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Impact of long-term meditation practice on cardiovascular reactivity during perception and reappraisal of affective images

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ABSTRACT

Meditation has been found to be an efficient strategy for coping with stress in healthy individuals and in patients with psychosomatic disorders. The main objective of the present study was to investigate the psychophysiological mechanisms of beneficial effects of meditation on cardiovascular reactivity. We examined effects of long-term Sahaja Yoga meditation on cardiovascular reactivity during affective image processing under "unregulated" and "emotion regulation" conditions. Twenty two experienced meditators and 20 control subjects participated in the study. Under "unregulated" conditions participants were shown neutral and affective images and were asked to attend to them. Under "emotion regulation" conditions they down-regulated negative affect through reappraisal of negative images or up-regulated positive affect through reappraisal of positive images. Under "unregulated" conditions while anticipating upcoming images meditators vs. controls did not show larger pre-stimulus total peripheral resistance and greater cardiac output for negative images in comparison with neutral and positive ones. Control subjects showed TPR decrease for negative images only when they consciously intended to reappraise them (i.e. in the "emotion regulation" condition). Both meditators and controls showed comparable cardiovascular reactivity during perception of positive stimuli, whereas up-regulating of positive affect was associated with more pronounced cardiac activation in meditators. The findings provide some insight into understanding the beneficial influence of meditation on top-down control of emotion and cardiovascular reactivity.

1. Introduction

Recent years have seen a growing interest in meditation as a tool for alternative therapy of stress-related and psychosomatic diseases (for reviews see Barnes and Orme-Johnson, 2012; Chen et al., 2012; Hagins et al., 2013; Khoury et al., 2013). For instance, relatively specific effects of meditation have been identified in relation to cardiovascular diseases. It has been shown that meditation, in short-term trainings and long-term practice, prevents elevated baseline blood pressure and heart rate in healthy individuals and reduces them in hypertensive patients (Anderson et al., 2008; Ankad et al., 2011; Astin et al., 2003; Barnes et al., 2004; Goldstein et al., 2012; Hughes et al., 2013; Nidich et al., 2009), and also decreases symptoms of angina pectoris, cholesterol levels, myocardial ischemia and left ventricular hypertrophy in patients (Barnes et al., 2012; Barnes and Orme-Johnson, 2012; Schneider et al., 2006; Walton et al., 2004). In this regard, the main aim of the present study was to investigate the possible psychophysiological mechanism of beneficial effects of long-term meditation practice on the cardiovascular system. It can be assumed that this mechanism is related not only to beneficial changes in the cardiovascular system during the meditation process, but also to less prominent cardiovascular activation in response to negative stimuli. A lessened impact of negative stimuli on practitioners of mindfulness meditation has been confirmed on attentional and neurophysiological levels. For instance, mindfulness-oriented intervention reduced attentional bias for pain-related stimuli in patients with chronic pain (Garland and Howard, 2013) and long-term mindfulness meditators showed attenuated brain response upon viewing negative pictures (Sobolewski et al., 2011; Taylor et al., 2011). Thus, reduced sensitivity to negative information allows meditators to prolong periods of cardiovascular "silence" leading to adaptive functional and morphological changes in the cardiovascular system. Probably, *changing* the *appraisal* of the significance of incoming aversive stimuli is one of the possible mechanisms for reducing the psychophysiological reactivity to negative information. This assumption is strongly supported by the mindful coping model, proposed by E. Garland et al., which argues for the role of mindfulness, inherent in many meditative styles, in positive reappraisal coping (Garland et al., 2009). Mindfulness practices involve monitoring the content of experience (thoughts, feelings, or sensations) occurring in the present moment while maintaining a

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specific attentional stance: awareness of the phenomenal field as an attentive and nonattached observer (for reviews see Cahn and Polich, 2006; Wadlinger and Isaacowitz, 2011). According to Garland's model, when a given event is "appraised as a threat, harm, or loss that exceeds one's capabilities, the individual may initiate an adaptive response by decentering from this stress appraisal into the mode of mindfulness, wherein one attends to the dynamic process of consciousness itself rather than its contents. From the vantage point of this expanded, metacognitive awareness, one can then reappraise the given event in a positive manner by attributing to it new meaning" (Garland et al., 2009, p. 8). Therefore it is likely that the ability to reappraise negative stimuli can be developed as a consequence of meditation practice and acts as an automatic and effortless emotion regulation strategy, allowing meditators to make less negative appraisals of stressful stimuli, thereby reducing the intensity and duration of concomitant cardiovascular activation.

Thus, the main aim of the present study was to investigate the influence of long-term Sahaja Yoga meditation practice,[1] largely related to a mindfulness type of meditation (Manocha et al., 2012), on the dynamics of the cardiovascular response to affective images, eliciting negative emotions. Considering that cardiovascular responding is multi-dimensional, particular care was taken to assess multiple measures of cardiovascular responding, including heart rate (HR), stroke volume (SV), cardiac output (CO), total peripheral resistance (TPR), and mean arterial blood pressure (MBP).

Generally, cardiovascular response to negative images is characterized by a large initial HR deceleration, sustained for several seconds and accompanied by subsequent CO and blood pressure (BP) decrease, which is indicative of heightened orienting and continued attention to a threatening stimulus (Bradley et al., 2001, 2012; Dan-Glauser and Gross, 2011; Minati et al., 2009). Excessively long bradycardia may diminish oxygen recourses, depress central nervous system function, reduce behavioral complexity and compromise the fight–flight potential of mammals (Porges, 1995, 2009). Thus, the cardiac component of the orienting response must be of short duration, providing a rapid recovery of hemodynamics. We hypothesized that meditators in contrast to controls would diminish threat patterns of cardiovascular activity in the early phase of emotional processing and would be characterized by less prominent orienting bradycardia, and, therefore, reduced subsequent CO and BP decreases in response to negative images. Since we and other authors recently showed that anticipation of negative stimuli was characterized by increased vascular resistance and decreased cardiac output (Pavlov et al., 2014; Zanstra et al., 2010), we also examined the impact of meditation practice on cardiovascular activity in the prestimulus periods. We hypothesized that meditators as compared to controls would be characterized by lower TPR and larger CO during anticipation of negative stimuli.

It should be noted, that there is growing evidence that positive emotion has beneficial effects on endocrine, immune and cardiovascular systems (Davidson et al., 2010; Dockray and Steptoe, 2010; Fredrickson, 2000, 2004; Kubzansky and Thurston, 2007; Steptoe et al., 2009; Tindle et al., 2010). So we have included positive stimuli in the experimental procedure. Early hemodynamic changes in response to positive images are usually characterized by a triphasic (deceleratory, acceleratory, deceleratory) heart rate response where HR and CO decreases are less pronounced than for negative stimuli (Bradley et al., 2001, 2012; Pavlov et al., 2014). Taking into account that long-term meditation practice and meditation trainings contribute to developing positive affectivity (Sridevi et al., 1998), we assume that meditators in comparison to controls would show more pronounced cardiac activation in response to positive images, indexed by greater HR and CO. Increased cardiac activation in the absence of vasoconstriction may characterize the challenge state, associated with the cognitive effort, approach motivation and positive emotion (Blascovich, 2008) and accompany up-regulation of positive affect (Pavlov et al., 2014; Giuliani et al., 2008).

Returning to the mechanisms of beneficial effects of meditation on the cardiovascular system, we may assume that long-term meditation practice not only contributes to automatic changes of appraisals, but also to the development of voluntary reappraisal, associated with deliberate attempts to down- or up-regulate emotion through reappraising the meaning of the emotion-eliciting situation or stimulus (Gross, 2002). Reappraisal, as a voluntary emotion regulation strategy, is implemented through different higher cognitive processes, such as memory, selective attention and response selection, which may be used to direct attention to reappraisal-relevant stimulus features and hold in mind reappraisal goals as well as the content of one's reappraisal (for review see Ochsner et al., 2012). Since mindfulness meditation practice significantly improves attention regulation, including selective attention (for review see Chiesa et al., 2011) we predict developed voluntary reappraisal skills in experienced Sahaja Yoga meditators. Therefore, we also investigated the impact of meditation on cardiovascular response to affective images during down-regulating negative affect through reappraisal of negative images and up-regulating positive affect through reappraisal of positive images. Instructions for increasing positive affect were used, because the ability to increase it seemed to be more actual for health outcomes than, for example, down-regulating of positive emotions.

We hypothesized that meditators would be more effective than controls in down-regulating, demonstrating lower TPR in the anticipatory period along with reduced orienting decreases of HR, CO and BP in comparison to natural perception of negative images. Based on our recent study (Pavlov et al., 2014) we expect that controls would only decrease TPR and increase CO in the anticipatory period, but would fail to reduce cardiac orienting response. But as we have mentioned above, meditators may change negative appraisals automatically, i.e. without any conscious efforts. In this case the hypothesized effects of down-regulation would be already manifested during natural perception of negative images and the additional attempts of meditators to decrease negative affect would not be reflected in cardiovascular activity. As for up-regulating, we hypothesized that meditators in comparison to controls could be more effective in regulating positive affect and would exhibit more pronounced cardiac (HR and CO increase), but not vascular (TPR increase) activation during viewing of positive stimuli. Thereby, we investigated the impact of long-term meditation practice on cardiovascular response under conditions contributing to the implementation of either automatic or deliberate reappraisal. Such an approach seems promising since it makes it possible to ascertain whether automatic or voluntary emotion regulation strategies are mainly developed during the long-term meditation practice.

2. Material and methods

2.1. Participants

Two groups of healthy right-handed males participated in our study. The experimental group included 22 experienced long-term Sahaja Yoga meditators (meditators, mean age = 36.23, SD = 8.96; mean meditation experience = 12.3 years, SD = 4.53) and 20 age-matched healthy controls with no meditation experience (controls, mean age = 33.55, SD = 5.48). None reported suffering from cardiovascular, respiratory, or psychiatric diseases and taking any drugs. All participants were normotensive. The differences between meditators and controls in age, systolic and diastolic blood pressure were insignificant (two tailed *T*-test, all $t < 1.47$, all $p > .1$). All the subjects gave written informed consent and were paid for participation. The research received approval of

[1] Sahaja Yoga meditation is characterized by the mental states of "thoughtless awareness", or "mental silence" and is accompanied by the experience of bliss. In general, the outcome of this meditative technique, as most others, is a sense of relaxation and positive mood and a feeling of benevolence toward oneself and others (Aftanas and Golocheikine, 2001; Aftanas and Golosheykin, 2005; Rai, 1993).

the institutional ethics committee. Meditators were required to have practiced for at least five previous years for a minimum of six hours a week (two meditations per day). Regularity and sincerity of practices of each meditator were additionally confirmed by two leaders of the Novosibirsk Sahaja Yoga regional organization who assisted in organizing the research. The last meditation session was held by Sahaja Yoga participants approximately three hours prior to the experimental study.

2.2. Stimuli

One hundred and sixty images (151 — from free websites, 9 — from the International Affective Picture System (IAPS, Lang et al., 2005)), including 32 neutral (people in emotionally neutral situations), 64 negative (loss, accidents), and 64 positive (attractive women, family) photos were selected for the main study. All pictures included people with well distinguishable facial expressions, experiencing negative or positive emotions or being in a neutral emotional state. An additional 14 images with similar content were selected for the training session (2 positive, 2 negative) and for the practice block (4 positive, 4 negative, 2 neutral) and were not used for further analysis.

2.3. Measures

2.3.1 . Subjective emotional report

After the image offset, two dimensions of valence and arousal (in a nine-point scale for each dimension) were assessed using a computerized Self-Assessment Manikin (SAM) (Bradley and Lang, 1994).

2.3.2 . Cardiovascular responses

Cardiovascular responses were assessed through the use of a Finometer instrument (FMS Finapres Medical Systems, Amsterdam, The Netherlands). The Finometer measures finger arterial pressure on a non-invasive beat-to-beat basis based on the volume-clamp method of Penaz (1973). The Finometer incorporates brachial artery reconstruction technology and the modelflow method providing hemodynamic parameters such as mean arterial blood pressure (MBP, mm Hg), stroke volume (SV, ml), cardiac output (CO, lpm), and total peripheral resistance (TPR, mm Hg × s/ml (medical unit, MU)). Heart rate (HR, bpm) was derived from the pulse interval. Beatscope 1.1 software was used to analyze blood pressure waveforms and related hemodynamic parameters. The Finometer device is successfully used by many research groups for the assessment of the temporal dynamic of cardiovascular response (e.g. Gomez and Danuser, 2010; Minati et al., 2009; Sarlo et al., 2005, 2008). The validity and reliability of this methodology in relation to blood pressure and other derived cardiovascular parameters have been confirmed in many studies (Bogert and van Lieshout, 2005; Jansen et al., 2001; Leonetti et al., 2004; Schutte et al., 2004).

2.4. Procedure

2.4.1 . Training session

Before preparation for the physiological recordings, participants completed a separate training session in the laboratory room. During this session participants received detailed instructions and step-by-step guidance about the reappraisal strategies that should be applied during the experimental session. When decreasing negative emotion during viewing of negative images, participants were instructed to increase their sense of objective distance, viewing pictured events from a detached, third-person perspective and refrain from delving into the emotion expressed by people on the photo. This type of instruction for down-regulating negative affect mainly refers to detached reappraisal strategy. When increasing positive affect during viewing of positive images, participants were instructed to increase their sense of subjective closeness to pictured events, vividly imagining themselves as involved in viewed actions and to try to experience positive emotions together with the people shown on the photos. The given set of instructions refer to self-focused reappraisal strategies characterized by altering the personal relevance of events and making one feel more or less connected to what is going on (Ochsner et al., 2004). After receiving the instructions, participants viewed two positive and two negative images presented sequentially, accompanied by step-by-step audio guidance, again explaining the reappraisal strategy on the example of a real image. After that, the subjects were asked to reappraise the same image without assistance for 1 min. At the end of the training session, the experimenter debriefed participants to ensure that they were able to effectively reappraise and address any questions the participant might have. This training session ensured that participants clearly understood the two types of regulation strategies and could effectively implement them to reappraise negative and positive images.

2.4.2 . Experiment session

After attachment of the sensors for cardiovascular monitoring, a 7-min resting period (2 min with eyes closed and 5 min with eyes open) was recorded. Then participants were given instructions, describing the experimental procedure and performed a practice block (not used for further analyses) including 10 trials. Each trial was composed of four events: cue word (increase, decrease, look) (2.5 s), image (neutral, negative, positive) (5 s), subjective emotional report (3–4 s), and blank screen (2.5 s) (see Fig. 1). While the image remained on the screen, participants performed the operations specified by the prior instructional cue. “LOOK” cues were paired with neutral (neutral trials), positive (unregulated positive trials) and negative images (unregulated negative trials), “INCREASE” cues were paired exclusively with positive images (regulated positive trials), “DECREASE” cues were paired exclusively with negative images (regulated negative trials). Thus, five types of trials were formed. On regulated trials, participants reappraised images as they learned in the training session. On unregulated trials, participants were instructed simply to look at the image and let themselves respond naturally. Unregulated trials were included to establish the basic effect of emotional salience on the cardiovascular response and were also used as a baseline for comparison with regulated trials. Participants were presented with 160 trials broken down into four experimental blocks. Each of the four experimental blocks included 5 sequentially presented series, consisting of 8 trials with similar instructional cues (i.e., 8 neutral, 8 unregulated positive, 8 unregulated negative, 8 regulated positive, and 8 regulated negative trials). Series sequences were counterbalanced across blocks. There was a break of 5 min after each experimental block. Our decision to use a block design was made for two related reasons: (1) a randomized presentation of stimuli, which was tested in a pilot experiment, was very inconvenient for the participants due to the need to rapidly jump between different regulation strategies; (2) the need to switch to a new task before each trial (look or decrease or increase) could contribute to confusion amidst efforts to switch to a new task and intending to reappraise. Such confusion could influence the early seconds of cardiovascular response, which were the main focus of our interest. Since during experimental blocks individuals could spontaneously switch to other emotion regulation strategies (e.g., suppression or attentional deployment in the case of negative images) we additionally controlled whether the participant implemented the requested strategies. After the experiment the participants were asked to describe in written form how they regulated their emotions while viewing affective images. It has been found that two participants from the control group (initially 22 participants) used nonrelevant strategies for negative images, mainly related to attentional deployment (diverting attention away from an image or redirecting thoughts to content not relating to the image) than to reappraisal and have been excluded. Remaining participants constituted the final sample (20 controls, 22 meditators) described above.

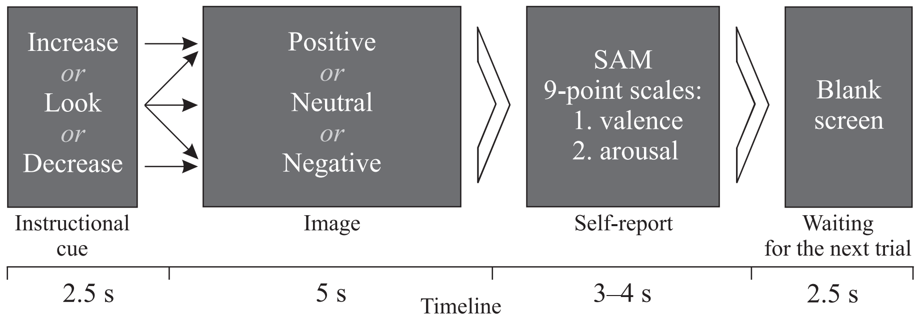

Fig. 1. Timeline for events in each trial. An initial cue instructs participants to increase, decrease, or look, which is followed by an image presentation period during which participants follow this instruction. "Look" cues are paired with neutral, positive and negative images, "increase" cues are paired exclusively with positive images, and "decrease" cues are paired exclusively with negative images. Participants then rate the images on the dimensions of valence and arousal, using SAM 9-points scales and finally wait for the onset of the next trial.

2.5. Data reduction

The software Beatscope 1.1a (FMS Finapres Medical Systems BV) was used to analyze the cardiovascular measures. Individual blood pressure waveforms were visually inspected for movement-related artifacts. Sixteen artifacts (usually spiked waveforms) lasting one to three beats were found in 7 subjects. Trials containing these artifacts were excluded from analyses. Beat-to-beat values of MBP, HR, SV, CO and TPR were converted to mean values for 1500 ms for each trial in the period from −2500 ms before image onset to 5000 ms after the image onset. Thus, 5 time points (duration 1500 ms) were used for analysis. The first two time points corresponded to the pre-stimulus period and the last tree time points — to the viewing period. Additionally beat-to-beat values were averaged for closed eye (2 min) and open eye (5 min) baseline periods. Change scores in the pre-stimulus and viewing periods were computed by subtracting the open eye baseline values from each of the time point values, corresponding to the pre-stimulus and post-stimulus cardiovascular activity and were used for the statistical analyses.

2.5.1 . Preliminary analysis

A preliminary analysis of the relationship of a serial number of trial and cardiovascular dynamics showed that the dynamics of the first trial were different from other trials in the series. On this basis, the first trials were excluded from further analyses.

2.6. Data analysis

Group differences in the effects of emotional salience on the subjective emotional report were analyzed for valence and arousal scores only for unregulated trials using repeated-measures ANOVAs with factors of Group (meditators, controls) and Emotion Category (neutral, negative and positive). Group differences in the effects of reappraisal on the subjective emotional report were analyzed for valence and arousal scores, separately for positive and negative trials, using repeated-measures ANOVAs with factors of Group (meditators, controls) and Regulation (unregulated and regulated).

Group differences in the baseline periods (eyes open and eyes closed) were assessed for each cardiovascular parameter by means of one-way ANOVAs.

Group differences in the effects of emotional salience on cardiovascular activity were analyzed for each cardiovascular parameter only for unregulated trials, using repeated-measures ANOVAs with factors of Group (meditators, controls), Emotion Category (neutral, negative and positive) and Time (5×1500 ms). Group differences in the effects of reappraisal on cardiovascular activity were assessed for each cardiovascular parameter, separately for positive and negative trials, using repeated-measures ANOVAs with factors of Group (meditators, controls), Regulation (unregulated, regulated) and Time (5×1500 ms).

For all analyses, degrees of freedom were Greenhouse–Geisser corrected where appropriate. All the post hoc comparisons were evaluated by means of the Tukey test. Whenever the main analysis showed interactions between Group and Time factors, contrast analyses within specific time points were carried out. Effect sizes are reported using a partial eta square (η_p^2).

3. Results

3.1. Baseline cardiovascular activity

Analyses of the baseline activity revealed that meditators in comparison to controls showed higher HR ($F(1, 40) = 11.37$, $p < .002$, $\eta_p^2 = .22$) and CO ($F(1, 40) = 4.82$, $p < .034$, $\eta_p^2 = .11$) along with lower TPR ($F(1, 40) = 4.38$, $p < .043$, $\eta_p^2 = .10$) in conditions with eyes closed and higher HR ($F(1, 40) = 12.17$, $p < .001$, $\eta_p^2 = .23$) in conditions with eyes open.

3.2. Effects of meditation on subjective and cardiovascular response upon unregulated conditions

3.2.1 . Subjective report

Mean valence and arousal scores for neutral, negative and positive images for meditators and controls in the unregulated and regulated conditions are shown in Table 1. No associations with the factor of group have been revealed. Meanwhile ANOVAs revealed significant effects of Emotion Category for valence ($F(2, 80) = 338.33$, $p < .001$, $\eta_p^2 = .89$) and arousal ($F(2, 80) = 48.15$, $p < .001$, $\eta_p^2 = .55$), showing that both meditators and controls rated positive images as significantly more pleasant as compared to negative and neutral ones, and negative images were rated as significantly more unpleasant than neutral ones (all $p < .01$). Arousal was rated significantly higher for positive and negative images in comparison to neutral images (all $p < .01$). No differences in arousal ratings were found between positive and negative images (all $p > .81$).

Table 1
Mean valence and arousal scores for neutral, negative and positive images in the unregulated and regulated conditions.

Images	Condition	Valence		Arousal		Valence		Arousal	
		M	SD	M	SD	M	SD	M	SD
Group		Controls (N = 22)				Meditators (N = 20)			
Neutral		5.13	0.43	3.23	2.15	5.73	0.93	2.79	2.00
Negative	Unregulated	3.20	0.67	5.26	2.10	3.13	0.78	4.78	2.20
	Regulated	3.27	0.69	5.11	2.01	3.26	0.78	4.26	2.42
Positive	Unregulated	7.24	0.79	5.86	1.88	7.54	0.78	4.53	2.14
	Regulated	7.57	0.64	6.63	1.50	7.96	0.41	5.47	2.15

M — mean values, SD — standard deviation.

3.2.2 . Cardiovascular activity

Analyses of the perception of the affective images revealed Group × Emotion Category × Time interactions for TPR and CO (see Table 2). Further analysis showed that emotional salience of the stimuli affected TPR only in controls (Emotion Category × Time: ($F(8, 152) = 3.38$, $p < .018$, $\eta_p^2 = .15$)), demonstrating greater pre-stimulus TPR for negative trials in comparison with neutral (post-hoc, all $p < .014$), and positive ones (post-hoc, all $p < .003$) during the whole pre-stimulus period. This effect was additionally confirmed by a significant interaction Group × Emotion Category for the first pre-stimulus time point ($F(2, 80) = 3.76$, $p < .032$, $\eta_p^2 = .09$) (Fig. 2A). Emotional salience of the stimuli also affected CO only in controls (Emotion Category × Time: $F(8, 152) = 3.14$, $p < .012$, $\eta_p^2 = .14$), showing that they exhibited lower CO for negative trials in comparison with neutral ones for all time points except time point 4 (post-hoc, all $p < .001$) and in comparison with positive trials during the whole analyzed time interval (post-hoc, all $p < .001$). This effect was additionally confirmed by a significant interactions Group × Emotion Category for the first ($F(2, 80) = 4.00$, $p < .024$, $\eta_p^2 = .09$) and second ($F(2, 80) = 3.64$, $p < .036$, $\eta_p^2 = .08$) pre-stimulus time point (Fig. 2A). Also both meditators and controls demonstrated significantly a low HR for negative trials during the pre-stimulus and viewing periods and were characterized by a less pronounced decrease of MBP in response to positive images in comparison with neutral and negative ones (see Table 2).

3.3. Effects of meditation on the subjective and cardiovascular response under regulated conditions

3.3.1 . Subjective report

The significant effects of Regulation were revealed for valence and arousal for negative (Valence: $F(1, 40) = 4.78$, $p < .040$, $\eta_p^2 = .10$; Arousal: $F(1, 40) = 5.64$, $p < .022$, $\eta_p^2 = .12$) and positive (Valence: $F(1, 40) = 21.16$, $p < .001$, $\eta_p^2 = .35$; Arousal: $F(1, 40) = 34.10$, $p < .001$, $\eta_p^2 = .46$) stimuli. These effects showed that meditators and controls rated negative images, subjected to reappraisal, as less unpleasant and arousing and positive images, subjected to reappraisal, as more pleasant and arousing. The significant effect of Group ($F(1, 40) = 4.56$, $p < .039$, $\eta_p^2 = .10$) was revealed for the arousal dimension during reappraisal of positive images, showing that meditators rated positive images in both regulated and unregulated conditions as less arousing.

Table 2

ANOVA results. $F/p/\eta_p^2$ values for main effects of *Regulation* (*Reg*) and *Emotional Category* (*EmCat*) and interactions between *Group* (*Gr*), *Time* and *EmCat* (or *Reg*) are shown for all cardiovascular parameters.

	Time	EmCat	EmCat × Time	Gr × EmCat × Time
Emotional salience of images				
HR	83.14/0.001/0.66	17.81/0.001/0.31	*n.s.*	*n.s.*
SV	32.34/0.001/0.45	*n.s.*	*n.s.*	*n.s.*
TPR	9.57/0.001/0.19	*n.s.*	*n.s.*	2.91/0.021/0.07
CO	30.90/0.001/0.44	3.91/0.026/0.09	*n.s.*	3.26/0.010/0.08
MBP	65.53/0.001/0.62	*n.s.*	3.72/0.010/0.08	*n.s.*
	Time	*Reg*	*Reg × Time*	*Gr × Reg × Time*
Reappraisal of negative images				
HR	93.74/0.001/0.70	*n.s.*	*n.s.*	*n.s.*
SV	28.84/0.001/0.42	7.62/0.009/0.16	*n.s.*	*n.s.*
TPR	5.26/0.011/0.12	*n.s.*	3.39/0.037/0.08	5.20/0.007/0.12
CO	30.96/0.001/0.44	6.33/0.016/0.14	*n.s.*	*n.s.*
MBP	63.44/0.001/0.61	*n.s.*	*n.s.*	*n.s.*
Reappraisal of positive images				
HR	38.07/0.001/0.49	20.34/0.001/0.34	7.17/0.002/0.15	*n.s.*
SV	20.98/0.001/0.34	*n.s.*	*n.s.*	*n.s.*
TPR	4.20/0.023/0.10	7.60/0.009/0.16	*n.s.*	*n.s.*
CO	9.58/0.001/0.19	14.10/0.001/0.26	5.17/0.005/0.11	4.30/0.012/0.10
MBP	24.03/0.001/0.38	*n.s.*	9.49/0.001/0.19	*n.s.*

Note: Degrees of freedom: 1, 40 for the *Reg*; 2, 80 for the *EmCat*; 4, 160 for the *Time*, *Reg × Time*, and *Gr × Reg × Time*; 8, 320 for the *EmCat × Time* and *Gr × EmCat × Time*. *n.s.* — nonsignificant.

3.4 . Cardiovascular activity

3.4.1 . Negative images

For the reappraisal of negative images ANOVAs revealed Group × Emotion Category × Time interaction for TPR (see Table 2). Analysis of this interaction revealed that reappraisal affected TPR only in controls (Regulation × Time: $F(4, 76) = 8.17$, $p < .002$, $\eta_p^2 = .30$), which were characterized by lower TPR for regulated trials during the pre-stimulus period in comparison with unregulated ones (post-hoc, all $p < .001$). This effect was additionally confirmed by a significant interaction Group × Regulation for the first pre-stimulus time point ($F(1, 40) = 4.49$, $p < .040$, $\eta_p^2 = .10$) (Fig. 2B). Also both meditators and controls demonstrated greater SV and CO during pre-stimulus and viewing periods for regulated trials than for unregulated trials (see Table 2).

3.4.2 . Positive images

For the reappraisal of positive images ANOVAs revealed Group × Emotion Category × Time interaction for CO (see Table 2), showing that reappraisal affected CO only in meditators (Regulation × Time: $F(4, 84) = 7.19$, $p < .001$, $\eta_p^2 = .26$) who showed greater CO for regulated trials than for unregulated ones during the whole analyzed time interval (post-hoc, all $p < .001$), with more pronounced differences at the end of the viewing period. Also meditators were characterized by the absence of significant CO decrease for regulated trials (Time: $F(4, 84) = 1.61$, $p > .21$, $\eta_p^2 = .07$) in contrast to controls (Time: $F(4, 84) = 9.69$, $p < .001$, $\eta_p^2 = .29$). Additional analyses revealed significant interaction Group × Regulation for the last time point of the viewing period ($F(1, 40) = 6.49$, $p < .015$, $\eta_p^2 = .14$) (Fig. 2C). Also both meditators and controls demonstrated lower TPR for regulated as compared to unregulated positive trials during pre-stimulus and viewing periods along with greater MBP and HR during the viewing period. (see Table 2).

4 . Discussion

The present study investigated effects of long-term meditation practice on cardiovascular dynamics during anticipation and viewing of affective stimuli under "unregulated" conditions and during cognitive reappraisal of negative (down-regulating of negative affect) and positive (up-regulating of positive affect) images. Subjective emotional report showed that both controls and meditators accurately determined emotional content of presented images under "unregulated" conditions, significantly decreased negative emotion when reappraising negative images and increased positive emotion when reappraising positive images. Unregulated cardiovascular response to all images, irrespective of their emotional content, was associated with a decrease of HR, CO and MBP, accompanied by compensatory SV increase. Both meditators and controls showed a prominent orienting bradycardia for negative images, and a large decrease of MBP for negative and neutral images.

As for the natural viewing of negative stimuli, our hypothesis has been partially confirmed, as the main differences between meditators and control subjects were found only for anticipatory cardiovascular activity. As was predicted, controls exhibited larger TPR and lower CO during the anticipation of negative images in comparison with neutral and positive images, whereas meditators showed similar TPR and CO for all categories of images. The cardiovascular pattern shown by controls reflects a motivational state of threat, accompanied by anxiety and characterized by an experience of insufficient resources to meet situational demands (Blascovich, 2008; Jamieson et al., 2012; Mauss et al., 2007; Mendes et al., 2003). Since meditators did not exhibit vasoconstriction for negative images, we can assume that meditators in contrast to controls experienced less anxiety while anticipating negative stimuli.

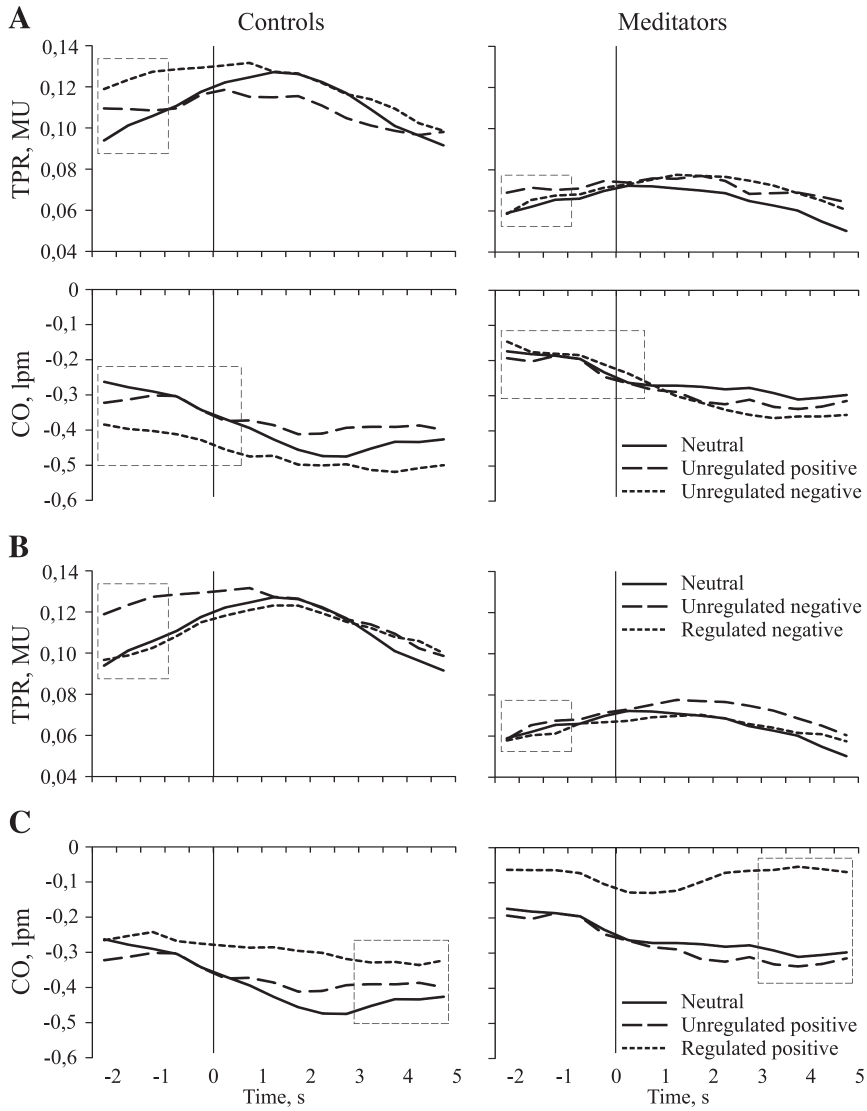

Fig. 2. A. Influence of meditation on emotional salience effects. Continuous plots of mean cardiovascular activity of controls and meditators in the pre-stimulus (from −2.5 s to 0 s before image onset) and viewing (from 0 s to 5 s after image onset) periods during neutral and unregulated negative and positive trials. B. Influence of meditation on reappraisal of negative images. Continuous plots of mean cardiovascular activity in the pre-stimulus and viewing periods during neutral, unregulated negative and regulated negative trials. C. Influence of meditation on reappraisal of positive images. Continuous plots of mean cardiovascular activity in the pre-stimulus and viewing periods during neutral, unregulated positive and regulated positive trials. CO — cardiac output; TPR — total peripheral resistance. Time points where Group × Emotional Category (panel A) or Group × Regulation (panels B and C) interactions were significant are marked by frame.

However, subjective ratings of emotional images did not confirm this assumption. Probably the reason for this contradiction was that the subjective scoring was conducted after image offset and rather reflected emotional state in the viewing period, than in the anticipatory period.

As for the down-regulation of negative affect it is noteworthy that reappraisal of negative images induced hemodynamic changes only in control subjects. As was predicted, they showed attenuation of vasoconstriction and an increase of CO in the anticipatory period, and no changes in the viewing period. These findings replicate the results of our previous study on a large sample (N = 53) of healthy subjects (Pavlov et al., 2014). From a physiological perspective the observed hemodynamic changes may contribute to accumulating metabolic resources before an encounter with an aversive stimulus in order to prevent oxygen and metabolic loss in the orienting phase of cardiovascular responding, which may be crucial for a timely and effective fight-or-flight response (Porges, 1995, 2009). It is important that these adaptive changes in the anticipatory period probably occurred in meditators in the unregulated condition, i.e. in the absence of any regulation efforts. It is for this reason that meditators, in contrast to controls, did not exhibit any hemodynamic changes during the intention to reappraise negative images. However, subjective ratings showed that meditators perceived images subjected to reappraisal, as less negative. This effect (also true for controls) could be partly due to the demand bias resulting from the reappraisal instruction, which clearly stated that participants should try to down-regulate negative emotion. On the other hand, it is likely that a decrease of negative affect in meditators could be reflected by changes of other physiological parameters such as, for example, brain activity. Generally the results, related to negative images, showed that the control subjects were characterized by adaptive hemodynamic profiles (attenuated vasoconstriction and increased blood flow) in the anticipatory period only, when they consciously intended to reappraise an incoming negative stimulus (i.e. under regulated conditions), whereas a similar profile was automatically formed in meditators under unregulated conditions without any conscious regulatory efforts. It is possible that automatic adaptive tuning of hemodynamics during anticipation of a threat, shown by meditators, is one of the mechanisms of stabilization of cardiovascular activity. This assumption is partly confirmed by a lower baseline TPR along with a larger HR and CO in meditators, in comparison with control subjects, which may be considered as a long-term consequence of this mechanism. Lower vasoconstrictive tone along with greater blood flow seem to be adaptive and reflect predominance of beta adrenergic activation over alpha adrenergic, which may be responsible for control of blood pressure increases over time. Another study partly confirms this assumption, showing decrease of blood pressure in hypertensive patients after two weeks of Sahaja Yoga meditation (Chung et al., 2012).

For positive images we hypothesized that experienced meditators would show a more pronounced cardiac activation during their natural viewing. However, this assumption has not been confirmed. Lack of increased activation in meditators in response to positive stimuli was also supported by the ERP study of Sobolewski and coauthors, showing that meditators as compared to controls are less affected by negative images, while processing of positive images remains unaltered (Sobolewski et al., 2011). These findings may be explained by the fact that meditators focus on internally generated positive experience and have a tendency toward emotional stability (Rai, 1993).

Up-regulation of positive emotion during presentation of positive images in comparison with their unregulated viewing was associated with distinct cardiovascular changes in meditators and controls, which consisted of attenuated bradycardia, less pronounced MBP decrease and lower TPR after stimulus onset. Studies investigating autonomic mechanisms of cardiac orienting showed that attenuated bradycardia was the result of concomitant sympathetic influences on the heart (Bernston et al., 1991; Quigley and Berntson, 1990; Sokolov and Cacioppo, 1997). Thus up-regulating of positive affect was associated with increased cardiac (but not vascular) arousal. We hypothesized that meditators would demonstrate more pronounced cardiac activation than controls during up-regulation. Indeed, meditators in contrast to controls showed no orienting decrease of CO after stimulus onset, which may be a result of more pronounced concurrent sympathetic influences on the heart during the orienting response. From a physiological perspective, the observed prevention of blood flow decrease in the early stage of emotional response to positive stimuli provides additional metabolic recourses for efficient functioning of the central nervous and somatic systems, thereby facilitating approach behavior and allowing an individual to rapidly move toward a potential reward (Carver, 2006; Gray, 1994). Our findings do not coincide with the results of Garland's study (Garland et al., 2014), which showed that patients with chronic pain who have opioid use problems demonstrated greater HR decelerations upon positive stimuli after mindfulness training. The discrepancy of the results may be due to the different task instructions. Attenuated orienting bradycardia during up-regulation may be explained by the activation of mental imagery (rejecting sensory input), motivated by the instructions, whereas natural viewing, used in Garland's study, did not urge the functioning of active imagery, so attention to positive images was maintained and even might improve after the mindfulness intervention, resulting in increased bradycardia.

From a theoretical perspective more effective up-regulation of positive emotion in meditators may be explained by the model proposed by Garland and colleagues (Garland et al., 2010). According to this model recurrent meditation (mindfulness) states trigger positive emotions. Positive emotions, in turn, expand people's mindsets and behavioral repertoires, and broaden cognition. Thus, these effects may facilitate deliberate up-regulation of positive emotion, if one is involved in pleasurable events. Despite the greater cardiac activation, meditators as compared to controls showed lower arousal scores for positive images regardless of the experimental conditions. This result may be partly explained by a conscious stance of meditators toward minimizing emotional arousal regardless of the valence of experienced emotion. In this regard, it is noteworthy that valence scores were similar for both groups, indicating identical categorization of the emotional content of the images by all subjects.

4.1 . Limitations of the present study

It is likely that the cardiovascular effects may vary depending on the type of meditation practiced, and brain patterns as well may differ for different practices (for a review see Cahn and Polich, 2006). The next limitation is related to the generalization of our results, because they cannot be extended to life situations, where a subject is faced with unexpected emotional (especially negative) events and should use reappraisal without any preparation. The last limitation is the use of a sample including only male participants. The results of gender difference studies suggest a predominance of sympathetic activity in regulation of blood flow and heart rate in men and a dominant parasympathetic influence on heart rate in women, that are probably determined by gender-related differences in sex steroid levels, and also by gender-specific tissue and cellular differences (Barnett et al., 1999; Evans et al., 2001; Vitale et al., 2009). Thus, we can assume that some effects of reappraisal, associated primarily with TPR and HR could be different in women.

5. Conclusions

In general, the results of the study showed a distinct influence of long-term meditation practice on cardiovascular activity during anticipation and early response to affective stimuli. An adaptive cardiovascular profile, shown by meditators during the anticipation of negative stimuli is probably implemented by means of automatic transition from primary negative appraisals into the transient, metacognitive state of “mindfulness”, which allows meditators to perceive aversive stimuli without personal involvement in their emotional context. As a result, the significance of the expected adverse events is reduced, which contributes to the reduction of anticipatory anxiety and concomitant vasoconstriction. Apparently, mental shifting from the contents of consciousness to the process of consciousness itself becomes the sustained cognitive style of meditators during anticipation of threat. In turn, preventing excessive and repeated vasoconstriction as a reaction to the threat may prevent damage to the endothelium, the formation of atherosclerotic changes in the arteries, and altered vascular reactivity, thus reducing the risk of cardiovascular diseases such as hypertension and coronary artery disease (Lovallo and Gerin, 2003). Probably, such a type of cardiovascular coping with expected stressors becomes intrinsic for meditators, which may explain adaptive functional and morphological changes in the cardiovascular system, associated with meditation practice. Additionally meditators showed more successful up-regulation of positive emotion, manifested in cardiac activation. It allows us to assume that long-term meditation practice may contribute to more efficient regulation of appetitive motivations, resulting in a positive mood and a feeling of benevolence toward oneself and others.

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