentally count the number of target presentations. At the end of the task, participants reported the number of targets detected. Error rate was defined as the percent of incorrect target detections. All participants had an error rate below 2%.

2.4. Meditation task

The 30-minute meditation task was structured in three sub-periods following the method taught by S. N. Goenka, a teacher in the Vipassana tradition of Sayagyi UBakhin of Burma, in his meditation courses (Confalonieri, 2006): (a) Anapana: an initial 10-minute period of self-regulation of attention focused on breathing sensations (sensations from air entering and leaving the body at the nostrils), (b) Vipassana: a central 15-minute period of focusing attention on sensations from all parts of the body while maintaining the non-reactivity and acceptance attitude, and (c) Metta: a final 5-minute period focused on generating feelings of compassion and unconditional love to all living beings. The 30-minute random-thinking task consisted of allowing the mind to wander freely with the explicit instruction of not engaging in meditation, as previously used by Telles et al. (2005) and Cahn and Polich (2009). At the end of the task, participants reported their success in doing the task using a scale from zero (not at all success) to 100 (complete success). All participants scored over 70 in both tasks.

2.5. Instruments and measures

2.5.1. Event-related potentials

ERP components were derived from the EEG recorded at Fz, Cz, and Pz using Nicolet-Bravo equipment (Midwest Neuro Medical, Inc.) and silver/silver chloride electrodes with conductive electrolyte paste (D. O. Weaver and Co. USA) referenced to interconnected earlobes and with the ground electrode being placed at the forehead (Fpz). Eye movements (EOG) were recorded with two electrodes placed 1 cm above and below the outer canthi of the right eye. Impedances were kept below 5 kΩ at all locations. The EEG recording used a band-pass filter of 0.01–30 Hz and a sampling rate of 666 Hz. Individual grand averages for target and standard tones were computed between 75 and 825 ms after stimulus onset. The EEG amplitude in the 75 ms before stimulus onset served as the baseline correction. The artifact rejection level was expressed as a percentage of the full-scale range of the analog-to-digital converter. This level was set at 90%. The individual Nicolet binary files were exported, processed, and analyzed offline using custom Matlab programs to obtain the grand averages across subjects and the mean P3b amplitude defined as the average voltage between 250 and 450 ms after stimulus onset.

2.5.2. Heart rate variability

HRV indices were derived from the EKG (lead I), which was recorded using a Polyrite model 10 polygraph (Records and Medicare systems, Chandirgah, India). The EKG signal was filtered using a 5–30 Hz band filter and sampled at 500 Hz. The interbeat (R–R) interval series were obtained using a peak detection algorithm that corrected potential artifacts (Carvalho et al., 2002). HRV was subsequently analyzed by Kardia (Perakakis et al., 2010), a Matlab toolbox calculating both frequency-domain (Fourier spectral analysis) and time-domain (root mean square of successive difference) HRV indices. In the present study, only the frequency-domain indices are reported since both methods were highly correlated (all correlations higher than .900). The following HRV indices were selected: High Frequency (0.15–0.5 Hz), Low Frequency (0.04–0.15 Hz), and Low Frequency/High Frequency ratio. The power spectral density of the High Frequency (HF) and Low Frequency (LF) bands—expressed in ms^2/Hz—was calculated from the squared absolute value of the discrete Fourier transform, which is multiplied by the sampling period and divided by the number of samples in the signal.

2.6. Procedure

Participants were contacted by phone and invited to participate in the study. They were provided with transport facilities to travel to the laboratory at the *Anvesana Research Center* (Bangalore, India). Upon arrival, each participant was fully informed about the procedure, signed an informed consent form, and completed a brief questionnaire to confirm the inclusion criteria. The assessment took place in a sound-attenuated cabin with dim light and an ambient temperature between 20 and 25 °C. Once in the cabin, specific instructions concerning the *oddball* and the meditation/random-thinking tasks were read to the participant. Instructions for the *oddball* task informed participants that they were going to listen to two types of tones: one presented more frequently at regular intervals and the other presented less frequently at irregular intervals. Their task was to pay attention and count mentally the number of less frequently presented tones. Instructions concerning the meditation asked participants to meditate in their usual manner as taught by S. N. Goenka within the Vipassana meditation tradition, each meditation period (Anapana, Vipassana, and Metta) being indicated by a bell sound. The control/random thinking instructions directed participants to allow their thoughts to wander freely with the only restriction of not engaging in meditation or in meditation-related thoughts. After assuring correct understanding of the instructions, the experimenter attached the ECG and EEG electrodes (always in this order), checked the electrode impedance and physiological recording levels, placed the earphones on the subject and left the participant alone in the cabin to initiate the recording session. Following the session, the earphones and electrodes were removed, and the participant was invited to return the following day for the second session.

2.7. Statistical analysis

Mean P3b amplitude to target and standard tones were analyzed by means of 2 (task: meditation vs. control) × 2 (oddball order: pre- vs. post-) × 2 (tone: target vs. standard) × 3 (electrode: Fz, Cz, Pz) repeated measures ANOVA using the multivariate test statistic (*Wilks' lambda*) generated by SPSS. This method is free of sphericity assumptions and, thus, is more suitable for repeated measures designs (O'Brien and Kaiser, 1985). HRV indices were analyzed by means of 2 (task) × 4 (periods) repeated measures ANOVA using the same multivariate test statistic. The 4 periods were the resting baseline before the task and the 3 periods into which the meditation/random thinking was divided. The results are presented reporting the *F*-value associated with the *Wilks' lambda* statistic. Assuming significant interaction effects of the task, specific contrasts were performed to examine differences between the meditation and control task at the three electrode locations before and after the task. Pairwise comparisons concerning the three electrode locations were performed using Bonferroni testing. The level of significance was set at .05 for all analyses.

3. Results

3.1. P3b amplitude

Fig. 1 displays the ERP grand averages for the target tone at Fz, Cz, and Pz before (left graphs) and after (right graphs) the meditation/control task. A P3b component is observed both before and after the meditation and control task, the amplitude being, in general, larger after the task and after practicing meditation than after practicing random thinking. Fig. 2

displays the mean P3b amplitude to target (top graphs) and standard (bottom graphs) as a function of task, oddball order, and electrode location. As expected, P3b amplitudes are larger in response to the target than to the standard. P3b amplitudes in response to the target are also larger after the meditation than after the control task. The P3b amplitude in response to the target is also larger at Cz than at Fz and Pz.

The 2 × 2 × 2 × 3 ANOVA yielded a significant main effect of tone ($F(1, 8) = 6.89$, $p < 0.03$, $\eta p^2 = 0.463$) and two significant interaction effects, task × oddball order ($F(1, 8) = 5.59$, $p < 0.046$, $\eta p^2 = 0.411$) and task × tone × electrode ($F(2, 7) = 5.96$, $p < 0.03$, $\eta p^2 = 0.630$). Analysis of the two-way interaction (task × oddball order) revealed significant effects of meditation after the meditation/control task ($p < 0.01$). Before the task, the effect was not significant ($p > 0.8$). Analysis of the three-way interaction (task × tone × electrode) revealed significant differences between meditation and control for the target tone after the task at the three electrode locations (Fz: $p < 0.02$; Cz: $p < 0.005$; Pz: $p < 0.05$) and for the standard tone at Pz ($p < 0.004$). No significant differences between meditation and control were found before the task for the target ($p > 0.77$) and standard ($p > 0.42$) tone. Electrode effects were found for the target tone both before the task ($p < 0.01$) and after the task ($p < 0.009$). After the task, the P3b amplitude was significantly larger at Cz than at Pz ($p < 0.03$). Before the task, the P3b amplitude was significantly larger at Cz than at Fz ($p < 0.02$). No significant electrode effect was found for the standard tone before ($p > 0.34$) or after ($p > 0.42$) the task.

3.2. HRV indices

Fig. 3 displays the HRV indices (LF, HF, and LF/HF ratio) during baseline and the three meditation/control periods. In general, LF and HF indices were diminished during the first meditation period (Anapana) followed by an increase during the second meditation period (Vipassana) and a decrease in the third meditation period (Metta) compared to baseline.

The 2 × 4 ANOVAs for the LF and HF indices did not yield any significant effect. However, the 2 × 4 ANOVA for the LF/HF ratio showed

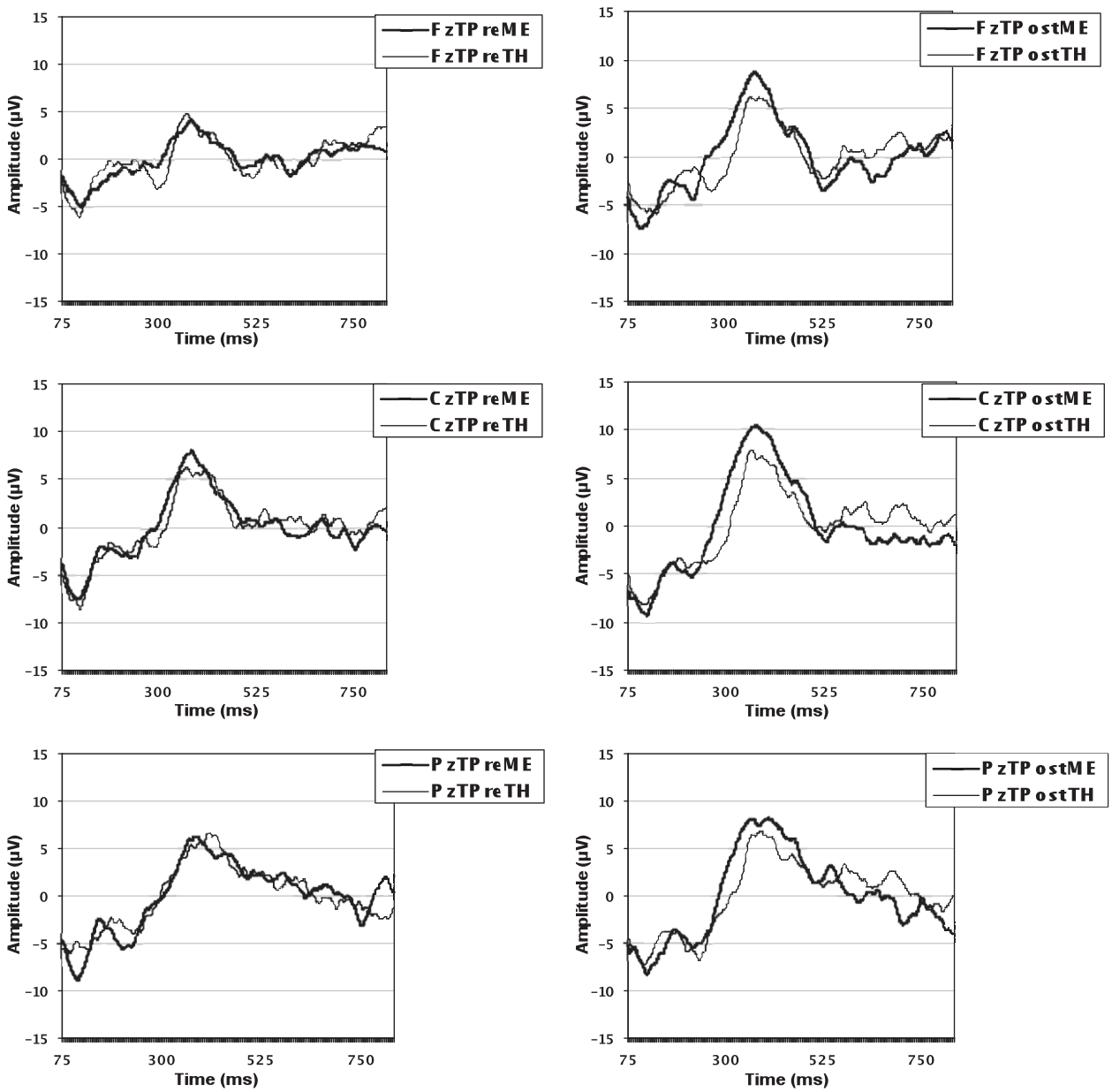

Fig. 1. ERP grand averages for the target tone before (left column) and after (right column) meditation (thick line) versus control (thin line) at Fz (top), Cz (middle), and Pz (bottom). TPreME = Target at Pre-Meditation; TPostME = Target at Post-Meditation; TPreTH = Target at Pre-Random Thinking; TPostTH = Target at Post-Random Thinking.

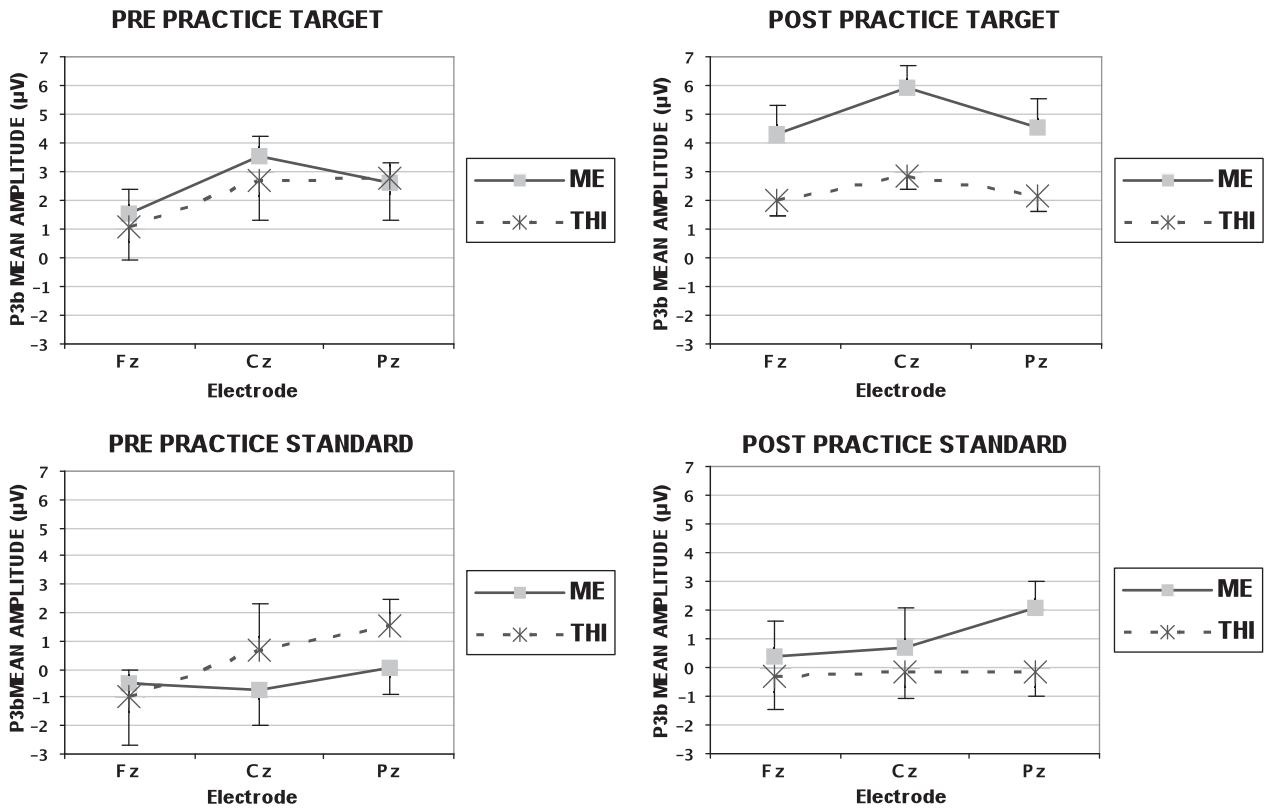

Fig. 2. P3b Mean amplitude for the target (top) and standard (bottom) before (left column) and after (right column) meditation (solid line) versus control (broken line) at Fz, Cz, and Pz.

significant effects of periods ($F(4, 3) = 9.48$, $p < 0.027$, $\eta p^2 = 0.877$) and task × periods ($F(4, 3) = 8.33$, $p < 0.034$, $\eta p^2 = 0.862$). In both meditation/control conditions, the LF/HF ratio, after an initial decrease, significantly increased from the first to the second meditation/control period ($p < 0.05$) and from the second to the third meditation/control period ($p < 0.05$) (periods effect). However, analysis of the significant task × periods interaction revealed that the increase during the second meditation/control period was larger for meditation (Vipassana) than for control ($p = 0.06$) conditions. No other meditation/control comparison approached significance (all $p > 0.5$).

Inspection of the LF and HF indices (see Fig. 3) suggests that the LF/HF ratio increase during Vipassana meditation compared to random thinking during the same period and to Anapana meditation during the previous period was due to a greater increase in the low than in the high frequencies during Vipassana. Fig. 4 shows the HRV power spectral density (PSD) of three participants, illustrating the increase in HRV both in the HF (0.15–0.5 Hz) and LF (0.04–0.15 Hz) bands during Vipassana compared to Anapana meditation. The higher increase in the LF compared to the HF is also evident in these participants. However, there is no clear indication that the increase in the LF band was due to an increase in the resonance frequency (0.1 Hz).

4. Discussion

As predicted, Vipassana experts demonstrated larger amplitudes of P3b to the target tone after meditation than (a) before meditation and (b) before and after no meditation (random thinking). These differences were found at the three electrode locations (Fz, Cz, and Pz). However, significant location effects were also found: the P3b amplitude was larger at Cz than at Fz before the meditation/random-thinking task and larger at Cz than at Pz after the task. The Vipassana experts also showed significant differences in HRV during meditation compared to random thinking but only in the LF/HF ratio and during the specific Vipassana period (the second meditation/random-thinking period).

The electrode location effect found for the target before meditation (greater P3b amplitude at Cz than at Fz) is consistent with the known topography of this ERP component (greater at central and parietal locations than at frontal ones). However, the electrode location effect found after meditation (greater P3b amplitude at Cz than at Pz) is new and difficult to explain in terms of a specific effect of Vipassana meditation. Cahn and Polich (2009) also reported greater amplitudes during Vipassana meditation at Cz than at Pz, but with reference to the distracter stimulus and for the P2 component. Some fMRI studies have reported increased frontal neural activity in experienced Vipassana meditators during meditation compared to novice meditators (Lazar et al., 2005; Holzel et al., 2008; Chiesa and Serretti, 2010). This frontal activation could indeed modify the topography of the ERP components during the oddball task. However, one would expect that the modification would be reflected more at frontal (Fz) than at central (Cz) or parietal (Pz) locations.

The larger amplitude of P3b to the target tone after Vipassana meditation compared to random thinking is consistent with the expected effect of this type of meditation on attention and awareness. Vipassana specifically trains concentration of attention on bodily sensations, accepting all sensations without reactivity or over-involvement (Confalonieri, 2006; Thera, 1962). On the other hand, P3b is believed to reflect the allocation of attentional resources to incoming stimulation to facilitate subsequent information processing (Cahn and Polich, 2009; Polich, 2007). Thus, the observed increase in P3b amplitude to the attended stimulus (target) can be interpreted in terms of increased attentional engagement after Vipassana meditation. Similar findings have been reported after other meditation practices, such as Yoga meditation (Banquet and Lesévre, 1980) or concentrative meditation (Murthy et al., 1997; Sarang and Tellles, 2006). Cahn and Polich (2009) studied experienced Vipassana meditators using the oddball task (with target, standard, and distracter stimuli), but the oddball task was performed during meditation, not after meditation. They found a significant decrease in P3a amplitude to the distracter stimulus compared to a control condition similar to our

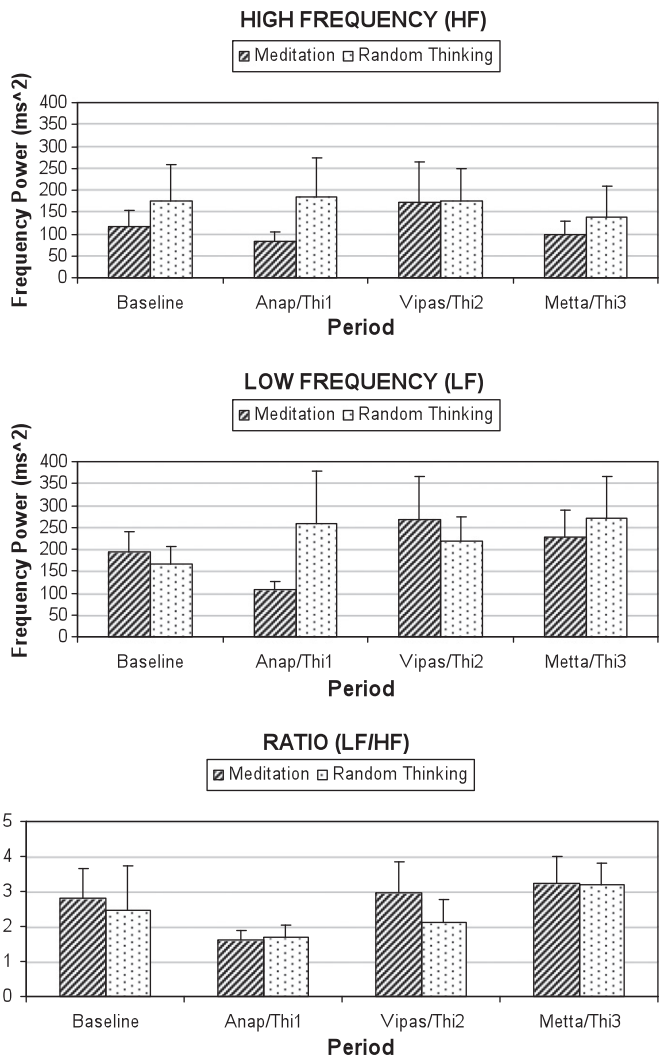

Fig. 3. HRV indices during baseline and the three meditation/control periods: High Frequency (top), Low Frequency (Middle), and LF/HF Ratio (bottom).

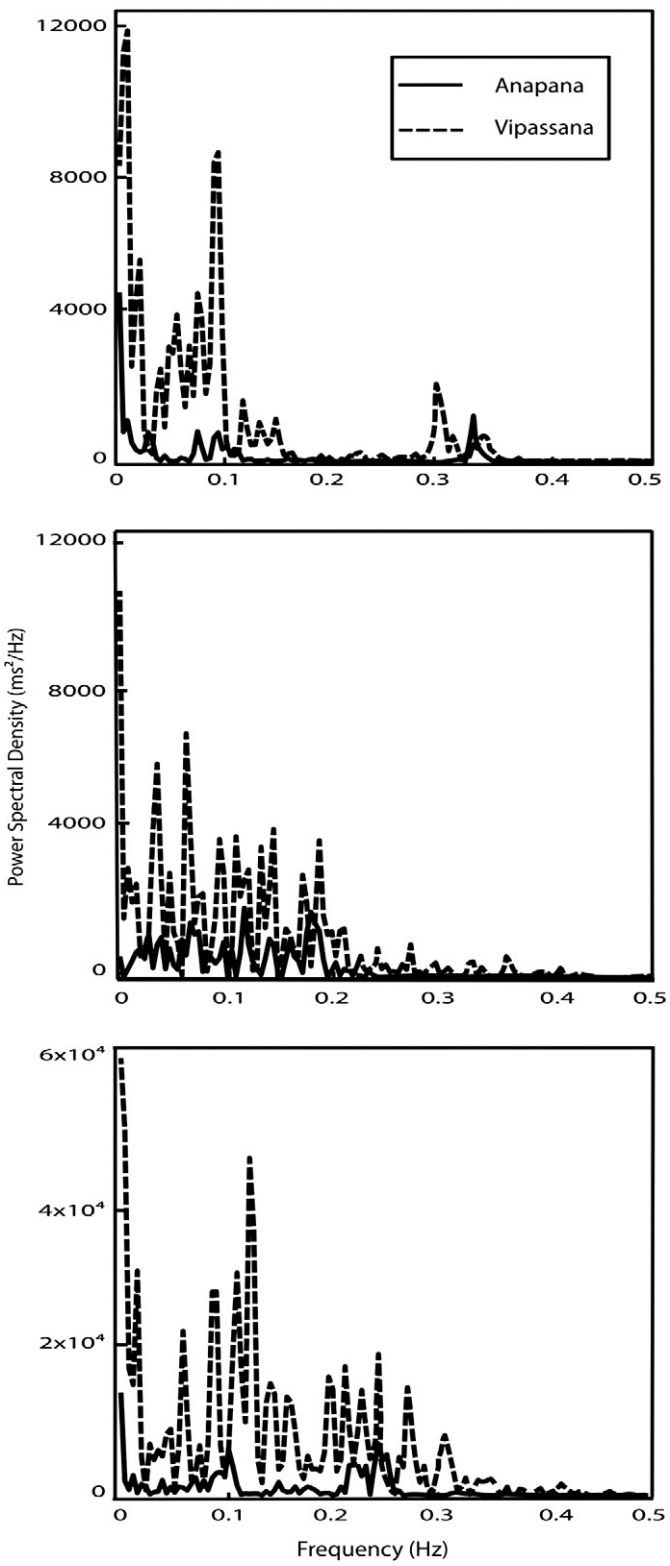

Fig. 4. HRV power spectral density of three participants during Vipassana (dashed line) and Anapana (continuous line).

random-thinking task, which was interpreted as reflecting decreased attentional engagement to distracting stimuli while Vipassana meditators were engaged with present-moment awareness of body sensations (Cahn and Polich, 2009).

The finding of an increase in heart rate variability indexed by the LF/HF ratio during the specific period of Vipassana meditation and relative to the same random-thinking period is more difficult to interpret in terms of the expected improved autonomic regulation (increased parasympathetic control). First, an increase in the LF/HF ratio is usually interpreted in terms of poor emotional regulation (increase sympathetic/decrease parasympathetic control), which is contrary to the expected effect of Vipassana. And second, an examination of the HRV power spectral density of each participant during the Vipassana/random-thinking period did not reveal any indication that the relative increase in LF compared to HF might be due to a dominant vagal effect caused by the synchronization of the respiratory and baroreflex frequencies, approximated at 0.1 Hz, the so-called *resonance frequency* (Lehrer et al., 1999, 2000; Peng et al., 2004).

In spite of this difficulty, an interpretation of the observed increase in the LF/HF ratio during Vipassana meditation with respect to improved autonomic regulation is still possible. The autonomic balance concept, based on the LF/HF ratio, has been criticized on the grounds that it assumes a reciprocally regulated continuum (increases in one branch coupled to decreases in another) that does not hold in many cases. A more comprehensive model of autonomic control accepts that sympathetic and parasympathetic systems can change reciprocally, co-actively, or independently (Berntson et al., 2007). Moreover, given recent evidence that the LF component of HRV is determined mainly by the parasympathetic nervous system (Reyes del Paso et al., 2013), an increase in the LF/HF ratio during Vipassana meditation, due to an increase in the LF component, might indeed be interpreted in terms of

increased autonomic regulation due to an increase in cardiac vagal control.

5. Limitations and conclusion

The implications of our findings should be evaluated taking into account several methodological limitations: First, the lack of a control group of non-meditators. Although our control condition has been successfully used in previous studies (Telles et al., 2005; Cahn and Polich, 2009), a control group of non-meditators would have helped to better link the observed changes in P3b—after meditation—and HRV—during meditation—to meditation expertise, controlling for both trait characteristics of the participants and demand characteristics of the tasks (oddball and meditation). Second, our control condition (random thinking) might not guarantee complete absence of some meditation effects in experienced meditators. Indeed, some of our participants did not report complete success in this task, thus suggesting that some meditation might have occurred. And third, although the heart rate data revealed a significant task × periods effect explained by the higher LF/HF ratio increase during Vipassana meditation than during random thinking and relative to the previous Anapana period, the differences between Vipassana and random-thinking periods were only marginally significant. This loss of statistical power was probably due to the reduced sample size (after exclusion of participants with HRV artifacts), a limitation that precludes firm conclusions on our heart rate data.

With these limitations in mind, the present study provides suggestive evidence supporting, at least partially, the two basic claims of mindfulness (Vipassana) meditation training: increased awareness of present experience—indexed by the increase in P3b event-related potential after meditation- and autonomic regulation—indexed by the increase in LF/HF ratio during meditation. These two components represent psychological and neurophysiological mechanisms that may facilitate a reduction of clinical symptoms through a process of learning new regulatory strategies, thus supporting the clinical use of mindfulness as a therapeutic tool. However, future research is needed to confirm and extend the present findings.

Acknowledgments

We thank the Spanish Ministry of Science and Education, Junta de Andalucia and University Jaume I for their support to the present research (PSI2008-04372, FPU-AP20042242, HUM-388, ECO2011-23634 and P1-1B2012-27). We also thank Dr. Naveen for his excellent collaboration, as well as the research assistants at the *Anvesana Research Center*, and the meditators from the *Dhamma Paphulla Vipasna Center* at Bangalore.

References

Allen, N.B., Chambers, R., Knight, W., Blashki, G., Ciechomski, L., Hassed, C., et al., 2006. Mindfulness-based psychotherapies: a review of conceptual foundations, empirical evidence and practical considerations. The Australian and New Zealand Journal of Psychiatry 40, 285–294.

Baer, R., 2003. Mindfulness training as a clinical intervention: a conceptual and empirical review. Clinical Psychology: Science and Practice 10, 125–143.

Banquet, J.P., Lesévre, N., 1980. Event-related potentials in altered states of consciousness. Progress in Brain Research 54, 447–453.

Barnhofer, T., Crane, C., Hargus, E., Amarasinghe, M., Winder, R., Williams, J.M.G., 2009. Mindfulness-based cognitive therapy as a treatment for chronic depression: a preliminary study. Behaviour Research and Therapy 47, 366–373.

Berntson, G.G., Quigley, K.S., Lozano, D., 2007. Cardiovascular psychophysiology, In: Cacioppo, J., Tassinary, L., Berntson, G.G. (Eds.), The Handbook of Psychophysiology, 3rd edition. Cambridge, New York, pp. 182–210.

Bishop, S.R., Lau, M., Shapiro, S., Carlson, L., Anderson, N.D., Carmody, J., et al., 2004. Mindfulness: a proposed operational definition. Clinical Psychology: Science and Practice 11, 230–241.

Bowen, S., Chawla, N., Collins, S.E., Witkiewitz, K., Hsu, S., Grow, J., et al., 2009. Mindfulness-based relapse prevention for substance use disorders: a pilot efficacy trial. Substance Abuse 30, 295–305.

Cahn, B.R., Polich, J., 2006. Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychological Bulletin 132, 180–211.

Cahn, B.R., Polich, J., 2009. Meditation (Vipassana) and the P3a event-related brain potential. International Journal of Psychophysiology 72, 51–60.

Carmody, J., 2009. Evolving conceptions of mindfulness in clinical settings. Journal of Cognitive Psychotherapy 23, 270–280.

Carvalho, J., Da Rocha, A., Nascimento, F., Souza-Neto, J., Junqueira Jr., L., 2002. In: Yuan, B., Tang, X. (Eds.), Development of a Matlab software for analisis of heart rate variability, Vol. 2. Institute of electrical and Engineers, Inc., Beijing, China, pp. 1488–1492.

Chambers, R., Gullone, E., Allen, B., 2009. Mindful emotion regulation: an integrative review. Clinical Psychology Review 29, 560–572.

Chiesa, A., Serretti, A., 2010. A systematic review of neurobiological and clinical features of mindfulness meditations. Psychological Medicine 40, 1239–1252.

Confalonieri, P., 2006. The Clock of Vipassana Has Struck. Vipassana Research Institute, Igatpuri.

Cranson, R., Goddard, P.H., Orme-Johnson, D., 1990. P300 underconditions of temporal uncertainty and filter attenuation: reduced latency in long-term practitioners of TM. Psychophysiology 27, S23.

Cysarz, D., Bussing, A., 2005. Cardiorespiratory synchronization during zen meditation. European Journal of Applied Physiology 95, 88–95.

Delgado, L.C., Guerra, P., Perakakis, P., Vera, M.N., Reyes del Paso, G., Vila, J., 2010. Treating chronic worry: psychological and physiological effects of a training programme based on mindfulness. Behaviour Research and Therapy 873–882.

Goddard, P.H., 1989. Reduced age-related declines of P300 latencies in elderly racticing Transcendental Meditation. Psychophysiology 26, S29.

Goddard, P.H., 1992. Transcendental meditation as an intervention in the aging of neurocognitive function: Reduced age-related declines of P300 latencies in elderly practitioners. (Doctoral dissertation, Maharishi University of Management, Fairfield, Iowa, 1992) Dissertation Abstracts International 53, 3189B.

Goshvarpour, A., Goshvarpour, A., Rahati, S., 2011. Analysis of lagged Poincaré plots in heart rate signals during meditation. Digital Signal Processing 21, 208–214.

Hayes, A.M., Feldman, G., 2004. Clarifying the construct of mindfulness in the context of emotion regulation and the process of change in therapy. Clinical Psychology: Science and Practice 11, 255–262.

Hayes, S.C., Strosahl, K., Wilson, K.G., 1999. Acceptance and Commitment Therapy: An Experiential Approach to Behavior Change. Guilford Press, Nueva York.

Holzel, B.K., Ott, U., Gard, T., Hempel, H., Weygandt, M., Morgen, K., et al., 2008. Investigation of mindfulness meditation practitioners with voxel-based morphometry. Social Cognitive and Affective Neuroscience 3, 55–61.

Hoshiyama, M., Hoshiyama, A., 2008. Heart rate variability associated with experienced zen meditation. Computers in Cardiology 35, 569–572.

Kabat Zinn, J., 1982. An out-patient program in behavioural medicine for chronic pain patients based on the practice of mindfulness meditation: theoretical considerations and preliminary results. General Hospital Psychiatry 4, 33–47.

Kuyken, W., Watlins, E., Holden, E., White, K., Taylor, R.S., Byford, S., et al., 2010. How does mindfulness-based cognitive therapy work? Behaviour Research and Therapy 48, 1105–1112.

Lazar, S.W., 2005. Mindfulness and psychotherapy. In: Germer, C.K., Siegel, R.D., Fulton, P.R. (Eds.), Mindfulness Research. Guilford Press, New York, pp. 220–238.

Lazar, S.W., Kerr, C.E., Wasserman, R.H., Gray, J.R., Greve, D.N., Treadway, M.T., et al., 2005. Meditation experience is associated with increased cortical thickness. Neuroreport 16, 1893–1897.

Lehrer, P.M., Sasaki, Y., Saito, Y., 1999. Zazen and cardiac variability. Psychosomatic Medicine 61, 812–821.

Lehrer, P.M., Vaschillo, E., Vaschillo, B., 2000. Resonant frecuency biofeedback training to increase cardiac variability: rationale and manual for training. Applied Psychophysiology and Biofeedback 25, 177–191.

Linehan, M., 1993. Cognitive-behavioral Treatment of Borderline Personality Disorder. Guilford Press, Nueva York.

Malliani, A., 1999. The pattern of sympathovagal balance explored in the frequency domain. News in Physiological Sciences 14, 111–117.

McCracken, L.M., Gutiérrez-Martínez, O., 2011. Processes of change in psychological flexibility in an interdisciplinary group-based treatment for chronic pain based on Acceptance and Commitment Therapy. Behaviour Research and Therapy 49, 267–274.

Murthy, P.J., Gangadhar, B.N., Janakiramaiah, N., Subbakrishna, D.K., 1997. Normalization of P300 amplitude following treatment in dysthymia. Biological Psychiatry 42, 740–743.

O'Brien, R.G., Kaiser, M.K., 1985. MANOVA method for analyzing repeated measures designs: an extensive primer. Psychological Bulletin 97, 316–333.

Patra, S., Telles, S., 2010. Heart rate variability during sleep following the practice of cyclic meditation and supine rest. Applied Psychophysiology and Biofeedback 35, 135–140.

Peng, C.K., Mietus, J.E., Liu, Y., Khalsa, G., Douglas, P.S., Benson, H., et al., 1999. Exaggerated heart rate oscillations during two meditation techniques. International Journal of Cardiology 70, 101–107.

Peng, C.K., Henry, I.C., Mietus, J.E., Hausdorff, J.M., Khalsa, G., Benson, H., et al., 2004. Heart rate dynamics during three forms of meditation. International Journal of Cardiology 95, 19–27.

Perakakis, P., Joffily, M., Taylor, M., Guerra, P., Vila, J., 2010. KARDIA: a Matlab software for the analysis of cardiac interbeat intervals. Computer Methods and Programs in Biomedicine 98, 83–89.

Peressitti, C., García-Manso, J.M., Mesa, D., 2010. Heart rate dynamics in different levels of Zen meditation. International Journal of Cardiology 145, 142–146.

Phongsuphap, S., Pongsupap, Y., Chandanamattha, P., Lursinsap, C., 2008. Changes in heart rate variability during concentration meditation. International Journal of Cardiology 130, 481–484.

Polich, J., 2007. Updating P300: an integrative theory of P3a and P3b. Clinical Neurophysiological 118, 2128–2148.

RenuMadhavi, C.H., Ananth, A.G., 2010. Estimation of approximate entropy of heart rate variability of healthy subjects and investigation of the effect of meditation on it. International Conference on Signal Acquisition and Processing, pp. 304–307.

Reyes del Paso, G.A., Langewitz, W., Lambertus Mulder, L.J.M., Van Roon, A., Duscher, S., 2013. The utility of low frequency heart rate variability as an index of sympathetic cardiac tone: a review with emphasis on a reanalysis of previous studies. Psychophysiology 50, 477–487.

Roemer, L., Orsillo, S.M., 2007. An open trial of an acceptance-based behavior therapy for generalized anxiety disorder. Behavior Therapy 38, 72–85.

Sarang, S.P., Tellles, S., 2006. Changes in P300 following two yoga based relaxation techniques. International Journal of Neuroscience 116, 1419–1430.

Segal, Z.V., Wiliams, J.M.G., Teasdale, J.D., 2002. Mindfulness-based Cognitive Therapy for Depression. Guilford, Nueva York.

Smallwood, J., Schooler, J.W., 2006. The restless mind. Psychology Bulletin 132, 946–958.

Telles, S., Mohapatra, R.S., Naveen, K.V., 2005. Heart rate variability spectrum during Vipassana mindfulness meditation. Journal of Indian Psychology 23, 1–5.

Thayer, J.F., Lane, R.D., 2000. A model of neurovisceral integration in emotion regulation and dysregulation. Journal of Affectives Disorders 61, 201–206.

Thera, N., 1962. The Heart of Buddhist Meditation: A Handbook of Mental Training Based on the Buddha's Way of Mindfulness. Rider and Company, London.

Toneatto, T., Nguyen, L., 2007. Does mindfulness meditation improve anxiety and mood symptoms? A review of the controlled research. Canadian Journal of Psychiatry 52, 260–266.

Travis, F., Miskov, S., 1994. P300 latency and amplitude during eyes-closed rest and transcendental meditation practice. Psychophysiology 31, S67.

Wu, S., Lo, P., 2008. Inward-attention meditation increases parasympathetic activity: a study based on heart rate variability. Biomedical Research 29, 245–250.

Zgierska, A., Rabago, D., Chawla, N., Kushner, K., Koehler, R., Marlatt, A., 2009. Mindfulness meditation for substance use disorders: a systematic review. Substance Abuse 30, 266–294.