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Cultivating Concern for Others: Meditation Training and Motivated Engagement With Human Suffering

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Contemplative traditions have long affirmed that compassion and kindness are trainable skills. While research on meditation practice has recently flourished, the mechanisms that might engender such changes are still poorly understood. Here, we present a motivational framework to explain why meditation training should increase concern for others and modulate empathic engagement with human suffering over time. Meditation practices are conceived as tools for enacting cognitive and emotion regulatory goals that are conditioned by the underlying ethical motivation of the training—to reduce and alleviate suffering. In support of this account, we present data from a randomized, wait-list-controlled study of intensive meditation. In Study 1, we use a novel cardiovascular index to show that 3 months of meditation training can increase the motivational salience of others' suffering, as compared to the salience of threats to oneself. In Study 2, we demonstrate that training-related changes in the ability to orient attention to suffering are mediated by the dynamic regulation of distress-related physiological arousal. Finally, in Study 3, we provide exploratory evidence suggesting that meditation training may influence how human suffering is encoded in memory, leaving lasting imprints on the recollection of emotional experience. Together, our findings suggest that meditation training can strengthen the motivational relevance of others' suffering, prompting a shift from self-focused to other-focused evaluative processing. Considering meditation training from a motivational standpoint offers an important perspective for understanding how compassion can be cultivated through intentional practice.

Public Significance Statement
We examined the question of whether meditation training can alter how people attend to human suffering in ways that might facilitate interpersonal empathy and compassion. After an intensive period of training, experienced meditators demonstrated physiological patterns that signal greater concern in response to indicators of suffering in others. Importantly, they also showed fewer signs of overwhelm and emotional distress. This study highlights the importance of considering people's motivations and intentions for engaging in contemplative practice when assessing the outcomes of meditation-based interventions.

Keywords: emotional memory, empathy, human suffering, meditation, motivation

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Human beings have a profound capacity to feel moved by the suffering of others. This ability—which is commonly called *empathy*—allows observers to share in the pain and predicaments of those in need. Empathy is a hallmark of interpersonal emotional experience, regarded as essential for promoting prosociality and adaptive social functioning (Batson, 1987; de Waal & Preston, 2017; Decety & Meyer, 2008). Yet empathy is not a universal phenomenon. Even when responding to similar situational cues, people can vary widely in their reactions to others' distress, from compassion, concern, and sympathy (Goetz et al., 2010), to indifference and passivity (Cikara et al., 2011), to intense experiences of distress and self-focused negative affect (Eisenberg & Eggum, 2009). Often, people will make concerted efforts to avoid empathizing altogether (Ferguson et al., 2020; Zaki, 2014).

Lapses in empathy are surprisingly common. Fortunately, emerging research suggests that kindness and compassion might be trainable skills. To date, much of this work has centered on the empathy-related effects of Buddhist-based meditation practices (Luberto et al., 2018; Skwara et al., 2017). Contemplative traditions have long pursued questions on the nature of suffering, how people attend to suffering in their lives, and how suffering might be alleviated by altering maladaptive habits of mind (Gethin, 1998; Nhat Hanh, 1998; Tashi Tsering, 2005). Still, despite the widespread adoption of contemplative practices in the clinical and psychological sciences (Creswell, 2017; Wielgosz et al., 2019), relatively little is known about the empirical effects of meditation on responses to suffering. There is also limited knowledge of how empathy changes or deepens over time with contemplative training. Here, we address these questions in hopes of generating knowledge to help mend empathic failures (Zaki & Cikara, 2015).

Overview

In this article, we investigate whether meditation training can enhance empathetic engagement with human suffering. We frame meditation from a motivational perspective to explain how and why concern for others might be cultivated through meditation practice over time. We then propose three hypotheses for how meditation training should modulate reactions to suffering and test these predictions in a longitudinal study that follows a cohort of meditators across a 7-year period. In formulating our predictions, we consider psychological and physiological mechanisms of action, as well as contextual features of modern meditation-based interventions (see McMahan, 2017; see also Condon, 2019; Lutz et al., 2015). In our view, meditation practices function as tools for strengthening cognitive and regulatory processes that act in service of goals embedded within broader contemplative worldviews. Foremost among these goals are the social, relational, and ethical commitments to reduce and alleviate suffering. Before outlining our hypotheses, we consider what kinds of empathic reactions are conducive to compassion and prosociality, how meditation might foster such responses, and how responses to suffering differ from those to other evocative negative stimuli—namely, threat.

Empathic Concern for Others' Well-Being

Empathy is a multifaceted process (Preston & Hofelich, 2012), which can occasion changes in phenomenal experience, peripheral physiology, attentional focus, and regulatory control. For decades, researchers have sought to characterize the features of empathy that tend to either promote or impede an observer's willingness to help others (Ashar et al., 2017; Batson, 1987; Decety & Meyer, 2008; Eisenberg & Eggum, 2009; Eisenberg et al., 1989; Goetz et al., 2010). In this literature, *empathic concern* has been afforded a prominent role as an antecedent of prosocial action. Empathic concern is defined as an other-focused emotional reaction that is oriented toward another's welfare and which motivates a desire to reduce another's distress. By other-focused emotional reaction, we mean that the affect, cognition, and behaviors involved are primarily motivated by attention to and concern for the other, rather than to one's own emotional state. Empathic concern is closely related to feelings of sympathy and compassion[1] and is often associated with adopting or taking on another person's perspective (Davis, 1983).

This same literature has distinguished empathic concern from *personal distress* (or *empathic distress*)—an empathy-related response with distinctive behavioral and physiological correlates. Personal distress reflects a self-focused and aversive or defensive reaction to witnessing another's suffering. Unlike empathic concern, personal distress often entails experience sharing, or vicariously mirroring another's negative affect (Decety & Meyer, 2008). While both can promote helping behavior, personal distress is thought to drive a self-oriented motivation to reduce one's own negative state. Individuals prone to personal distress will help others when it reduces their own felt discomfort but will avoid helping if escape is the easier course of action (see Batson, 1987).

Critically, states of empathic concern have been linked to the optimal self-regulation of vicarious emotional arousal. Chronic under arousal may lead to callousness when witnessing suffering (Decety et al., 2012), whereas over arousal may lead to distress and a felt inability to cope (Eisenberg & Eggum, 2009). For example, accelerated heart rate and increased sympathetic nervous system activation have been associated with personal distress during empathy inductions, while reduced heart rate has been associated with empathic concern and prosocial responding (Eisenberg et al., 1989, 1991; Goetz et al., 2010). In such contexts, heart rate slowing is thought to reflect the outward orienting of attention to targets of empathy. Thus, reactions that are motivated by concern for others tend to be more other-focused than self-focused and are likely strengthened through behavioral routines—including meditation practice—that allow individuals to flexibly attend to shifting emotional and regulatory priorities.

Meditation Training and the Motivation to Reduce Suffering

In its broadest sense, meditation can be conceptualized as a process of intentional self-cultivation, in which practitioners work to develop certain experiential states or modes of being in the world (McMahan, 2017). Within Buddhist contemplative traditions, these modes of being are grounded in a motivation to reduce suffering, which is developed and internalized over time through meditation techniques (Dahl et al., 2015; Lutz et al., 2015), as well as nonmeditative training elements (e.g., rituals, social relationships; Condon & Makransky, 2020; Kirmayer, 2015), that aim to foster relaxation and equanimity,

[1] From this point forward, we use the terms empathic concern and compassion interchangeably to refer to an affective reaction to suffering that is engaged, other-focused, and not driven by personal distress.

self-inquiry, ethical conduct, attentional control, metacognitive reflection, and ongoing behavioral regulation.

One way that meditation training encourages engagement with suffering is through relational-based[2] meditation practices. These are techniques specifically designed for cultivating feelings of sympathy, concern, compassion, friendliness, and well-wishing for others (Jinpa, 2015; Salzberg, 1995; Wallace, 2004). Relational-based practices aim to develop motivational states and traits that increase the incidence of beneficent intentions and that decrease maladaptive or afflictive intentions (e.g., hatred or envy). They also aim to foster a cognitive basis for seeing others as fundamentally like oneself—who also desire happiness and freedom from suffering. These techniques traditionally center around the themes of lovingkindness, compassion, empathetic joy, and equanimity. For example, compassion meditation focuses on the active generation of compassion for suffering individuals and emphasizes skills such as perspective taking, emotion regulation, and seeing our shared humanity in others. During compassion meditation, practitioners may engage in visualizations or episodic simulations (Wilson-Mendenhall et al., 2022) where they call to mind the suffering of sentient beings. Prior research has emphasized the potential for compassion meditation to alter affective or neural responses to human suffering, and to increase prosocial attitudes or behavior (e.g., Ashar et al., 2016; Lutz et al., 2008; Weng et al., 2018; see also Skwara et al., 2017 for a general review).

In addition to relationally oriented practices, the Buddhist tradition offers a much wider scheme of contemplative training techniques, all of which ultimately aim to reduce suffering and to improve the welfare of oneself and others. Included among these are mindfulness-based practices that strengthen faculties of attention and concentration (e.g., Wallace, 2006), and practices that foster meta-awareness, insight, and wisdom into the changing and transient nature of self-identity and phenomenal experience (e.g., Goldstein & Kornfield, 1987). From a psychological perspective, it is assumed that improving one's ability to direct and reorient attention will contribute to broader regulatory capacities (Kaplan & Berman, 2010; Wadlinger & Isaacowitz, 2011), including the ability to cognitively engage with human suffering in the world, and the ability to reduce overarousal resulting from empathy (Eisenberg & Eggum, 2009). In support of this idea, there is some evidence to suggest that mindfulness-based practices can promote empathic concern and prosocial responding, either directly (Berry et al., 2018; Lim et al., 2015), or in conjunction with relationally oriented techniques (Rosenberg et al., 2015).

Finally, meditation practice might also influence responses to suffering through contextual features of the training environment (Condon, 2019; Condon & Makransky, 2020; Lutz et al., 2015). These will include any compassion-supporting frameworks or worldviews that are present in the meditation instructions or that are embedded in the larger sociocultural milieu in which the training is conducted. Key to this perspective is the understanding that meditation training contains elements that help "to give experience meaning and moral significance" (Kirmayer, 2015, p. 452). Or, as Lutz and colleagues have summarized: "… in its broadest Buddhist sense, the term mindfulness often involves a Buddhist practitioner's commitment to a way of life and a stance toward experience that extends beyond any particular set of meditation techniques" (2015, p. 635). Thus, many elements that influence compassion-relevant outcomes may operate relatively independently of the meditation practices being taught. Examples include personal motivations for practice, including any spiritual or religious beliefs, and social factors such as identification with a teacher and interaction with a group of like-minded individuals.

The Empirical Approach

Many research studies have aimed to address the question of how skills learned during the practice of compassion meditation might generalize beyond the training environment and influence the disposition to respond compassionately toward others. Relatively fewer studies have examined how meditative skills such as attentional control might enhance concern for others within the broader context of contemplative training. Here, we suggest that meditation practice might increase the propensity to empathize by enhancing the value placed on other people's welfare and well-being (Batson et al., 1995). At the same time, it should train cognitive and self-regulatory capacities that can be used to enact these motivational goals. People can be incentivized to empathize with others (Ferguson et al., 2020), and meditation training might provide a powerful and pervasive inclination to do so.

In general, if meditation training promotes compassionate tendencies, then such changes should be accompanied by shifts in the motivational relevance (or salience) of others' suffering to individuals' behavioral goals (Goetz et al., 2010; see also Weng et al., 2018 for a similar line of reasoning). Thus, the present studies focused on examining the effects of meditation training on motivational responses to suffering, defined broadly in terms of their cognitive, affective, and physiological components. As a comparison condition, responses to suffering were contrasted with responses to threat—a highly intrinsically motivating category of stimuli. We also chose to implement a holistic training intervention that (a) has strong contextual features of motivation and ethics, (b) includes relationally oriented practices, and (c) emphasizes the training of attentional regulatory techniques. Here, this was achieved by investigating the effects of an intensive meditation retreat on experienced practitioners. We chose to investigate a retreat intervention because retreats can serve as useful model systems for studying the plausible effects of meditation through extended periods of concentrated practice (King et al., 2019).

Motivational Relevance and Stimulus Appraisals

There is ample research showing that the quality and intensity of emotional responses are influenced by people's subjective appraisals, or evaluations, of the situations they face. If a situation or stimulus is deemed important or relevant to a person's goals (Cunningham & Brosch, 2012; Maratos & Pessoa, 2019; C. A. Smith & Kirby, 2009), emotion systems are rapidly mobilized to support action and cognition. Some stimuli or events hold high intrinsic motivational relevance. For instance, humans share a core motivation for survival; stimuli that are perceived as in conflict with this goal (e.g., the appearance of a predator) will elicit emotional reactions consistent with securing safety (Bradley et al., 2001). In the case of threatening stimuli, appraisals tend to be biologically ingrained, and motivational

[2] For simplicity, we use *relational-based* or *relationally oriented practices* as shorthand for a larger family of techniques that center on ethical conduct and the cultivation of interpersonal well-being. These are the constructive practices with a relational orientation in Dahl et al.'s (2015) typology.

responses will be relatively universal, invariant, and obligatory across individuals and situations (Maratos & Pessoa, 2019; Öhman & Mineka, 2001). Consequently, depictions of primary threats to survival (e.g., direct violence, animal attack) will evoke uniformly large increases in sympathetic arousal, oriented attention, and preparedness for action (Bradley et al., 2001; Schupp et al., 2004).

In contrast, depictions of human suffering are among the least reliable elicitors of negative affect in normative populations. Compared to other negative themes and contents, images of suffering (e.g., illness, loss, starvation) evoke low levels of physiological activation and arousal (Bradley et al., 2001; Gomez & Danuser, 2010; Schupp et al., 2004). Notably, responses to suffering are often undifferentiated from those to neutral stimuli. This pattern of weak or inconsistent activation may reflect, in part, the dependence of suffering-relevant appraisals on contextual factors, including the perceived similarity, closeness, or deservingness of the target (Cialdini et al., 1997; Krebs, 1975; Loewenstein & Small, 2007). Dangers to others are typically less motivationally salient than dangers to self (e.g., Craig, 1968) and are therefore less likely to compel behavior to reduce the source of distress. This implies, however, that responses to suffering may be more labile than responses to threat and that empathic engagement might be promoted by interventions that increase the salience of human suffering to personal values and goals.

Previous research has found mixed results for the effects of meditation training on markers of motivational salience. For example, compassion-based meditation has been associated with both increases (Desbordes et al., 2012; Lutz et al., 2008) and decreases (Engen & Singer, 2015; Weng et al., 2018) in amygdala activation to representations of human suffering. In the one study to combine measures of motivational salience, Weng et al. (2018) reported that increases in visual attention to images of suffering were associated with decreases in amygdala activation following compassion-based training. The authors interpreted their findings in terms of greater attentional preference for suffering, coupled with reductions in aversive emotional arousal. However, in absence of increases in amygdala activation, firm conclusions regarding the (physiological) salience of suffering could not be made. Given the complex functional relationships between the amygdala and components of fear-related processing (Cunningham & Brosch, 2012), additional studies using concurrent measures of salience and distress-related arousal are needed. Moreover, these prior studies were limited in that they did not test the selectivity of salience effects for suffering against other arousing or aversive stimuli.

Description of Studies

In the studies below, we recorded cardiovascular measures of motivational salience and distress-related arousal while experienced meditators viewed images of suffering and threat (as well as pleasant images) before and after a meditation intervention. Half of the participants were randomly assigned to a training group and half were assigned to serve as wait-list controls. For 3 months, the training participants practiced meditation in the context of an intensive residential retreat that emphasizes compassionate motivations and the cultivation of calm, focused, and stable attention (MacLean et al, 2010; Rosenberg et al., 2015; Wallace, 2006). Training participants also completed a long-term follow-up assessment to gather retrospective measures of cognitive engagement with human suffering.

We had two core hypotheses, and one exploratory hypothesis, which we investigated using a series of data-analytic approaches. First, we hypothesized that meditation training would increase the motivational salience of others' suffering, relative to the salience of threats to oneself. We tested this hypothesis in Study 1, which presents a between-subjects analysis of meditation training participants and wait-list controls. Heart rate orienting was used to index motivational salience, and growth curve analyses were used to model changes in heart rate responses resulting from the intervention. Dispositional measures of empathy and positive emotion were also assessed and associated with heart rate indexes of motivational salience.

Second, we hypothesized that training-related changes in the salience of suffering would be supported by the physiological regulation of distress-related arousal. This hypothesis was tested in Study 2, which presents a within-subject analysis of the regulatory effects of meditation training on empathic responding. A mediation model was used to test whether reductions in sympathetic cardiovascular reactivity could account for any observed relationships between dispositional empathy and the motivational salience of suffering.

Finally, in exploratory Study 3, we hypothesized that intensive meditation would be associated with physiological patterns of outward cognitive engagement with human suffering. To assess cognitive engagement, we tested training participants on their episodic memory for images that were originally viewed during their intervention 7 years prior. We then used these data to reexamine physiological signals during training as a function of subsequent memory performance.

By addressing these hypotheses, we aimed to better understand how compassionate motivations manifest in attention, emotion, and experience with training. This is important not only for evaluating traditional claims of meditation practice, but for designing more effective empathy building interventions in the future.

Study 1: Between-Subjects Analysis

Study 1 was designed to establish whether meditation training is associated with an increase in the motivational salience of suffering. The main premise was that meditation practice should lead to greater dispositional concern for others, thereby increasing the value that individuals place on others' well-being. As a result, representations of suffering in others should become more motivationally relevant and more readily evoke attentional and visceral responses that signal the significance of events in the environment.

To test this hypothesis, it was necessary to show that the effects of meditation training on motivational responding were (a) specific to themes of human suffering[3] and (b) evident to the mere presentation of these themes. The first concern was addressed by including a comparison condition of threat-relevant stimuli (e.g., weapons, animal attack, human violence) that have high intrinsic relevance, but that

[3] In the studies that follow, images of suffering did not include representations of active violence or physical threat as it was occurring. That is, the immediate threat to the suffering person had already passed. For example, images depicting victims of physical assault were not shown as currently under threat from their attacker. They would only be shown in a state of distress or injury after the attack. Images in the threat category included scenes of direct threat (e.g., guns pointed at the viewer) as well as indirect threat (e.g., one person aiming a gun at another person).

are less likely to be sensitive to changes in empathy. The second concern pertains to the issue of dispositional change. To the extent that meditation training leads to trait-like changes in concern for others, responses to suffering should be altered as a matter of course, whether participants are instructed to generate feelings of compassion or not. Thus, participants were not asked to explicitly engage in any meditation or regulatory techniques at the time of assessment, unlike some previous studies of compassion meditation (e.g., Lutz et al., 2008; Weng et al., 2018; cf., Desbordes et al., 2012).

Heart rate orienting was used to index motivational salience. Salient stimuli tend to capture attention and prompt information intake in anticipation of goal-relevant action. In its initial moments, this attentional cascade co-occurs with a bradycardia response, or a slowing of heart rate, as attention shifts to process the cue's significance (Bradley, 2009; Graham & Clifton, 1966). Under passive viewing conditions, the degree to which heart rate decelerates to a class of stimuli can be taken as a measure of orienting that registers the motivating power of these cues. Moreover, phasic reductions in heart rate have directly been associated with feelings of other-oriented concern and compassion in response to pictures or videos of people in need (Eisenberg et al., 1989, 1991; Stellar et al., 2015).

Our main prediction was that meditation training would lead to greater heart rate orienting (i.e., deceleration) in response to human suffering. We also expected that increases in dispositional concern for others would predict the extent to which orienting responses to suffering were similar in magnitude to threat following training. We reasoned that as empathic concern increases, the relative salience between threats to self and the suffering of others should diminish. This follows from the idea that empathic concern is often associated with greater perceptions of self-other similarity, or a merging of one's own self-concerns with the feeling states of others (Oveis et al., 2010; Preston & Hofelich, 2012). Finally, changes in dispositional measures of several positive emotions were also assessed. These were used to discriminate whether the effects of the intervention were specific to dispositional empathy or were associated with general enhancements in adaptive emotional responding.

Method

Transparency and Openness

The data for the following studies were collected as part of a longitudinal, multimethod investigation of intensive meditation known as the Shamatha Project. Additional details regarding the methods and measures employed in the broader intervention can be found in several of our prior reports: MacLean et al. (2010), Rosenberg et al. (2015), Sahdra et al. (2011), Shields et al. (2020), Zanesco et al. (2018, 2019, 2021). We only report on a limited subset of measures in this article. The processed data supporting the findings of these studies and the statistical code needed to reproduce the major analyses are available on the OSF platform at https://osf.io/e3g5m/ (King et al., 2023). The raw data will be shared upon request. The image materials are available for research use from the Center for the Study of Emotion and Attention (Lang et al., 2008). These studies and analyses were not preregistered.

Participants

The study was advertised as "a research project exploring the relationship between meditation and well-being." The advertisement called for individuals who (a) were interested in practices drawn from the Theravada and Mahayana Buddhist traditions, (b) were between the ages of 21 and 70, (c) were willing to be randomly assigned to a wait-list control group or to a 3-month residential intervention, and (d) had completed at least two previous meditation retreats, including one retreat with the instructor of the present study. The latter requirement ensured that all candidates understood the demands of intensive meditation practice prior to enrollment.

Sample size was determined based on practical and logistical considerations of conducting a study at a remote retreat center. We used a randomized, stratified matching procedure to assign 30 eligible participants to a training group and 30 eligible participants to a wait-list control group (see Table 1; see also MacLean et al., 2010; Shields et al., 2020 for additional matching and recruitment criteria). For 3 months, the training group members lived at a residential retreat center in Northern Colorado and practiced meditation on the retreat grounds. During this time, the control group members lived at home, where they continued their typical daily routines and meditation practices. The control participants traveled to the retreat center for onsite testing at each assessment.[4] All participants gave informed consent and were compensated $20 for each hour of data collection during their enrollment. The Institutional Review Board of the University of California, Davis approved all study protocols.

Training Intervention

The intervention was designed as a cohesive training experience typical of residential meditation retreats (King et al., 2019). Training participants paid for their own room and board, met twice daily for group practice and instruction, and spent most of their day meditating in relative silence and quietude. The content and structure of the training were organized by B. Alan Wallace, who served as the instructor for the retreat (Wallace, 2006).

Two families of meditation practice were taught: *shamatha* techniques that aim to foster calm, focused attention; and the four immeasurables (or *brahma-vihārā*) of lovingkindness, compassion, empathetic joy, and equanimity. During shamatha practice, attention is placed on a sensory or mental object, such as the sensations of the breath, or the field of arising mental events. While mindfully attending to this object, the practitioner seeks to monitor the quality of their attention, detect moments of distraction or lethargy, and refresh focus as necessary. Together, the four immeasurables are used to promote aspirations of compassion and benevolence for oneself and others. The training program emphasized the practice of shamatha techniques, with supportive or ancillary practice of the four immeasurables.[5]

[4] Approximately 3 months after Study 1, these same waitlist participants completed a formally identical retreat intervention of their own (e.g., see Zanesco et al., 2018). However, by this time the control participants had already viewed each image from the stimulus set once. This precluded our ability to investigate the orienting response to novel picture presentations during this second intervention. We therefore only present the results from training and waitlist control participants for the first retreat.

[5] Training participants tended to develop a more rigorous shamatha regimen as the intervention progressed. They reported practicing significantly more hours of shamatha during the last 5 days of retreat ($M = 6.76$, $SD = 1.23$), than during the first 5 days of retreat ($M = 3.86$, $SD = 1.35$), $t(29) = 11.73$, $p < .0001$, Hedges' $g = 2.11$. By contrast, the amount of four immeasurables practice remained constant over time, with Ms of 0.63 and 0.56 hr at the beginning and end of retreat, respectively (SDs = 0.64

Table 1
Participant Demographics, Meditation Experience Variables, and Self-Report Characteristics at Baseline

Variable	Control group ($n = 30$)	Training group ($n = 30$)	Group difference	
			Hedges' g	95% CI
Age	46.4 (22–65)	49.3 (23–69)	0.20	[−0.32, 0.72]
Female/male	16/14	16/14	—	—
Education	4.9 (3–6)	5.4 (3–6)	0.48	[−0.05, 1.00]
Income	6.5 (1–11)	6.9 (1–11)	0.11	[−0.41, 0.62]
Meditation experience				
Years of experience	11.6 (2–35)	13.4 (3–43)	0.15	[−0.36, 0.67]
Lifetime practice hours[a]	2,696.5 (200–15,000)	2,551.4 (250–9,500)	−0.05	[−0.57, 0.47]
Number of retreats	15.2 (2–100)	12.8 (2–50)	−0.15	[−0.67, 0.37]
Minutes of daily practice[b]	54.1 (13–155)	56.0 (9–180)	0.05	[−0.50, 0.60]
Dispositional empathy				
Empathic concern	5.6 (4.1–6.9)	5.9 (4.4–7.0)	0.40	[−0.12, 0.92]
Personal distress	2.8 (1.4–5.6)	2.5 (1.0–4.4)	−0.23	[−0.74, 0.29]
Perspective taking	5.6 (3.3–7.0)	5.5 (2.9–7.0)	−0.11	[−0.63, 0.40]
Positive emotionality				
Amusement	5.0 (2.4–6.8)	5.1 (2.8–6.6)	0.09	[−0.43, 0.61]
Compassion	5.7 (3.2–6.8)	5.9 (4.4–7.0)	0.15	[−0.37, 0.67]
Contentment	5.4 (3.2–7.0)	5.8 (3.8–7.0)	0.44	[−0.08, 0.96]
Joy	5.2 (3.7–6.8)	5.4 (2.8–6.8)	0.15	[−0.36, 0.67]
Love	5.2 (3.8–6.8)	5.5 (4.3–6.7)	0.48	[−0.05, 1.00]

Note. Means and ranges (in parentheses) are displayed for participant characteristics collected prior to group assignment. Education was reported on the following scale: 1 = *less than high school diploma*, 2= *high school diploma*, 3 = *some college*, 4 = *college degree*, 5 = *some graduate study*, 6 = *graduate degree*. Income was reported in increments of $10,000, where 1 = *$10,000 or less per year*, 2 = *$10,001–$20,000 per year*, and so on, up to 11 = *$100,000 or more per year*. Meditation experience variables are lifetime estimates of formal practice, except for minutes of daily practice, which reflects average daily formal practice over the previous 3 years.
[a] $n = 30/29$ for control/retreat groups, respectively. [b] $n = 28/25$.

Procedure

Participants completed an assortment of laboratory tasks during their enrollment in the intervention. The sessions took place in two sound-attenuated and darkened testing chambers located at the retreat center. Physiological signals—including autonomic and electroencephalographic measures—were gathered continuously throughout each session (e.g., see Zanesco et al., 2019). The picture viewing task was administered at the beginning (preassessment) and end (postassessment) of the 3-month study period. We also administered a self-report inventory on three occasions: at preassessment, at postassessment, and at an additional baseline assessment collected prior to random group assignment.

Laboratory Session. Participants sat approximately 60 cm away from a 19-in. liquid-crystal display monitor while a series of images was presented on screen. Each image appeared full screen for 6 s, followed by a 15–18 s variable interstimulus interval. Participants were instructed that each image should be viewed for its full duration and that occasional loud (100 dB) noise bursts would be heard, but that these noises should be ignored.[6] No instructions were given regarding the use of meditation techniques or other regulatory strategies during the task. Participants were only asked to view each image.

Self-Report Assessments. Participants were given 36 hr to complete an inventory of paper-and-pencil questionnaires. From this inventory, we selected two instruments that include measures of dispositional concern for others. The Interpersonal Reactivity Index (21 items; Davis, 1983) was used to assess the three empathy-related facets of empathic concern, personal distress, and perspective taking. The Dispositional Positive Emotions Scale (27 items; Shiota et al., 2006) was used to assess participants' tendencies to experience the five positive emotions of compassion, amusement, contentment, joy, and love. Participants indicated their responses on a 7-point scale from *strongly disagree* (1) to *strongly agree* (7). Scale reliabilities for the questionnaire inventory are available in Sahdra et al. (2011). Data for one control participant are missing for the dispositional positive emotions due to incomplete responding.

Picture Stimuli

We selected 72 pleasant images and 72 unpleasant images from the International Affective Picture System (IAPS; Lang et al., 2008). The *pleasant images* depicted diverse themes of affiliation (e.g., babies, cute animals), natural scenery, daily life, and positive social engagement. The unpleasant images comprised two subcategories: *threat images*, which depicted scenes of active violence, direct or vicarious threat, and physical danger; and *suffering images*, which showed people in pain, emotional distress, or in obvious need of physical or material aid.

We constructed two stimulus sets, such that (a) each set contained 36 pleasant images and 36 unpleasant images, (b) the two sets were

and 0.24), $t(29) = 0.61$, $p = 0.55$, $g = 0.11$. In an ancillary set of analyses, we used meditation hours while on retreat as predictors of heart rate and self-report outcomes. In all cases, the results were not statistically significant.

[6] The intervention included several tasks that were designed to assess multiple scientific questions. In this case, startle probes were included to track the time course of emotion regulation to pleasant and unpleasant images. The noise bursts were presented either 1.5 or 4.5 s after picture onset, or 1 s after picture offset. Preliminary analyses demonstrated that heart rate waveforms were unduly influenced by the earliest probe latency, and so we dropped these trials from all further analyses (see the Appendix). A direct investigation of participants' responses to the startle probes is beyond the scope of the present report.

equated on normative valence and arousal, and (c) pairs of stimuli between the two sets were matched on visual thematic content. In some cases, the thematic matching was based on specific visual exemplars (e.g., an image of a shark), and in other cases on general semantic content (e.g., themes of loss). The presentation order of the two sets was counterbalanced across assessments. A listing of the matched threat and suffering images is given in the Appendix. There were 15 images of threat and 15 images of suffering presented at each assessment. The remaining six negative images depicted nonspecific negative content. After removing trials accompanied by an early-latency auditory probe (see Footnote 6), there were 10 threat images, 11 suffering images, and 24 pleasant images available for analysis at each assessment. The presentation order of images was fully randomized at each assessment.

Physiological Measurement

An electrocardiogram (ECG) signal was acquired from two active Ag/AgCl flat surface electrodes placed at the left collar bone and lowest right rib. The ECG was recorded using a Biosemi Active2 system with 24-bit resolution. The signal was sampled at 2,048 Hz, band-pass-filtered offline between 0.5 and 40 Hz, and then reduced to an interbeat interval (IBI) series using the ANSLAB physiological processing software (Blechert et al., 2016). The continuous IBI series was then converted to heart rate in beats per minute (bpm) at a sampling rate of 4 Hz. For each trial, mean heart rate was extracted from each of 12 consecutive half-second bins and baseline corrected against a 1 s prestimulus baseline. We averaged these bins within levels of assessment and picture content category to create condition-averaged waveforms for each participant.

Two control participants were excluded from heart rate analyses because they declined to participate in this portion of the study. Heart rate data from one additional control participant could not be used due to poor overall signal quality.

Statistical Analysis

We used multilevel growth curve models (Hoffman, 2015) to characterize condition differences in the orienting waveforms. The models included fixed and random polynomial slope parameters to describe the shape and variability of the heart rate responses across bins. The models also included the fixed between-subjects factor of group (control, training) and the within-subject factors of assessment (preassessment, postassessment) and picture content category (pleasant, threat, and suffering). The effects of primary interest were the three-way interaction of group, assessment, and picture category, and the four-way interactions of group, assessment, and category with the polynomial slopes. All models were estimated using full maximum likelihood in SAS PROC MIXED Version 9.4. Degrees of freedom were determined using the Satterthwaite approximation.

Dispositional measures of empathy and positive emotionality were analyzed via correlation and multivariate analyses of variance (MANOVA). For the correlations, we partialled out preassessment scores from changes across assessments (postassessment–preassessment). Due to the number of resultant tests, we controlled for multiple corrections in these analyses using the false discovery rate (FDR) method of Benjamini and Hochberg (1995).

Results

Table 1 presents baseline characteristics and demographic information for the training and control groups. The groups were matched on age, sex, education level, annual household income, and estimates of lifetime meditation experience. There was a wide range of practice experience overall—though at minimum all participants had been meditating for 2 years and had attended at least two previous residential retreats. Importantly, the training and control participants reported similar levels of empathy and positive emotionality prior to random group assignment. Additional demographics, including ethnicity and country of origin, are available in Sahdra et al. (2011).

Correlations between baseline measures of empathy and positive emotionality are presented in Table S1 in the online supplemental materials for the full participant sample. Empathic concern was strongly correlated with compassion ($r = .75$, $p < .0001$), indicating a high degree of conceptual overlap between these two constructs. Empathic concern and compassion were also negatively associated with personal distress ($rs = -.39$ and $-.29$, respectively, $ps < .024$), and positively associated with love ($rs = .46$ and .47, $ps < .001$). The positive emotions of amusement, contentment, and joy did not significantly correlate with the empathy-related constructs of compassion, empathic concern, or empathic distress.

Changes in Empathy and Positive Emotionality

We first examined changes in self-report outcomes as a function of group and assessment. Descriptive statistics for each measure are presented in Table S2 in the online supplemental materials. One MANOVA was conducted for the three empathy facets and another for the five positive emotions. A significant Group × Assessment interaction was obtained for empathy, $F(3, 56) = 4.13$, $p = .010$, as well as positive emotionality, $F(5, 53) = 5.92$, $p < .001$.

Summary statistics and effect sizes for the univariate effects of assessment from each MANOVA are presented in Table 2. Training participants increased significantly in all positive emotions from pre- to postassessment and changed in expected directions in all three empathy subscales. The effect sizes ranged from moderate for empathic concern and perspective taking to large (around 1.0) for contentment and love. Of these, only the change in perspective taking did not survive correction for multiple comparisons. No significant changes were observed for control group participants, and there were no significant group differences at preassessment for either set of measures, according to the multivariate tests, $ps > .396$.

Changes in Heart Rate Orienting

Figure 1 depicts the condition-averaged heart rate responses to pleasant, threat, and suffering images. The orienting response is seen as a rapid and sustained deceleration following picture onset. As in prior research (Bradley et al., 2001), the magnitude of the response was appreciably stronger (more decelerative) for negative than for pleasant picture contents.

We used a sequential model-building procedure to test the significance of fixed and random effects in describing the shape of the heart rate waveforms. Fixed effects (and their interactions) were tested first; then variance components were tested to arrive at an appropriate covariance pattern (Hoffman, 2015). Across all conditions, the response curves were well-described by a quadratic function,

Table 2
Changes in Dispositional Empathy and Positive Emotionality From Pre- to Postassessment

Self-report measure	Control group				Training group			
	M	95% CI	*p*	*g*	*M*	95% CI	*p*	*g*
Dispositional empathy								
Empathic concern	0.01	[−0.20, 0.22]	.945	0.01	0.29[a]	[0.08, 0.50]	.008	0.43
Personal distress	−0.04	[−0.24, 0.16]	.698	−0.11	−0.52[a]	[−0.72, −0.32]	<.001	−0.75
Perspective taking	0.07	[−0.13, 0.27]	.485	0.12	0.21	[0.01, 0.42]	.040	0.41
Positive emotionality								
Amusement	−0.07	[−0.30, 0.16]	.544	−0.12	0.46[a]	[0.24, 0.68]	<.001	0.72
Compassion	0.05	[−0.13, 0.22]	.585	0.09	0.29[a]	[0.11, 0.46]	.002	0.65
Contentment	−0.01	[−0.21, 0.20]	.947	−0.01	0.58[a]	[0.38, 0.78]	<.001	1.01
Joy	−0.07	[−0.32, 0.17]	.550	−0.11	0.43[a]	[0.18, 0.67]	<.001	0.62
Love	0.06	[−0.14, 0.26]	.566	0.11	0.59[a]	[0.40, 0.79]	<.001	1.05

Note. Summary statistics and *p* values are pairwise contrasts from multivariate ANOVA, and *g* is Hedges' measure of effect size for dependent samples. Positive mean values indicate increases from pre- to postassessment. CI = confidence interval; ANOVA = analysis of variance.
[a]Significant discovery based on false discovery rate control for 16 tests (adjusted $\alpha = .022$).

$F(1, 4{,}047) = 109.55$, $p < .0001$, and so fixed effects of linear and quadratic slopes were included in all models. The slopes were centered at the 10th heart rate bin (or 5 s after picture onset) to assess the effects of group and assessment. This is the latency at which the grand-averaged mean response across all image categories and participants reached its peak deceleration. Consequently, for all models, the intercept is interpreted as the expected response magnitude at the absolute maximum of the global waveform function. The predictor of group was referenced to controls, and the predictor of assessment was referenced to preassessment.

Model Fitting. The results of the model fitting procedure are summarized in Table 3. Step 1 was a baseline main effects model. Step 2 added the interaction of Linear Slope × Picture Category × Group × Assessment (and all lower-order effects). The inclusion of these effects significantly improved model fit, and the four-way interaction was significant, $F(2, 4{,}047) = 4.30$, $p = .014$. Next, the interaction of Quadratic Slope × Picture Category × Group × Assessment was added. Model fit again improved, $-2\Delta LL(11) = 36.8$, $p < .001$, but the four-way interaction was not significant, $F(2, 4{,}047) = 0.22$, $p = .801$. In this case, the improved fit was due to a significant lower-order interaction of Quadratic Slope × Picture Category, $F(2, 4{,}047) = 17.08$, $p < .0001$. This interaction was retained in Step 3, but all other (nonsignificant) effects of quadratic slope were removed.

The remaining steps assessed the fit of random slopes and the heterogeneity of variance components across the stimulus categories. Step 4 allowed individuals to vary in the magnitude of their linear heart rate slope. Steps 5 and 6 showed that fit is further improved when each picture category is given a unique random slope, intercept, and residual variance. The model with heterogeneous random linear slopes (Step 5) was preferred to a model that included homogenous random quadratic slopes (i.e., a model where random quadratic slopes take a constant value across levels of picture category). Finally, Step 7 allowed individuals to vary in their average response change from pre- to postassessment.

Model Parameters. Parameter estimates for the best-fitting heart rate model (Step 7) are presented in Table 4. Type III tests indicated significant interactions between picture category, group, and assessment, $F(2, 2{,}284) = 5.95$, $p = .003$, and between picture category, group, assessment, and linear heart rate slope, $F(2, 2{,}284) = 7.84$, $p < .001$. In interpreting these model parameters, the fixed effects[7] of group, assessment, and Group × Assessment represent modulations of overall response magnitude, while the interactions of these effects with linear slope indicate changes in the rate of linear change in heart rate across the picture viewing interval.

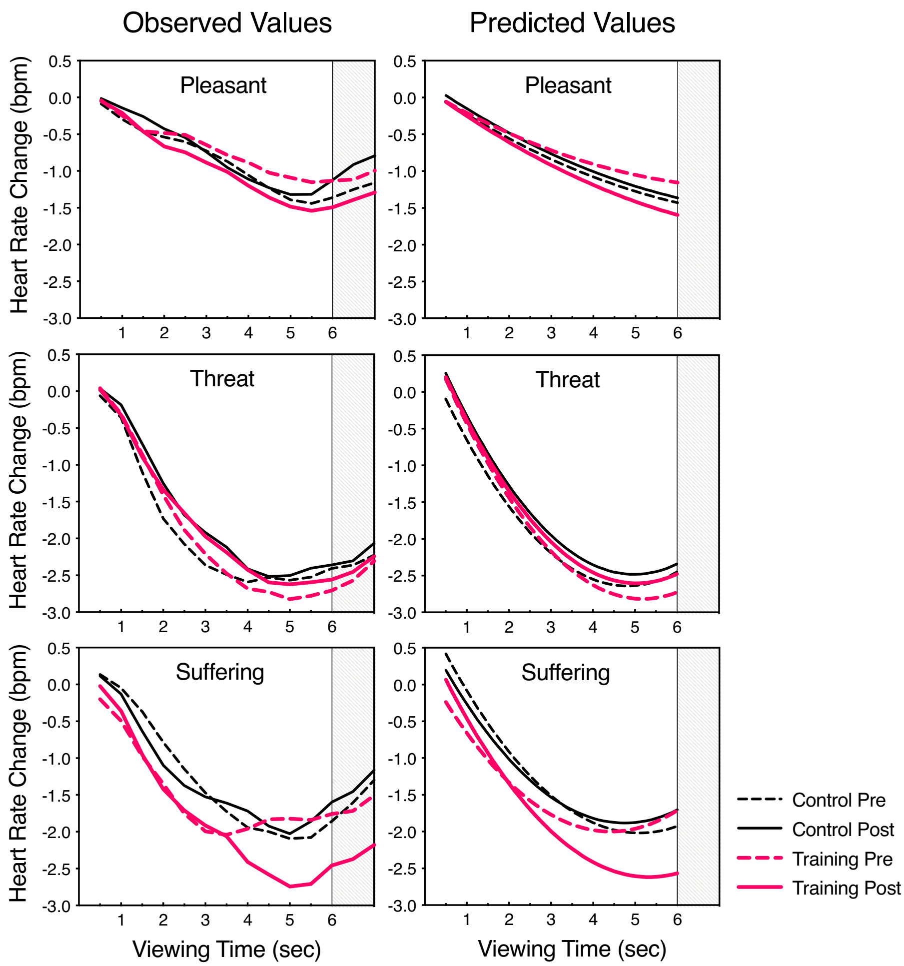
As shown in Table 4, the two-way interaction of group and assessment and the three-way interaction of group, assessment, and linear slope were significant for suffering content but negligible for threat. For suffering, control participants showed no significant changes across assessments in overall magnitude (effect of assessment: $\beta = 0.141$, 95% confidence interval [CI] [−0.280, 0.562], $p = .508$) or in the linear rate of change in heart rate (Assessment × Linear Slope: $\beta = 0.040$, 95% CI [−0.003, 0.083], $p = .065$). Compared to controls, training participants demonstrated significantly greater changes in peak deceleration (Group × Assessment: $\beta = -0.787$ bpm, 95% CI [−1.367, −0.207], $p = .008$) and linear rate of change (Group × Assessment × Linear Slope: $\beta = -0.146$, 95% CI [−0.205, −0.087], $p < .0001$) to suffering from pre- to postassessment. For suffering, training participants showed a model-estimated increase in peak deceleration of −0.646 bpm ($SE = 0.201$, 95% CI [−1.045, −0.247], $p = .002$) at postassessment compared to preassessment, and an estimated increase in the rate of deceleration of −0.105 bpm ($SE = 0.021$, 95% CI [−0.146, −0.065], $p < .0001$), across assessments (see also Figure 1, bottom-right panel). There were no significant effects of group or assessment for threatening or pleasant picture contents.

Correlations Between Dispositional Outcomes and Orienting to Suffering

We next examined whether the strength of the orienting response to suffering, relative to threat, was related to training-related changes in dispositional concern for others. We computed a summary

[7] An interpretation of the random effects of Table 4 is beyond the scope of the present investigation. They were modeled principally to allow for individual variability in the response curve parameters and to maximize the random effect structure. However, it is worth noting that model fit was substantially improved by allowing for heterogeneous growth parameters and residuals across the three picture categories. The variance in magnitude for threat (4.03) was roughly twice as large as that of suffering (1.97).

Figure 1
Heart Rate Responses to Emotional Images by Group and Assessment



Note. Observed subject grand averages are shown on the left, with corresponding growth curve trajectories on the right. Values shown after picture offset (shaded in grey) are for descriptive purposes only. See Table 4 for the parameterization of predicted values. bpm = beats per minute; Pre = preassessment; Post = postassessment. See the online article for the color version of the figure.

orienting index by subtracting each training participant's mean heart rate response to suffering from their mean response to threat, averaged across the picture-viewing interval. We then correlated these values with changes in each dispositional outcome from pre- to postassessment. Larger values of the orienting index indicate relatively enhanced orienting to suffering, as compared to threat. These analyses were restricted to training group participants because no changes in orienting or dispositional outcomes were observed among control group participants across assessments.

Correlations among the orienting indexes at each assessment and changes in dispositional outcomes are presented in Table S3 in the online supplemental materials. For training participants, greater orienting to suffering at postassessment was significantly correlated with increases in empathic concern ($r = .44$, $p = .016$) and amusement ($r = .49$, $p = .007$) from pre- to postassessment. Moreover, changes in empathic concern were significantly negatively correlated with changes in personal distress ($r = -.49$, $p = .008$), and positively correlated with changes in compassion ($r = .54$, $p = .003$) and love ($r = .54$, $p = .003$). No correlations with the preassessment orienting index survived FDR correction. A scatterplot of the association between the orienting index at postassessment and changes in empathic concern is shown in the left of Figure 2a.

Summary and Discussion

The results of Study 1 support the prediction that meditation training can enhance the motivational relevance of human suffering. Meditation training increased heart rate orienting to suffering images, but not to pleasant scenes or threatening content. Changes in orienting were manifest in a steeper rate of decline in heart rate, leading to a greater overall peak magnitude of deceleration. As proxies for motivational salience, these findings are compatible with the idea that suffering more readily captures attention after intensive meditation. Importantly, by the end of the intervention, training

Table 3
Sequential Fit Statistics for Growth Curve Model of Heart Rate Orienting to Emotional Images

Model step and summary of added effects	AIC	BIC	Param.	2ΔLL (*df*)
Model for the means				
1. Main effects model with random subject intercept	14,988	15,007	9	—
2. Linear HR Slope × Picture Category × Group × Assessment Interaction	14,926	14,981	27	98 (18)
3. Quadratic HR Slope × Picture Category Interaction	14,896	14,955	29	34 (2)
Model for the variances				
4. Random linear HR slope and covariance with the intercept	14,589	14,653	31	311 (2)
5. Heterogeneous random HR slopes, intercepts, and covariances	13,424	13,499	37	1,178 (6)
6. Heterogeneous residual variances	13,075	13,155	39	353 (2)
7. Random assessment variance	12,178	12,260	40	899 (1)

Note. The incremental fit of fixed effects (means) and random effects (variances) was evaluated as the difference in −2ΔLL between successive models, with degrees of freedom (*df*) equal to the difference in model parameters. All steps significantly improved fit at $p < .0001$. Step 1 includes fixed main effects of picture category, participant group, and assessment, and linear and quadratic polynomial HR slopes. Steps 2 and 3 include all lower-order fixed effects implied by the interaction terms. Steps 5 and 6 allow variance components to vary freely across levels of picture content category. The number of data points modeled was 4,104. AIC = Akaike information criterion; BIC = Bayesian information criterion; Param. = parameters; −2ΔLL = −2 log likelihood; HR = heart rate.

participants' orienting responses to suffering were more similar in magnitude to those evoked by threatening stimuli with high intrinsic motivational significance (see Figure 1).

The present findings concur with prior research demonstrating broad improvements in socioemotional functioning following residential meditation retreats (Cohen et al., 2017; Sahdra et al., 2011). Reports of positive emotionality, compassion, and empathic concern all increased with training, and reports of personal distress decreased. Our study was limited, however, in that we did not assess situational reports of empathic distress during the picture viewing task. It is still possible that the intervention could have increased distress to images of suffering, despite the association that was observed between orienting to suffering and dispositional reports of empathic concern. This could have occurred if the intervention had heightened participants' motivation to respond compassionately to others without also increasing their ability to downregulate aversive feelings resulting from their efforts to empathize (Weng et al., 2017). In this case, greater heart rate deceleration to images of suffering may have signaled enhanced motivational activation by the sources of this personal discomfort. We address this issue in Study 2, where we revisit the data of Study 1 using peripheral measures of sympathetic autonomic arousal.

Study 2: Within-Subject Analysis

Study 2 involved an extended analysis of the suffering and threat conditions of Study 1. There were two primary aims. First, we sought to demonstrate that the orienting increases observed among training group participants in the previous study were not accompanied by concomitant increases in autonomic markers of empathic distress.

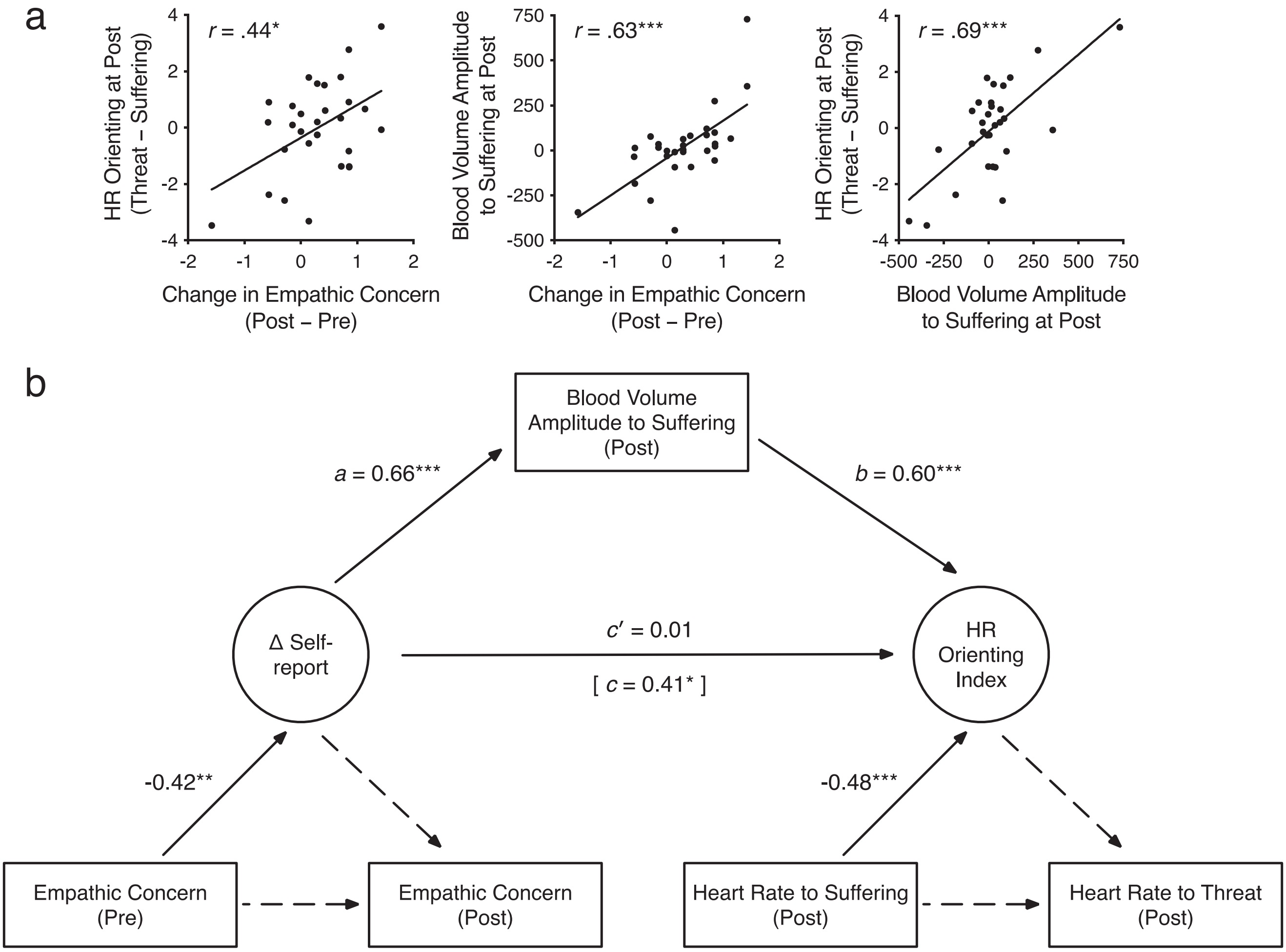
Table 4
Parameter Estimates for Growth Curve Model of Heart Rate Orienting to Emotional Images

	Pleasant		Threat		Suffering	
Parameter	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
Fixed effects						
Intercept[a]	−1.275	0.239	−2.637***	0.399	−2.017***	0.281
Linear slope (0 = 5 s)	−0.088**	0.029	0.025	0.046	−0.012	0.037
Quadratic slope[a]	0.005**	0.002	0.034***	0.003	0.029***	0.002
Group (0 = *control*)	0.224	0.329	−0.176	0.550	0.057	0.387
× Linear slope	0.025	0.037	−0.050	0.056	0.079	0.045
Assessment (0 = *pre*)	0.070	0.197	0.154	0.231	0.141	0.212
× Linear slope	−0.001	0.015	−0.022	0.029	0.040	0.022
Group × Assessment[b]	−0.432	0.271	0.055	0.319	−0.787**	0.292
× Linear slope[c]	−0.039	0.021	0.042	0.040	−0.146***	0.030
Variance components						
Intercept variance	1.468***	0.284	4.027***	0.782	1.969***	0.385
Linear slope variance	0.016***	0.003	0.033***	0.007	0.022***	0.005
Intercept–slope cov.	0.116***	0.027	0.330***	0.071	0.181***	0.040
Assessment variance	0.902***	0.177	—	—	—	—
Residual variance	0.431***	0.022	1.602***	0.071	0.923***	0.042

Note. Maximum likelihood estimates are reported for Model Step 7 of Table 3. For each picture category, the intercept is the expected mean heart rate (in bpm) for control group participants at 5 s post-picture onset at preassessment (pre). Dashes (—) indicate that a parameter was held constant across levels of picture category. cov. = covariance; bpm = beats per minute.
[a]For this parameter, the pleasant condition differs significantly from threat and suffering. [b]All three conditions significantly differ. [c]The suffering condition differs significantly from pleasant and threat.
$^{**}p < .01$. $^{***}p < .001$.

Figure 2

Correlation and Mediation Analyses of the Primary Outcomes of Studies 1 and 2



Note. (a) Scatterplots showing observed relationships between heart rate orienting to suffering, changes in empathic concern, and blood volume amplitude to suffering among training group participants. (b) Standardized path coefficients for the effect of changes in empathic concern on a latent difference measure of heart rate orienting to suffering. The total effect is indicated in brackets. Dashed paths are fixed to 1, and error variance parameters are omitted. HR = heart rate; Post = posttraining assessment; Pre = pretraining assessment.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Second, we hoped to show that training participants' capacity to regulate their autonomic arousal helped to facilitate their ability to orient attention to suffering after training.

As an aversive emotional experience, states of personal distress are often accompanied by heightened levels of sympathetic autonomic arousal. Most work in this area has used skin conductance to index sympathetic activation in the context of empathically distressing situations (Eisenberg et al., 1991; Goetz et al., 2010). Alternatively, sympathetic influences on the cardiovascular system can be used to infer empathic motivations and states. In prior studies, these have included peripheral measures of vascular blood flow, such as blood volume amplitude and the timing of pulse waves to arterial sites (Krebs, 1975; Levenson & Ruef, 1992). Here, we quantified these two cardiovascular indexes distally at the finger. Evidence for the selectivity of sympathetic effects on these measures comes from studies of reactions to laboratory stressors (Bloom & Trautt, 1977; T. W. Smith et al., 1984) as well as studies utilizing autonomic blockades (Contrada et al., 1995; Miller & Ditto, 1991).

Our two study aims were tested as follows. First, we characterized changes in blood volume amplitude and pulse transit time in response to images of suffering and threat in the training participants of Study 1. Then, tests of statistical mediation were conducted to determine whether lower levels of sympathetic arousal after training could explain the observed relationship between increases in dispositional concern for others and heart rate orienting to suffering. As before, we limited these analyses to training group participants because no changes in the relevant outcomes were observed among control group participants in the previous study.

Method

The participants for this study were the 30 training group members already described for Study 1. The procedures and processing steps were the same as Study 1, except that (a) control group members and pleasant images were excluded from analysis, and (b) we included additional cardiovascular measures that were gathered but not assessed as part of the previous study.

Physiological Measurement

A finger photoplethysmograph (ADI instruments MLT1020) was used to measure modulations in peripheral blood flow during the picture viewing task. The sensor was affixed to participants' nondominant index finger as their hand rested palm facing upwards in their lap. The pulse wave signal was sampled at 400 Hz, band-pass-filtered (0.13–20 Hz), and synchronized with the IBI series (see Study 1 Method) so that differences between the two signals would reflect the real-time latency of cardiovascular events.

Three signal features were identified for each cardiac cycle: (a) the R-spike of the ECG; (b) the foot, or onset of the pulse wave—marked by the maximum second derivative of the plethysmogram (Elgendi, 2012). This is the point during early systole when acceleration of blood flow to the finger is greatest; and (c) the peak of the pulse wave, reflecting the maximal extent of blood profusion to the microvasculature. We then quantified two measures of peripheral sympathetic arousal: *blood volume amplitude*, defined as the foot-to-peak difference in pulse wave magnitude (measured in arbitrary units); and *pulse transit time*, defined as the difference, in milliseconds, between the peak of each R-spike and its succeeding pulse wave foot.

Continuous samples of blood volume amplitude and pulse transit time were reduced to condition-averaged waveforms using the same procedure as Study 1. Lower values of the resulting waveforms indicate relatively greater levels of sympathetic outflow to the periphery. We used growth curve models to examine changes in the level of the waveforms as a function of assessment (pre- vs. posttraining) and picture category (threat vs. suffering). In addition, summary measures of sympathetic activation at the posttraining assessment were created for use in correlation and mediation analyses by averaging values of blood volume amplitude and transit time across the picture-viewing interval.

Statistical Analysis

Mediation analyses were conducted in a structural equation modeling framework using the lavaan software package in R (Rosseel, 2012). Separate models were run for each dispositional predictor of empathy and positive emotionality. The independent variables were changes in dispositional outcomes from pre- to posttraining; the dependent variable was orienting to suffering versus threat at the posttraining assessment; and the mediating variable was finger pulse activity to suffering at the posttraining assessment. The independent and dependent variables were estimated as latent difference scores (McArdle, 2009). See Figure 2b for a depiction of the structural path model with empathic concern as the independent variable and blood volume amplitude as the mediator.

For all models, the main parameters of interest were the indirect effect of the independent variable on the dependent variable, acting through the mediator; and the total effect, which represents the sum of the indirect and direct effects of the independent variable acting on the outcome. The test of indirect effects was based on the product of path coefficients (MacKinnon et al., 2002). Standardized parameter estimates and confidence intervals are reported for all effects, as estimated with full maximum likelihood. *SE*s were bootstrapped based on 10,000 permutations (Shrout & Bolger, 2002).

Results

Peripheral Pulse Response Curves

Figure 3 presents condition-averaged waveforms for peripheral pulse responses to suffering and threat. For pretraining images, blood volume amplitude tended to reduce across the latter half of the picture interval, indicating a progressive increase in peripheral vasoconstriction. The pattern for transit time was more phasic in form. Nevertheless, for suffering images, both cardiovascular measures tended to change in the expected positive direction from pre- to posttraining.

Blood volume amplitude was best described by a quadratic polynomial function, $F(1, 1{,}030) = 30.89$, $p < .0001$, and transit time by a cubic (or third-order) polynomial, $F(1, 1{,}088) = 5.33$, $p = .021$. Both measures showed a significant three-way interaction between linear slope, assessment, and picture category: for blood volume amplitude, $F(1, 971) = 4.36$, $p = .037$; for transit time, $F(1, 1{,}088) = 9.77$, $p = .002$. Transit time was also characterized by a significant Quadratic Slope × Assessment × Category interaction, $F(1, 1{,}088) = 8.29$, $p = .004$, and a Cubic Slope × Category × Assessment interaction, $F(1, 1{,}088) = 6.31$, $p = .012$. The predicted slopes for each model are shown on the right-hand side of Figure 3, and the full parameter estimates are presented in Tables S4 and S5 in the online supplemental materials.

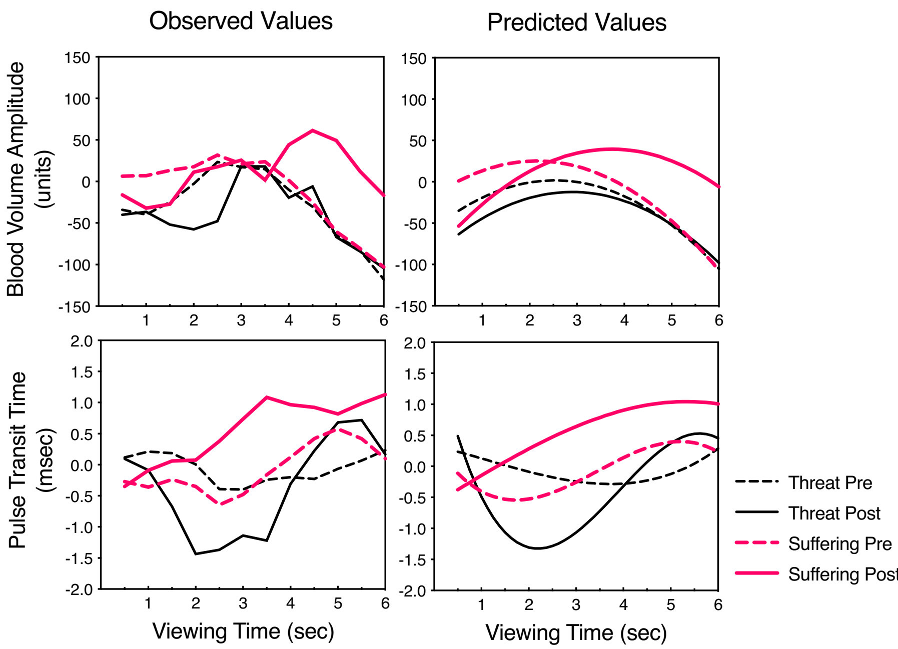
Table 5 presents selected parameter estimates for changes in the expected response level of blood volume amplitude and pulse transit time at three viewing latencies: at image onset, 3 s after image onset, and 6 s after image onset. Significant increases to suffering images (i.e., decreases in sympathetic activity) were found for both measures from the pre- to posttraining assessment. For blood volume amplitude, the estimated increase was about 100 units by the end of the viewing interval and was significantly greater than the estimated change in magnitude for threat (7.3 units). For transit time, the difference emerged earlier in the viewing window, with an estimated change of 0.90 ms at 3 s after picture onset. This change was significantly greater—and opposite in direction—than the change observed for threat. Overall, the estimates supported the prediction that sympathetic activity was lessened in response to suffering in the training group.

Correlations of Pulse Activity With Dispositional Outcomes and Orienting to Suffering

Table S6 in the online supplemental materials presents correlations between summary measures of finger pulse activity at the posttraining assessment and the orienting indexes and dispositional change scores of Study 1. There was a strong positive correlation between the post-assessment orienting index and levels of blood volume amplitude to suffering at the end of training ($r = .69$, $p < .0001$). This suggests that greater orienting to suffering was associated with a lessening of the sympathetic cardiovascular response. A scatterplot of this correlation is shown in the right of Figure 2a.

Blood volume amplitude to suffering also showed several significant correlations of moderate to strong effect size with dispositional predictors of empathy and positive emotionality. Four of these correlations—those for empathic concern ($r = .63$, $p < .001$; see Figure 2a),

Figure 3
Finger Pulse Activity to Images of Suffering and Threat in Training Participants



Note. Observed subject grand averages are shown on the left, with corresponding growth trajectories on the right. Negative values indicate relatively greater sympathetic cardiovascular activation. See Tables S4 and S5 in the online supplemental materials for the parameterization of predicted values. Pre = pretraining assessment; Post = posttraining assessment. See the online article for the color version of the figure.

amusement ($r = .52$, $p = .004$), compassion ($r = .61$, $p < .001$), and love ($r = .50$, $p = .006$)—exceed 25% of the total explained variance. By contrast, pulse transit time to suffering was negligibly correlated with the dispositional predictors and the post-retreat orienting index ($r = -.07$, $p = .700$). Pulse responses to threat were not associated with heart rate orienting responses and, with one exception (blood volume amplitude with perspective taking, $r = -.57$, $p = .001$), were not significantly correlated with any of the dispositional predictors.

Mediation Models

The foregoing correlations suggest that levels of blood volume amplitude might mediate the relation between changes in empathic concern and heart rate orienting to suffering that was observed in Study 1. A structural model for this effect is presented in Figure 2, along with scatterplots depicting the observed relationships among the independent, dependent, and mediating variables. The

Table 5
Growth Curve Estimates of Finger Pulse Activity to Images of Suffering and Threat in Training Participants

Measure and response latency	Change from pre- to postassessment						Difference statistic	
	Threat			Suffering				
	Estimate	*SE*	95% CI	Estimate	*SE*	95% CI	*t*	*p*
Blood volume amplitude								
Image onset	−28.4	46.6	[−121.5, 64.7]	−54.7	42.1	[−139.6, 30.3]	−0.77	.439
3 s	−12.2	40.3	[−93.9, 69.5]	16.0	38.8	[−63.2, 95.2]	1.55	.122
6 s	7.3	46.6	[−85.8, 100.5]	100.8*	42.1	[15.9, 185.8]	2.76	.006
Pulse transit time								
Image onset	0.25	0.60	[−0.93, 1.44]	−0.27	0.45	[−1.15, 0.62]	−0.78	.438
3 s	−0.82*	0.37	[−1.56, −0.08]	0.90**	0.31	[0.28, 1.52]	5.05	<.001
6 s	0.17	0.60	[−1.02, 1.35]	0.78	0.45	[−0.11, 1.66]	0.91	.362

Note. Maximum likelihood estimates were obtained by centering growth curve models (see Figure 3; Tables S4 and S5 in the online supplemental materials) at image onset, 3 s after onset, and 6 s after onset. Positive estimates indicate increases in response level from pre- to posttraining. For values of t, $df = 971$ and 1,088 for blood volume amplitude and pulse transit time, respectively. CI = confidence interval.
* $p < .05$. ** $p < .01$.

Table 6
Path Coefficients From Structural Mediation Models of Heart Rate Orienting to Suffering

Model	Path *a*		Path *b*		Total effect		Indirect effect	
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
Dispositional empathy								
Empathic concern	0.66***	[0.47, 0.86]	0.60**	[0.23, 0.98]	0.41*	[0.07, 0.76]	0.40**	[0.10, 0.70]
Personal distress	−0.33	[−0.70, 0.04]	0.62***	[0.31, 0.92]	−0.18	[−0.56, 0.19]	−0.20	[−0.49, 0.09]
Perspective taking	0.19	[−0.08, 0.46]	0.64***	[0.36, 0.91]	0.02	[−0.26, 0.29]	0.12	[−0.04, 0.28]
Positive emotionality								
Amusement	0.54***	[0.25, 0.83]	0.65***	[0.32, 0.98]	0.25	[−0.21, 0.70]	0.35*	[0.05, 0.65]
Compassion	0.52***	[0.28, 0.76]	0.61***	[0.26, 0.96]	0.33	[0.02, 0.63]	0.32*	[0.08, 0.55]
Contentment	0.21	[−0.04, 0.46]	0.62***	[0.32, 0.92]	0.05	[−0.30, 0.39]	0.13	[−0.05, 0.31]
Joy	0.28	[−0.01, 0.57]	0.62***	[0.33, 0.92]	0.10	[−0.20, 0.39]	0.17	[0.00, 0.35]
Love	0.44*	[0.10, 0.78]	0.62***	[0.27, 0.97]	0.26	[−0.10, 0.62]	0.27	[0.01, 0.53]

Note. Selected parameter estimates are reported from the structural mediation model specified in Figure 2b. Separate models were conducted for each self-report predictor. All parameters are maximum likelihood estimates given in their standardized metrics. Significance was evaluated based on false discovery rate control for 32 tests (adjusted $\alpha = .025$). CI = confidence interval.
$^{*}p < .025$. $^{**}p < .01$. $^{***}p < .001$.

dependent and independent variables were both modeled as latent difference scores. Selected coefficients from this mediation model are presented in Table 6, along with coefficients from models for the seven other dispositional predictors.

For empathic concern, the path estimates of Figure 2b and Table 6 indicate a case of complete statistical meditation. The total effect of 0.41 (path *c*) suggests that increases in empathic concern were significantly predictive of greater orienting to suffering. However, the indirect effect (path *a* * path *b*) was seen to explain almost all of this variance. After accounting for the mediating effect of blood volume amplitude, the total effect was reduced to a direct effect of 0.01 (path c'; 95% CI [−0.35, 0.38]). Significant indirect effects were also found for compassion and amusement. For these predictors, the total effects were reduced to 0.01 and −0.10, respectively, 95% CIs [−0.27, 0.30] and [−0.45, 0.25], after the mediating effect was considered. However, for these models, the total effects were weaker than for empathic concern and did not significantly explain variance in the orienting outcome. None of the direct effects for the remaining predictors were significant, all *p*s > .395.

Summary and Discussion

The results of Study 2 provide strong evidence against the possibility that the orienting increases found in Study 1 were driven by situational empathic distress. Meditation training was associated with a relative decrease in peripheral sympathetic outflow to images of human suffering. In addition, lower levels of sympathetic activation were found to account for the observed relationship between training-related increases in empathic concern and heart rate orienting to suffering. These findings are consistent with the idea that the effective regulation of physiological arousal may be necessary to enact other-oriented motivations and successfully deploy attentional resources to targets of empathy (Eisenberg & Eggum, 2009). Amusement also showed a significant mediating effect, suggesting that certain positive emotions may facilitate engagement with suffering by buffering against empathic distress.

Overall, the findings of Studies 1 and 2 support the idea that meditation training can alter engagement with suffering at the level of physiological responding and broad motivational tendencies. Many meditative traditions, however, are principally concerned with how observers, as subjective agents, relate to suffering in their perceptions and experiences of the world (e.g., Goldstein & Kornfield, 1987; Nhat Hanh, 1998). Meditation practices, including attention-based variants, are believed to reduce habitual patterns of evaluative processing (such as ruminative elaboration) that can lead to distraction or avoidance of salient emotional cues (Farb et al., 2012; Wielgosz et al., 2019). In its place, these practices are expected to build cognitive capacities that support a receptive, present-centered awareness of emotional experience. From this idea it follows that the quality of one's cognitive engagement may be an important outcome of meditation-based trainings. We address this possibility in our next study, where we leverage data from a long-term follow-up assessment to explore the relationship between emotional memory and motivated engagement with images of suffering and threat.

Study 3: Subsequent Memory Analysis

In the preceding studies, meditation training was associated with apparent increases in oriented attention and decreases in distress-related arousal for themes of human suffering. In our final study, we employed a subsequent memory analysis (Paller & Wagner, 2002) to gain insight into the cognitive correlates of these patterns. While conducting our longitudinal investigation, the opportunity arose to follow up with study participants many years later (Zanesco et al., 2018). As part of this follow-up, we used a recognition memory task to assess how accurately and confidently training participants could remember the images they had viewed 7 years earlier. Using these memory data, we then segregated the heart rate orienting responses of Study 1 according to whether or not the images were successfully remembered. By contrasting subsequently remembered with subsequently forgotten images, we hoped to characterize the physiological signatures of memory encoding and whether they differed as a function of meditation training and emotional content.

It is well established that memory is enhanced for emotional as compared to nonemotional information. In studies of affective picture viewing, the dimensions of arousal and valence have most frequently been invoked to explain this effect (Bradley et al., 1992; Gavazzeni et al., 2012; Ochsner, 2000). While it has received less empirical attention, goal relevance has also been proposed as a central mechanism for emotional memory enhancement (Levine &

Edelstein, 2009). For example, it has been shown that increasing the personal or goal relevance of target items through appraisal manipulations can heighten memory recall for neutral stimuli (Montagrin et al., 2013) as well as emotionally laden images (Knight & Ponzio, 2013), both at immediate test and up to 48 hr later. On this basis, we expected that threat images would automatically activate the physiological correlates of successful memory encoding, given the relevance of threat to biological imperatives for survival (Sakaki et al., 2012). Conversely, images of human suffering—holding less intrinsic relevance—might not as equally enhance physiological markers of encoding prior to training.

The goals of Study 3 were largely exploratory. However, previous work has demonstrated that heart rate deceleration is associated with enhanced memory for complex emotionally laden scenes (Abercrombie et al., 2008; Pilarczyk et al., 2022). Therefore, for images of suffering, we expected to observe a correspondence between greater heart rate deceleration at the posttraining assessment and better memory confidence for these themes. If so, this would establish a potential relationship between other-oriented attention and cognitive engagement with human suffering. As before, threatening and pleasant images were used to ascertain the selectivity of effects to suffering content, and peripheral pulse measures were used to test post hoc hypotheses of sympathetic activation. In addition, we restricted these analyses to the training group participants described in Studies 1 and 2. Emotional memory for control group participants could not be evaluated because they had viewed each image twice during their study enrollment—once as wait-list participants and once during a later training intervention (see Footnote 4).

Method

Study 3 involved a subsequent memory analysis of the cardiovascular measures obtained in Studies 1 and 2.

Participants

Beginning about 6 years after the conclusion of Study 1, we invited the 30 training group members to take part in a long-term follow-up assessment. Twenty-one individuals agreed to participate and completed a memory recognition task. The average age of the follow-up sample was 56.2 years (range: 31.9–70.9). There were 12 females and nine males. All participants gave full informed consent and were compensated $20 per hour of data collection.

Procedure

The recognition task was administered on a rolling basis across a 14-month period. On average, it was completed 7.1 years ($SD = 0.4$) after participants' posttraining assessment. Each participant was mailed a kit containing an IBM T-40 ThinkPad laptop and materials for assembling an ad hoc testing environment at their place of residence. Instructions were included for creating a quiet, distraction-free area with dim ambient lighting. All participants had previously completed at least one at-home assessment of this kind during their ongoing study enrollment (see Zanesco et al., 2018). In addition to the recognition task, participants completed a battery of cognitive tasks, self-report measures, and open-ended interviews at the 7-year follow-up.

Participants were told they would view a series of images, some of which they had previously seen at prior study assessments. Each image was presented at full screen resolution (1,024 × 768) until the participant pressed the space bar to proceed. To serve as a cue, the image remained visible in 20% thumbnail size while participants made responses via mouse clicks. Continuous ratings were made on a horizontal line containing seven Likert-style demarcations. Participants could click anywhere along the rating dimension to indicate their response.

On each trial, participants first rated the pleasantness and intensity of their current emotional reaction to each image. These affect ratings were included primarily to increase participant interest and engagement in the task and are not reported on here. Participants were next asked whether the picture was “Old” or “New,” where New indicated an image they had not seen before. This was followed by a confidence rating, which asked participants to rate how certain they were in their Old/New judgment. The confidence rating had anchors of *Not at all certain* to *Extremely certain*.

Picture Stimuli

The recognition task included 108 images: 72 previously seen (or old) images and 36 previously unseen (or new) images. Half the old images had been seen by participants at their pretraining assessment and half been seen at their posttraining assessment. Thus, there were three possible initial encoding periods: pretraining images, posttraining images, and the follow-up session for new images. There were 12 threat images, 12 suffering images, and 12 pleasant images for each encoding period. Each new image was thematically matched to a pair of previously viewed images based on its visual content (see Picture Stimuli in Study 1). A full list of the IAPS stimuli that served as memory foils and previously seen images is given in the Appendix.

Statistical Analysis

Multilevel models were used to estimate heart rate magnitudes and slopes using a procedure identical to Study 1, except that (a) the fixed factors of group and assessment were replaced with factors of memory performance (remembered, forgotten) and period of encoding (pretraining, posttraining), and (b) growth curves were fit to individual trial responses, rather than condition-averaged waveforms. This latter change was made so that the imbalance in observed trial counts between remembered and forgotten images could be accommodated by the modeling procedure. In addition, random effects could now be specified at both the by-subject and by-item levels to account for data dependencies within participants and specific stimulus items, respectively. This is a benefit of crossed random effects models (Hoffman, 2015), where trial outcomes are simultaneously nested within subjects and stimuli. The confidence rating was converted to z scores within subjects prior to analysis. This was done to minimize the effects of individual differences in how participants employed the continuous visual analog rating scale. We also excluded from analyses any trials for which the picture-averaged physiological response fell above or below three *SD*s of the grand average across all participants. This resulted in the removal of 1.3% of trials for heart rate, 1.8% for blood volume amplitude, and 1.6% for pulse transit time.

Results

Table 7 gives the proportion of images that were correctly remembered or forgotten 7 years after the training intervention. The table also shows the proportion of correct and incorrect judgments to

Table 7
Correct and Incorrect Memory Judgments 7 Years After Training

Picture category	Seen at pretraining		Seen at posttraining		Previously unseen	
	Correct	Incorrect	Correct	Incorrect	Correct	Incorrect
Pleasant	.32	.68	.31	.69	.79	.21
Threat	.31	.69	.37	.63	.70	.30
Suffering	.33	.67	.33	.67	.88	.12

Note. Proportions are global statistics summarized across all observed trials. Correct judgments correspond to "Old" responses to previously seen images and "New" responses to previously unseen images.

new memory foils. The observed proportion accuracy for each individual stimulus exemplar is listed in the Appendix.

About one-third of all images were successfully remembered 7 years later. The proportion of images remembered from the pretraining and posttraining assessments was similar and, in the case of suffering images, was nominally equivalent (.33). The false alarm rate was low (0.21, on average), such that participants were relatively adept at recognizing new images. The average discriminability index (d'; Stanislaw & Todorov, 1999) was 0.40 ($SD = 0.31$) for pretraining images and 0.41 ($SD = 0.34$) for posttraining images. Both values differed significantly from zero, ts(20) > 5.61, ps < .0001, indicating that memory performance was greater than would be expected by chance. Further tests revealed no significant differences between the pretraining and posttraining encoding periods for suffering, threat, or pleasant image contents, ps = .990, .160, and .742, respectively.

Heart Rate at Encoding

We conducted two subsequent memory analyses on the heart rate responses presented in Study 1. First, heart rate responses to all images were modeled as a function of successful and unsuccessful memory recognition. Then, the relationship between trial-level recognition confidence and heart rate at encoding was examined for remembered images only.

Remembered Versus Forgotten. Figure 4 presents grand-averaged heart rate waveforms for remembered versus forgotten images. There was an apparent memory effect for pleasant images from the posttraining assessment, with remembered images incurring greater heart rate deceleration than forgotten images. For threat, the magnitude of deceleration was noticeably greater for remembered than forgotten trials at both encoding periods. For suffering, the pattern appeared to depend on the period of encoding, with greater deceleration for remembered images from the posttraining assessment, and an acceleratory component for remembered images from the pretraining assessment.

Model Fitting. The results of the model fitting procedure are summarized in Table 8. Step 1 was a baseline model including crossed random intercepts and all fixed main effects. Step 2 added the four-way interaction of memory, encoding period, and picture category with linear slope. The inclusion of this interaction significantly improved model fit, as did inclusion of the interaction between quadratic slope and picture category in Step 3. The inclusion of additional interactions with quadratic slope did not improve fit and so were not retained in the model.

For the random effects, fit was improved by including random linear heart rate slopes for participants (Step 4), then further by allowing these variance components to be uniquely estimated by picture content (Step 5). To describe the by-item variation, a random slope for encoding period was included in Step 6. Allowing the by-item intercepts and encoding slopes to differ by picture category did not improve fit in Step 7. Alternative random effects specifications either failed to converge or were less parsimonious than those described by Step 6.

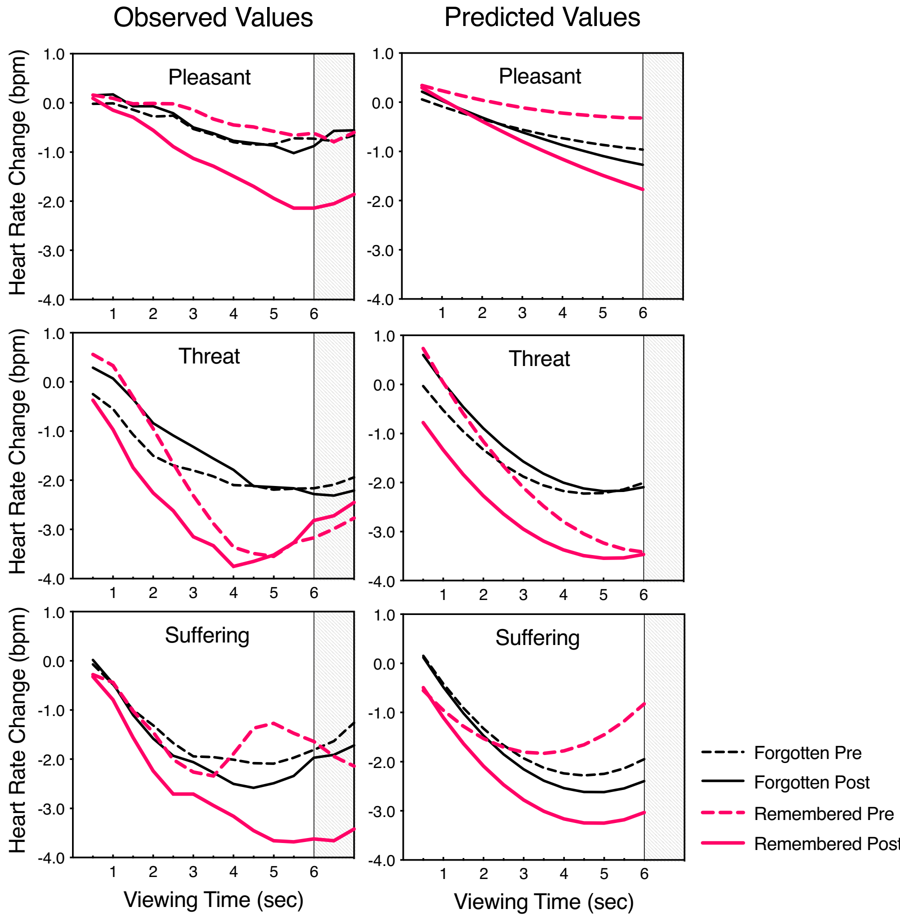
Model Parameters. Parameter estimates for the best-fitting model are presented in Table 9, and predicted slopes are presented in the right-hand column of Figure 4. The main effect of memory gives the expected difference in heart rate magnitude for remembered versus forgotten images from the pretraining assessment. For threat, remembered images were associated with a reduction in heart rate of 1.017 bpm (95% CI [−1.621, −0.413], $p < .001$) prior to training, while for suffering a relative increase of 0.794 bpm (95% CI [0.209, 1.379], $p = .008$) was observed. A similar pattern was found for the Memory × Linear Slope interaction: Threat and suffering were associated with significant negative, $\beta = -0.198$, 95% CI [−0.315, −0.081], $p < .001$, and positive, $\beta = 0.167$, 95% CI [0.053, 0.281], $p = .004$, slopes, respectively, for successfully remembered images before training. The omnibus effects of Memory × Category, $F(2, 8{,}295) = 10.40$, $p < .0001$, and Linear Slope × Memory × Category, $F(2, 2{,}452) = 9.73$, $p < .0001$, were both significant. For both effects, the estimates for threat and suffering differed by tests of simple contrasts, ps < .0001.

The interaction of memory and encoding period was significant for suffering but not for threat. For suffering, remembered images from posttraining were associated with an estimated reduction of 0.632 bpm ($SE = 0.299$, 95% CI [−1.219, −0.045], $p = .035$), which contrasts with the relative increase observed for pretraining images. For threat, however, the effect for posttraining images was similar in direction and magnitude to pretraining images, $\beta = -1.369$, $SE = 0.306$, 95% CI [−1.970, −0.769], $p < .0001$. In addition, the three-way interaction of memory, encoding, and linear slope was significant for suffering, as well as for threat. In contrast to pretraining images, the difference in linear slopes between remembered and forgotten images tended toward zero for posttraining images, with an estimate of $\beta = -0.002$, $SE = 0.058$, 95% CI [−0.116, 0.111], $p = .968$, for suffering, and $\beta < 0.001$, $SE = 0.058$, [−0.113, 0.115], $p = .986$, for threat. This can be seen by the solid red and black lines having similar shapes but differing levels for the predicted values in Figure 4. The omnibus effect of Linear Slope × Memory × Encoding × Category was significant, $F(2, 10{,}676) = 5.96$, $p = .003$, as was the simple comparison between suffering and threat for this parameter, $p < .001$.

Finally, pleasant contents showed relatively little modulation of heart rate as a function of subsequent memory, as indicated by the lack of significant slope effects overall. Although the Memory × Encoding interaction was significant, $\beta = -0.969$, 95% CI [−1.752, −0.187], $p = .015$, there were no main effects of memory for pretraining, $\beta = 0.577$, 95% CI [−0.043, 1.196], $p = .068$, or for posttraining, $\beta = -0.393$, $SE = 0.320$, 95% CI [−1.020, 0.234], $p = .220$, images.

Trial-Based Recognition Confidence. In our next analysis, we removed forgotten trials from the growth curve model of Table 9 and replaced the categorical predictor of memory with the continuous predictor of recognition confidence. The three-way

Figure 4
Heart Rate Responses to Emotional Images by Subsequent Trial Memory



Note. Stimulus-locked heart rate responses to images that were remembered or forgotten 7 years after the beginning (Pre) and end (Post) of training. Observed grand mean averages are shown on the left, with corresponding mean growth trajectories on the right. See Table 9 for parameterization of predicted values. Pre = pretraining assessment; Post = posttraining assessment. See the online article for the color version of the figure.

interaction of Confidence × Category × Encoding Period was significant, $F(2, 2{,}853) = 33.60$, $p < .0001$. Simple slopes for this model are presented in Figure 5, with estimates of heart rate magnitude plotted at one *SD* above, below, and at the average participant mean for trial-based confidence. Full parameter estimates are given in Table S7 in the online supplemental materials.

As depicted in Figure 5, suffering images showed a characteristic X-shaped interaction between confidence level and period of encoding, $p < .0001$. There was a significant positive association between heart rate magnitude at encoding and memory confidence for pretraining images, $\beta = 1.515$, 95% CI [0.513, 2.517], $p = .004$, but a significant negative association for posttraining images, $\beta = -1.592$, 95% CI [−2.567, −0.618], $p = .002$. The simple slopes for threat were opposite in direction to those for suffering. Moreover, for threat, the interaction was significant, $p < .008$, but the slopes were not: for pretraining images, $\beta = -0.491$, 95% CI [−1.480, 0.498], $p = .325$, and for posttraining images, $\beta = 0.496$, 95% CI [−0.467, 1.458], $p = .306$. The simple slopes for pleasant images were also not significant: for pretraining, $\beta = -0.538$, 95% CI [−1.485, 0.409], $p = .259$, and for posttraining, $\beta = -0.659$, 95% CI [−1.615, 0.297], $p = .172$.

Notably, for high confidence judgments (+1 *SD*), the expected magnitude of heart rate to suffering was near baseline before training (−0.01 bpm), but by the end of training, this value was approximately four bpm slower (−4.29 bpm). By contrast, for threat, the expected heart rate at encoding for high confidence judgements was nearly equivalent for images seen before (−2.50 bpm) versus after (−2.57 bpm) training. The corresponding values for pleasant images were −1.52 bpm before training, and −2.71 bpm after training.

Sympathetic Activation at Encoding

The preceding analyses suggest that the successful encoding of suffering was associated with a phasic increase in heart rate prior to training (see Figure 4, bottom left panel). In a final analysis, we tested whether remembered images of suffering were also associated with greater levels of sympathetic activation at this encoding period.

Table 8

Sequential Fit Statistics for Growth Curve Model of Heart Rate Orienting by Subsequent Trial Memory

Model step and summary of added effects	AIC	BIC	Param.	−2ΔLL (*df*)
Model for the means				
1. Main effects model with crossed random intercepts	67,926	67,906	10	—
2. Linear HR Slope × Picture Category × Memory × Encoding interaction	67,870	67,814	28	92 (18)
3. Quadratic HR Slope × Picture Category interaction	67,858	67,798	30	16 (2)
Model for the variances				
4. By-subject random linear HR slope and covariance with the intercept	67,816	67,752	32	46 (2)
5. Heterogeneous by-subject random effects	67,574	67,498	38	255 (6)
6. By-stimulus random encoding variance and covariance with the intercept	67,409	67,329	40	168 (2)
7. Heterogeneous by-stimulus random effects	67,415	67,323	46	7 (6)

Note. Step 1 includes fixed main effects of picture category, memory, and encoding period; linear and quadratic polynomial HR slopes; and crossed random intercepts for subjects and stimuli. Steps 2 and 3 include all lower-order effects of the fixed interaction terms. Steps 5 and 7 allow variance components to vary by picture content category. Incremental fit is shown as the difference in −2ΔLL, with *df* equal to the difference in model parameters (Param.). Steps 1–6 significantly improved fit (all $ps < .001$), but Step 7 did not ($p = .354$). The number of data points modeled was 11,916. AIC = Akaike information criterion; BIC = Bayesian information criterion; Param. = parameters; −2ΔLL = −2 log likelihood; *df* = degrees of freedom; HR = heart rate.

Peripheral pulse waves for remembered and forgotten images of suffering are presented in Figure 6, and parameter estimates are presented in Tables S8 and S9 in the online supplemental materials. Memory effects of blood volume amplitude were best described by a Linear Slope × Memory × Encoding Period interaction, $F(1, 3{,}331) = 15.42$, $p < .0001$. The linear slope for remembered images was negative before training, $\beta = -25.1$, 95% CI [−39.3, −10.8], $p < .001$, but positive after training, $\beta = 15.1$, 95% CI [0.9, 29.4], $p = .038$. Moreover, by 6 s after picture onset, successful memory for suffering was associated with a decrease in estimated amplitude for pretraining images, $\beta = -146.9$, 95% CI [−252.5, −41.3], $p = .006$, but with an increase in amplitude for posttraining images, $\beta = 199.7$, 95% CI [92.8, 306.5], $p < .001$.

For pulse transit time, the waveforms for remembered images differed in shape as a function of encoding period. In this case, a simpler growth model was preferred, with condition differences described in terms of their average value across the picture interval. A significant Memory × Encoding interaction was observed, $F(1, 3{,}685) = 24.69$, $p < .0001$, such that successful memory was associated with an average decrease in transit time for pretraining images, $\beta = -0.82$, 95% CI [−1.53, −0.10], $p = .025$, but with an average increase in transit time for posttraining images, $\beta = 1.56$, 95% CI [0.82, 2.29], $p < .0001$.

Table 9

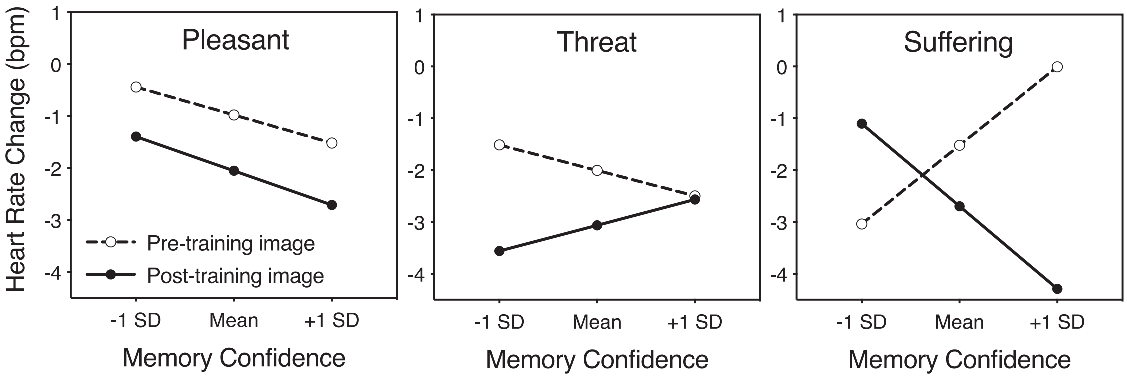
Parameter Estimates for Growth Curve Model of Heart Rate Orienting by Subsequent Trial Memory

Parameter	Pleasant		Threat		Suffering	
	Estimate	*SE*	Estimate	*SE*	Estimate	*SE*
Fixed effects						
Intercept[a]	−0.866*	0.412	−2.215***	0.411	−2.246***	0.389
Linear slope (0 = 5 s)	−0.058	0.060	0.042	0.061	0.072	0.061
Quadratic slope[a]	0.005	0.006	0.032***	0.006	0.038***	0.006
Memory (0 = *forgotten*)[b]	0.577	0.316	−1.017***	0.308	0.794**	0.299
× Linear slope[b]	0.032	0.058	−0.198***	0.060	0.167**	0.058
Encoding (0 = *pre*)	−0.225	0.379	0.040	0.382	−0.371	0.379
× Linear slope	−0.043	0.046	−0.066	0.046	−0.037	0.046
Memory × Encoding	−0.969*	0.399	−0.352	0.405	−1.426***	0.392
× Linear slope[b]	−0.085	0.079	0.199*	0.079	−0.169*	0.078
Variance components						
Random effects for subjects						
Intercept variance	1.725**	0.599	1.732**	0.592	1.339**	0.479
Linear slope variance	0.015*	0.007	0.020**	0.008	0.020*	0.009
Intercept–slope cov.	0.151*	0.060	0.155*	0.063	0.134*	0.058
Random effects for stimuli						
Intercept variance	0.960***	0.225	—	—	—	—
Encoding variance	1.471***	0.359	—	—	—	—
Intercept–encoding cov.	−0.613**	0.228	—	—	—	—
Residual variance	16.098***	0.211	—	—	—	—

Note. Maximum likelihood estimates are reported for Model Step 6 of Table 8. For each picture category, the intercept is the expected mean heart rate (in bpm) at 5 s post-picture onset for forgotten images from the pretraining assessment (pre). Dashes (—) indicate that a variance component was held constant across picture categories; $N = 21$ subjects and 48 stimulus exemplars. cov. = covariance.
[a]For this parameter, the pleasant condition differs significntly from threat and suffering. [b]The threat condition differs significantly from pleasant and suffering.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Figure 5

Simple Slopes for the Relationship Between Heart Rate at Encoding and Subsequent Memory Confidence



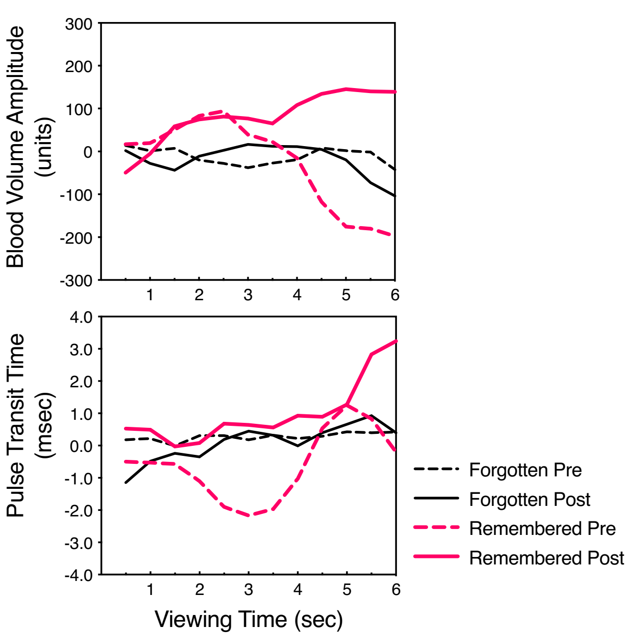
Note. Estimates of heart rate magnitude are plotted at one *SD* above, below, and at the average participant mean for trial memory confidence. Images were originally viewed at the beginning (Pre) versus end (Post) of training. See Table S7 in the online supplemental materials for parameterization of the predicted values. bpm = beats per minute; Pre = preassessment; Post = postassessment.

Summary and Discussion

The key finding of Study 3 was that successfully remembered images of suffering occasioned distinctive encoding processes before versus after training. Before training, remembered images of suffering were associated with a relative *acceleration* in heart rate (following an initial deceleration) and an increase in peripheral sympathetic activation. After training, these items were associated with a uniform heart rate deceleration and a lessening of sympathetically mediated arousal. Similar effects of heart rate at encoding were observed for trial-level memory confidence. In contrast to suffering, successful memory for threat was associated with robust reductions in heart rate at encoding, before as well as after training.

Figure 6

Finger Pulse Activity to Images of Suffering by Subsequent Trial Memory



Note. Observed grand mean averages of finger pulse activity to images of suffering that were originally viewed at the beginning (Pre) or end (Post) of training. Negative values indicate relatively greater sympathetic cardiovascular activation. See Tables S8 and S9 in the online supplemental materials for the parameterization of predicted values. Pre = preassessment; Post = postassessment. See the online article for the color version of the figure.

The physiological patterns obtained for suffering images prior to training suggest the contribution of aversive emotional arousal to the successful encoding of these themes. In addition, the patterns may reflect processes of cognitive elaboration (Cacioppo et al., 1978) or the defensive inhibition of outwardly oriented attention (Vila et al., 2007). Meditation training appears to have then prompted a change in encoding processes, such that successful memory for suffering was associated with a sustaining of attention to the images after the intervention. These findings are in line with the proposed role of mindfulness-based training in diminishing the automatic elaboration of negative stimuli in favor of reduced reactivity and the foregrounding of present-centered sensory awareness (Farb et al., 2012; see also MacLean et al., 2010, for improvements in sustained attention in this same cohort of participants). It is important to note that the number of items that contributed to the remembered curves of Study 3 did not substantially differ between periods of encoding. As such, differences in the shape or magnitude of the curves ought to reflect differences in the physiological processes that contributed to later remembrance.

Finally, for pleasant scenes, the observed data of Figure 4 (top left) suggests greater deceleration for remembered images after training. No such effect was found, however. One explanation is that the trial responses for pleasant images were quite variable in comparison to the mean estimates for this category. For example, the by-subject intercept variances for pleasant and threat were nearly equivalent (at 1.73), despite the considerably larger mean estimate for threat (−2.21 bpm) than for pleasant (−0.87 bpm) contents (see Table 9). As a result, the differences among slopes for pleasant images may not have been reliable.

General Discussion

Meditation practice is commonly believed to foster the ability to attend to human suffering with compassion, equanimity, and receptive awareness (Goldstein & Kornfield, 1987; Makransky, 2007; Salzberg, 1995). The present results appear to corroborate this view. In a longitudinal study, participants who completed 3 months of meditation demonstrated greater attentional orienting to suffering than did wait-list controls. This capacity was directly tied to feelings of concern for others, the regulation of distress-related arousal, and the strong encoding of cues of suffering in memory. Similar changes were not observed for pleasant or threatening image contents. Overall, these findings support the hypothesis that meditation training can enhance the motivational relevance of human suffering. As discussed further below, the findings also imply a shift in empathy appraisals with training, from more self-focused to other-focused modes of engagement. Importantly, participants were not explicitly asked to meditate or to engage in any specific regulatory strategies while viewing the image stimuli. Thus, our results seem to indicate a generalized effect of the training intervention on trait-like patterns of cognitive and emotional responding (Slagter et al., 2011).

Our primary outcome measure was heart rate orienting to suffering. Analytically, multilevel growth curves offered a flexible method for modeling these responses and their modification by meditation training. By simultaneously estimating parameters of magnitude and slope, the waveforms could be represented with more fidelity than if simple summary averages were used. Moreover, in Study 2, we used latent difference scores to estimate an index of orienting to suffering that was adjusted against levels of responding to threat. Together, these two modeling approaches were used to account for dynamic changes in physiological outcomes and their dependence on individual differences in emotional reactivity (Burt & Obradović, 2013; Hoffman, 2015). Presumably, they also better reflect the functional role of the orienting response itself—as a cascade of perceptual and motor processes (Bradley, 2009). For example, in Study 1, the condition-averaged waveforms showed a clear morphology that was well-explained by a quadratic polynomial function. The fit for the trial-level data of Study 3 was also acceptable, though it might have been improved (at the cost of parsimony) by introducing additional growth factors, such as piecewise slopes or exponential functions.

Meditation, Emotion, and Motivation

The present investigation was rooted in the idea that the emotional effects of meditation training are inherently shaped by motivational factors. When meditation is practiced within an ethical framework emphasizing compassion and the reduction of harm, then the preferential processing of human suffering should occur. This preference, in turn, should be enacted via cognitive and regulatory skills that are acquired through the practice of specific mental training techniques. Some techniques may target engagement with human suffering directly (e.g., compassion meditation), while some may exert their influence through more indirect routes (e.g., attentional control). In both cases, the quality of emotional responding should be conditioned by motivational goals that are internalized through repeated exposure and practice.

Several notable findings emerged on the basis of this logic. First, we showed that meditation training can increase the motivating power of human suffering while decreasing its aversive emotional impact. Training participants exhibited enhanced heart rate orienting to suffering, which was mediated by reductions in sympathetic nervous system activation. Unlike previous studies (e.g., Desbordes et al., 2012; Weng et al., 2018), we employed separate measures of motivational salience and distress, which allowed us to dissociate the impact of training on these two emotional facets. Following Weng et al. (2018), we conclude that meditation training supports a more equanimous response toward suffering—increasing interest and attention while moderating reactivity and arousal (see also Desbordes et al., 2015). From a motivational perspective, meditation likely increased the value placed on others' well-being. When coupled with practices emphasizing self-regulation, compassionate engagement (rather than distress) was the apparent result. Consistent with this view, our intensive intervention has previously been shown to improve neural, self-reported, and behavioral markers of attentional focus and cognitive control (Sahdra et al., 2011; Shields et al., 2020; Zanesco et al., 2019, 2021).

Second, we observed few effects of meditation training on emotional responses to pleasant or threatening images. This may seem puzzling given our self-report findings and the putative role of meditation practice in fostering positive well-being and reducing negative affectivity (Fredrickson et al., 2008; Lindsay et al., 2018; Sahdra et al., 2011; Schumer et al., 2018; Wielgosz et al., 2019). One explanation is that we recruited a participant sample with considerable prior meditation experience. It is plausible, for example, that the emotional effects of meditation training may manifest at different stages of contemplative development (Skwara et al., 2017). If so, then evidence of general changes in affective responding may have been masked by our inability to characterize the initial stages of training (i.e., effects in novices). Likewise, we also screened our participants for major anxiety and mood disorders (MacLean et al., 2010). As a result, threatening images elicited reactions that were well within the bounds of adaptive fear responding. Absent an explicit motivational set to reduce reactivity to primary elicitors of threat, such responses may be relatively resistant to modification through training. It may also be that our measures were too coarse to register subtle emotional changes, such as increased smiling displays or approach-related behaviors to happy families or scenic vistas. In any case, our findings underscore the importance of moving beyond typical valence classifications. All negative stimuli are not created equal (Kveraga et al., 2015), and the dearth of targeted hypotheses to specific negative contents may well explain some of the null effects in the broader mindfulness literature (cf., Kral et al., 2018). By this same reasoning, it might have been advantageous had we also examined subcategories of pleasant emotional stimuli (e.g., social vs. nonsocial content).

Finally, while participants were not asked to meditate during the picture viewing task, they were also not instructed to refrain from meditating. It thus remains unclear whether they engaged in formal meditation practice or not. In a similar vein, we cannot know to what extent participants relied on automatic versus controlled forms of emotion regulation (Braunstein et al., 2017). We suspect that participants' attempts to regulate their emotions were mostly effortful at first, then became more automatic and implicit as training progressed. Still, as part of their training, participants were encouraged to bring their meditation practice to awareness at repeated moments throughout the day (Wallace, 2006). Thus, in addition to fostering nonreactivity, the intervention probably promoted at least two kinds of regulatory process: the implicit affective biasing of top-down attention (Todd et al., 2012), and the habitual but controlled recruitment of conscious reappraisal (Braunstein et al., 2017). While admittedly speculative, a fruitful avenue for future research could involve varying the availability of mental resources through cognitive load while practitioners either engage or disengage in formal meditation to regulate their emotions.

Empathy, Physiology, and Self-Other Similarity

Prior research has linked heart rate deceleration in empathy-inducing contexts to feelings of compassion and prosociality (Goetz et al., 2010; Stellar et al., 2015). The present findings build on this work by showing that training-related changes in concern for others are also accompanied by reductions in heart rate to suffering. More broadly, our use of an orienting index holds both practical and theoretical implications for the measurement of empathy. Increases in empathic concern, as well as amusement, were both predictive of lower levels of heart rate to suffering, but only when reactivity to suffering was contrasted with threat.[8] In controlling for threat, the orienting index likely accounted for individual differences in cardiac chronotropy and emotional range. The result was a measure of how strongly others' suffering activated motive systems relative to participants' capacity to respond to intrinsically motivating stimuli.

Prior research has also linked experiences of sympathy, compassion, and altruistic helping to an increased sense of similarity between self and others (Cialdini et al., 1997; Loewenstein & Small 2007; Oveis et al., 2010). Our finding that training participants showed less differentiation in heart rate between suffering and threat aligns with this notion and suggests that training may have diminished the relative salience between the concerns of others (the suffering condition) and the concerns of self (the threat condition). Indeed, research has shown that perceptions of similarity with others can modulate heart rate responses to suffering. In one study, observers evidenced greater heart rate deceleration when they were led to believe that they shared traits and values with a confederate who was about to receive a painful upcoming shock (Krebs, 1975). These and other findings implicate self-other overlap as a major determinant of empathy (Preston & Hofelich, 2012) and raise the possibility that increasing the salience of suffering through meditation training may be beneficial in allowing individuals to empathize with others, despite their differences. Though further validation is needed, we believe that our orienting index is a promising psychophysiological metric of the inclusion of self in others (see Aron et al., 1992), and hope future research will test its predictive utility against other outcome measures (e.g., helping behaviors) and salience modalities (e.g., amygdala responding).

Measures of blood volume amplitude and pulse transit time were also informative in discriminating suffering from threat with training. This speaks to their potential utility as situational measures of empathic responding. Furthermore, increases in blood volume amplitude were strongly associated with reductions in heart rate to suffering. This pattern of peripheral vasodilation coupled with orienting bradycardia is indicative of reciprocal parasympathetic activation of the cardiovascular system (Berntson et al., 1991; see also Campbell et al., 1997) and aligns with theory and data that associate compassion with vagal dominance of autonomic control (Stellar et al., 2015). No significant correlations were found, however, between transit time and heart rate or self-report outcomes. We see two possible explanations for this discrepancy. First, blood volume amplitude and pulse transit time index partially separable subsystems of sympathetic cardiovascular control. Blood volume amplitude is a relatively direct measure of vasoconstriction at the periphery, under the putative control of alpha-adrenergic influences (e.g., Miller & Ditto, 1991). Pulse transit time is under greater beta-adrenergic control (e.g., Contrada et al., 1995), being a summative index of intracardiac contractility and vascular distensibility (Steptoe et al., 1983). Second, there are restrictions on the possible range of values that transit time can take, being constrained by cardiac timing (i.e., IBIs) and physical limb length. For this reason, blood volume amplitude may provide a more responsive measure of sympathetic arousal that is better suited for correlational study.

Lastly, we note that reports of perspective taking were relatively insensitive to intervention effects or to associations with physiological outcomes. As recent evidence suggests (Favre et al., 2021), it may be that affective, rather than cognitive, components of empathy are predominately responsible for the regulation of emotion to suffering with meditation training, at least for static image presentations.

Differential Encoding of Emotional Memory

In an exploratory analysis, we employed a 7-year interval to assess recognition memory for the incidental encoding of suffering and threat. To our knowledge, this is the longest retention period for emotional images that has been reported in the literature (cf., a 1-year retention interval; Bradley et al., 1992; Dolcos et al., 2005; Gavazzeni et al., 2012). It is rather remarkable that participants were able to successfully identify images that were presented during an experimental battery conducted many years prior. This sense of recollection was borne out by patterns of physiology at encoding, which showed a clear facilitative effect of heart rate change on subsequent trial memory.

The autonomic profiles we observed for remembered images of suffering imply a shift in appraisal processes with training. Before training, the successful encoding of suffering was associated with a relative cardioacceleration and sympathetic activation, whereas after training it was associated with heart rate deceleration and sympathetic withdrawal. As emphasized earlier, these profiles are congruous with self-focused attention and emotional distress, on the one hand, and other-oriented concern and compassion, on the other. Regarding the former, there exists considerable evidence documenting the negative effects of excessive self-focus on psychological health and emotional reactivity (Ingram, 1990; Mor & Winquist, 2002). We posit that meditation training may have served to decouple affective cues of suffering from aversive self-focus, enabling more adaptive and flexible appraisal processes. This idea accords with emerging work on self-transcendence and meditation practice. Self-transcendent experiences are characterized by increases in felt connectedness, reductions in self-salience, and a drive to benefit the welfare of others (Kang, 2019; Yaden et al., 2017). By limiting self-focus, self-transcendence may foster a less defensive cognitive stance, broadening attention for novel social information and enabling a richer encoding of experience. This could explain the

[8] For training participants, we confirmed that reductions in absolute levels of heart rate to suffering were not correlated with changes in empathic concern ($r = -.25$), personal distress (.20), compassion ($-.23$), or amusement (.04) with training, all $ps > .195$.

significant association we observed between heart rate deceleration at the posttraining assessment and enhanced memory confidence for suffering.

As mentioned previously, images of suffering that were presented before versus after training were remembered with similar accuracy, despite their distinct encoding processes. Hence, in addition to different modes of attention, our findings emphasize two possible routes to emotional memory. For pretraining images, the encoding patterns described above are consistent with memory enhancement via heightened emotional arousal (e.g., Bradley et al., 1992). For posttraining images, the observed patterns implicate memory enhancement through relevance appraisals (e.g., Knight & Ponzio, 2013), absent sympathetically mediated activity. Memory accuracy for threat—which showed substantial deceleration at both encoding periods—was presumably influenced by a combination of these factors. We speculate that training-related increases in the motivational relevance of suffering may have led to greater meaning being weighed to these scenes in emotional experience. As a result, participants presumably attended to suffering images with greater depth of processing after training, which likely strengthened their sense of encoding (i.e., confidence) in memory. In contrast, threatening images—with their high intrinsic relevance—may have benefitted from a primacy effect, which could have enhanced memory encoding at the onset of training.

A significant limitation of Study 3 was the lack of a nonmeditation control comparison. It is unclear, for example, how self-selection bias to reengage with the study at the long-term follow-up might have influenced the present findings. In addition, our use of a long retention interval likely introduced factors that may have altered recollective experience and memory consolidation in unknown ways, such as through aging, enrollment in additional retreats or training programs, and major life stressors. While our use of trial-based analyses presumably increased our power to detect the underlying relationships of interest (P. L. Smith & Little, 2018), more controlled research is needed to confirm and support the present conclusions in a larger sample of participants.

Meditation Training in Context

Our decision to investigate an intensive residential retreat affords both benefits and limitations to the interpretation of our findings (King et al., 2019). In studying a retreat, we examined a large "dose" of training, which likely increased our statistical power despite our modest sample size. More importantly, it helped to highlight effects of practical significance to the training of compassion through contemplative practice. Had we investigated a nonintensive intervention, or a less experienced sample, we may not have demonstrated comparable effects. Indeed, training participants opted to spend 3 months away from their friends and family to hone and deepen their meditation practice; by the end of the retreat, they reported engaging in about 7 hr of formal meditation practice per day. Whether such dedication is necessary to increase the salience of suffering is not known, though our use of an experience-matched control group suggests that the intention to engage in intensive meditation is not sufficient in itself for explaining these effects. Moreover, Weng et al. (2018), who reported results in accordance with ours, employed a nonintensive intervention with a meditation-naïve sample. Even so, most of our participants held an earnest commitment to their training. We expect that personal motivations for practice were at least as consequential to the present results as were the meditation instructions, teacher, and techniques. Ultimately, direct empirical data are needed to clarify this claim (though see Chen & Jordan, 2020, for promising evidence along these lines).

A second benefit of meditation retreats is their high ecological validity. Retreats are an integral part of many people's meditation regimen or lifestyle, used to promote individual, relational, or soteriological growth, or to mitigate personal suffering. Along with formal practice techniques, retreats include other elements that aim to support meditators in these pursuits. In the present study, these included a secluded and scenic natural environment; the guidance of an experienced teacher; a rigorous formal practice schedule; the social support of fellow practitioners; regular meals and comfortable housing; and a commitment to abstain from alcohol, recreational drugs, and the unnecessary use of technology or media. Participants also refrained from speaking, communicating, or initiating eye contact with others for much of their time on retreat. These conditions supplied a unique setting in which participants could observe their experience and cultivate specific qualities of mind. Although this holistic approach to training can be quite powerful, it naturally limits our ability to attribute our outcomes to any given set of intervention characteristics. Our use of a wait-list control group (in Study 1) and within-group analyses (in Studies 2 and 3) also preclude strong inferences regarding the active or passive components of training. What we can say within reasonable bounds is that the retreat intervention *in toto* had the effect of altering motivational engagement with suffering and that formal meditation practice formed the backbone of the intervention.

Regarding formal meditation: Although training participants engaged in relational-based practices while on retreat, more than 90% of their practice time was dedicated to focused attention meditation (see Footnote 5). The relationally oriented practices were intended to support training participants as they developed their concentration for sustained periods of time (Wallace, 2006). This raises the question of whether we would have found similar effects had the intervention excluded overt training in ethics and compassion. This is an area of active and ongoing debate in the field (Monteiro et al., 2015; Purser, 2015). Recent meta-analyses indeed suggest that mindfulness training can promote prosocial outcomes, even without an explicit appeal to ethics-based instruction (Berry et al., 2020; Donald et al., 2019). In the present studies, we did not directly examine prosocially oriented behavior. However, work from our lab has shown that this same retreat intervention can reduce facial expressions of aversion (e.g., anger, contempt, and disgust) and increase expressions of sadness in response to film clips of human suffering (Rosenberg et al., 2015). When considered alongside the present results, these findings suggest that compassion-based practice need not be the central component of training programs that nevertheless result in measurable changes in engagement with suffering.

Constraints on Generality

As our research centered on an intensive retreat setting, our findings will most likely generalize to populations of experienced meditators or individuals who have a keen interest in practicing meditation. Further research will be needed to extend the findings to meditation-naïve populations using randomized control trials employing active control conditions. Moreover, a key premise of our approach is that one's motivation to practice meditation is partly determinative of the outcomes of training. In the present study, all participants were interested in cultivating shamatha, or calm, focused, and stable attention. Participants chose to engage in this pursuit for various ends, including strengthening their concentration, attaining spiritual development, and healing different forms of suffering. The motivational bases of our participants were thus fairly heterogeneous, although all participants received training and instruction in the broader Buddhist context of using attentional techniques to cultivate these goals. There likely exist complex functional mappings between personal motivations for practice and the styles of meditation being taught in a given intervention. Future studies could extend the generalizability of our results by investigating participant groups and interventions with more homogenous motivational sets and training techniques, including interventions that solely recruit participants interested in cultivating compassion.

Our use of static image stimuli represents another constraint on the generality of our findings. Static images have the advantage of being well-controlled and repeatable across participants within a given study. The use of images also allowed us to present a diverse array of types of human suffering, thus generalizing beyond specific stimulus exemplars. However, this level of control may come at a cost to external validity. A critical test for our findings will be to link physiological measures of motivated engagement with suffering to real-world behavioral responses to suffering individuals in need (e.g., Lim et al., 2015). More generally, there is a need to pair the findings of mechanistic studies like ours to translational outcomes obtained from settings outside the training environment itself.

Conclusion

Feeling compassion for others does not always come easy (Scheffer et al., 2022), especially toward those who are perceived as distant or unfamiliar. The present studies suggest that meditation training might be used to remedy this problem by enhancing the motivational relevance of others' suffering. To the degree that this approach can be implemented in less intensive interventions, it offers a method for countering empathy avoidance and other barriers to interpersonal flourishing. The approach also brings into view the oft-overlooked role of motivation in accounting for the effects of meditation practice and training. We focused here on the intention to reduce harm and alleviate suffering, but other motivational biases may color the outcomes of meditation training as well. Examples include the dereification of cognitions that lead to unhealthy appetitive behaviors (Baquedano et al., 2017; Papies et al., 2015), the tendency to value calm affective states (Koopmann-Holm et al., 2013), the reduction of craving in relation to addiction (Brewer et al., 2013), and the savoring of positive life experiences (Garland et al., 2015). It is also worth mentioning that our operationalization of suffering as visible signs of distress or misfortune is one of many possible definitions of the term in contemplative schools of thought (Lindahl, 2015; Purser, 2015). As the science of mindfulness and meditation continues to progress, there is ample room to investigate how motivational forces shape the experience and expression of contemplative training.

References

Abercrombie, H. C., Chambers, A. S., Greischar, L., & Monticelli, R. M. (2008). Orienting, emotion, and memory: Phasic and tonic variation in heart rate predicts memory for emotional pictures in men. *Neurobiology of Learning and Memory*, *90*(4), 644–650. https://doi.org/10.1016/j.nlm.2008.08.001

Aron, A., Aron, E. N., & Smollan, D. (1992). Inclusion of other in the self scale and the structure of interpersonal closeness. *Journal of Personality and Social Psychology*, *63*(4), 596–612. https://doi.org/10.1037/0022-3514.63.4.596

Ashar, Y. K., Andrews-Hanna, J. R., Dimidjian, S., & Wager, T. D. (2017). Empathic care and distress: Predictive brain markers and dissociable brain systems. *Neuron*, *94*(6), 1263–1273.e4. https://doi.org/10.1016/j.neuron.2017.05.014

Ashar, Y. K., Andrews-Hanna, J. R., Yarkoni, T., Sills, J., Halifax, J., Dimidjian, S., & Wager, T. D. (2016). Effects of compassion meditation on a psychological model of charitable donation. *Emotion*, *16*(5), 691–705. https://doi.org/10.1037/emo0000119

Baquedano, C., Vergara, R., Lopez, V., Fabar, C., Cosmelli, D., & Lutz, A. (2017). Compared to self-immersion, mindful attention reduces salivation and automatic food bias. *Scientific Reports*, *7*(1), Article 13839. https://doi.org/10.1038/s41598-017-13662-z

Batson, C. D. (1987). Prosocial motivation: Is it ever truly altruistic? In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 20, pp. 65–122). Academic Press. https://doi.org/10.1016/S0065-2601(08)60412-8

Batson, C. D., Turk, C. L., Shaw, L. L., & Klein, T. R. (1995). Information function of empathic emotion: Learning that we value the other's welfare. *Journal of Personality and Social Psychology*, *68*(2), 300–313. https://doi.org/10.1037/0022-3514.68.2.300

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, *57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1991). Autonomic determinism: The modes of autonomic control, the doctrine of autonomic space, and the laws of autonomic constraint. *Psychological Review*, *98*(4), 459–487. https://doi.org/10.1037/0033-295X.98.4.459

Berry, D. R., Cairo, A. H., Goodman, R. J., Quaglia, J. T., Green, J. D., & Brown, K. W. (2018). Mindfulness increases prosocial responses toward ostracized strangers through empathic concern. *Journal of Experimental Psychology: General*, *147*(1), 93–112. https://doi.org/10.1037/xge0000392

Berry, D. R., Hoerr, J. P., Cesko, S., Alayoubi, A., Carpio, K., Zirzow, H., Walters, W., Scram, G., Rodriguez, K., & Beaver, V. (2020). Does mindfulness training without explicit ethics-based instruction promote prosocial behaviors? A meta-analysis. *Personality and Social Psychology Bulletin*, *46*(8), 1247–1269. https://doi.org/10.1177/0146167219900418

Blechert, J., Peyk, P., Liedlgruber, M., & Wilhelm, F. H. (2016). ANSLAB: Integrated multichannel peripheral biosignal processing in psychophysiological science. *Behavior Research Methods*, *48*(4), 1528–1545. https://doi.org/10.3758/s13428-015-0665-1

Bloom, L. J., & Trautt, G. M. (1977). Finger pulse volume as a measure of anxiety: Further evaluation. *Psychophysiology*, *14*(6), 541–544. https://doi.org/10.1111/j.1469-8986.1977.tb01195.x

Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology*, *46*(1), 1–11. https://doi.org/10.1111/j.1469-8986.2008.00702.x

Bradley, M. M., Codispoti, M., Cuthbert, B. N., & Lang, P. J. (2001). Emotion and motivation I: Defensive and appetitive reactions in picture processing. *Emotion*, *1*(3), 276–298. https://doi.org/10.1037/1528-3542.1.3.276

Bradley, M. M., Greenwald, M. K., Petry, M. C., & Lang, P. J. (1992). Remembering pictures: Pleasure and arousal in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*(2), 379–390. https://doi.org/10.1037/0278-7393.18.2.379

Braunstein, L. M., Gross, J. J., & Ochsner, K. N. (2017). Explicit and implicit emotion regulation: A multi-level framework. *Social Cognitive and*

Affective Neuroscience, *12*(10), 1545–1557. https://doi.org/10.1093/scan/nsx096

Brewer, J. A., Elwafi, H. M., & Davis, J. H. (2013). Craving to quit: Psychological models and neurobiological mechanisms of mindfulness training as treatment for addictions. *Psychology of Addictive Behaviors*, *27*(2), 366–379. https://doi.org/10.1037/a0028490

Burt, K. B., & Obradović, J. (2013). The construct of psychophysiological reactivity: Statistical and psychometric issues. *Developmental Review*, *33*(1), 29–57. https://doi.org/10.1016/j.dr.2012.10.002

Cacioppo, J. T., Sandman, C. A., & Walker, B. B. (1978). The effects of operant heart rate conditioning on cognitive elaboration and attitude change. *Psychophysiology*, *15*(4), 330–338. https://doi.org/10.1111/j.1469-8986.1978.tb01389.x

Campbell, B., Wood., G., & McBride, T. (1997). Origins of orienting and defensive responses: An evolutionary perspective. In P. J. Lang, R. F. Simons, & M. Balaban (Eds.), *Attention and orienting* (pp. 41–68). Erlbaum.

Chen, S., & Jordan, C. H. (2020). Incorporating ethics into brief mindfulness practice: Effects on well-being and prosocial behavior. *Mindfulness*, *11*(1), 18–29. https://doi.org/10.1007/s12671-018-0915-2

Cialdini, R. B., Brown, S. L., Lewis, B. P., Luce, C., & Neuberg, S. L. (1997). Reinterpreting the empathy-altruism relationship: When one into one equals oneness. *Journal of Personality and Social Psychology*, *73*(3), 481–494. https://doi.org/10.1037/0022-3514.73.3.481

Cikara, M., Bruneau, E. G., & Saxe, R. R. (2011). Us and them: Intergroup failures of empathy. *Current Directions in Psychological Science*, *20*(3), 149–153. https://doi.org/10.1177/0963721411408713

Cohen, J. N., Jensen, D., Stange, J. P., Neuburger, M., & Heimberg, R. G. (2017). The immediate and long-term effects of an intensive meditation retreat. *Mindfulness*, *8*(4), 1064–1077. https://doi.org/10.1007/s12671-017-0682-5

Condon, P. (2019). Meditation in context: Factors that facilitate prosocial behavior. *Current Opinion in Psychology*, *28*, 15–19. https://doi.org/10.1016/j.copsyc.2018.09.011

Condon, P., & Makransky, J. (2020). Recovering the relational starting point of compassion training: A foundation for sustainable and inclusive care. *Perspectives on Psychological Science*, *15*(6), 1346–1362. https://doi.org/10.1177/1745691620922200

Contrada, R. J., Del Bo, A., Levy, L., & Weiss, T. (1995). Form and magnitude of beta-sympathetic and parasympathetic influences on pulse transit time. *Psychophysiology*, *32*(4), 329–334. https://doi.org/10.1111/j.1469-8986.1995.tb01215.x

Craig, E. D. (1968). Physiological arousal as a function of imagined, vicarious, and direct stress experiences. *Journal of Abnormal Psychology*, *73*(6), 513–520. https://doi.org/10.1037/h0026531

Creswell, J. D. (2017). Mindfulness interventions. *Annual Review of Psychology*, *68*(1), 491–516. https://doi.org/10.1146/annurev-psych-042716-051139

Cunningham, W. A., & Brosch, T. (2012). Motivational salience: Amygdala tuning from traits, needs, values, and goals. *Current Directions in Psychological Science*, *21*(1), 54–59. https://doi.org/10.1177/0963721411430832

Dahl, C. J., Lutz, A., & Davidson, R. J. (2015). Reconstructing and deconstructing the self: Cognitive mechanisms in meditation practice. *Trends in Cognitive Sciences*, *19*(9), 515–523. https://doi.org/10.1016/j.tics.2015.07.001

Davis, M. H. (1983). Measuring individual differences in empathy: Evidence for a multidimensional approach. *Journal of Personality and Social Psychology*, *44*(1), 113–126. https://doi.org/10.1037/0022-3514.44.1.113

Decety, J., & Meyer, M. (2008). From emotion resonance to empathic understanding: A social developmental neuroscience account. *Development and Psychopathology*, *20*(4), 1053–1080. https://doi.org/10.1017/S0954579408000503

Decety, J., Norman, G. J., Berntson, G. G., & Cacioppo, J. T. (2012). A neurobehavioral evolutionary perspective on the mechanisms underlying empathy. *Progress in Neurobiology*, *98*(1), 38–48. https://doi.org/10.1016/j.pneurobio.2012.05.001

Desbordes, G., Gard, T., Hoge, E. A., Hölzel, B. K., Kerr, C., Lazar, S. W., Olendzki, A., & Vago, D. R. (2015). Moving beyond mindfulness: Defining equanimity as an outcome measure in meditation and contemplative research. *Mindfulness*, *6*(2), 356–372. https://doi.org/10.1007/s12671-013-0269-8

Desbordes, G., Negi, L. T., Pace, T. W. W., Wallace, B. A., Raison, C. L., & Schwartz, E. L. (2012). Effects of mindful-attention and compassion meditation training on amygdala response to emotional stimuli in an ordinary, non-meditative state. *Frontiers in Human Neuroscience*, *6*, Article 292. https://doi.org/10.3389/fnhum.2012.00292

de Waal, F. B. M., & Preston, S. D. (2017). Mammalian empathy: Behavioural manifestations and neural basis. *Nature Reviews Neuroscience*, *18*(8), 498–509. https://doi.org/10.1038/nrn.2017.72

Dolcos, F., LaBar, K. S., & Cabeza, R. (2005). Remembering one year later: Role of the amygdala and the medial temporal lobe memory system in retrieving emotional memories. *Proceedings of the National Academy of Sciences*, *102*(7), 2626–2631. https://doi.org/10.1073/pnas.0409848102

Donald, J. N., Sahdra, B. K., Van Zanden, B., Duineveld, J. J., Atkins, P. W. B., Marshall, S. L., & Ciarrochi, J. (2019). Does your mindfulness benefit others? A systematic review and meta-analysis of the link between mindfulness and prosocial behaviour. *British Journal of Psychology*, *110*(1), 101–125. https://doi.org/10.1111/bjop.12338

Eisenberg, N., & Eggum, N. D. (2009). Empathic responding: Sympathy and personal distress. In J. Decety & W. Ickes (Eds.), *The social neuroscience of empathy* (pp. 71–84). MIT Press. https://doi.org/10.7551/mitpress/9780262012973.003.0007

Eisenberg, N., Fabes, R. A., Miller, P. A., Fultz, J., Shell, R., Mathy, R. M., & Reno, R. R. (1989). Relation of sympathy and personal distress to prosocial behavior: A multimethod study. *Journal of Personality and Social Psychology*, *57*(1), 55–66. https://doi.org/10.1037/0022-3514.57.1.55

Eisenberg, N., Fabes, R. A., Schaller, M., Miller, P., Carlo, G., Poulin, R., Shea, C., & Shell, R. (1991). Personality and socialization correlates of vicarious emotional responding. *Journal of Personality and Social Psychology*, *61*(3), 459–470. https://doi.org/10.1037/0022-3514.61.3.459

Elgendi, M. (2012). On the analysis of fingertip photoplethysmogram signals. *Current Cardiology Reviews*, *8*(1), 14–25. https://doi.org/10.2174/157340312801215782

Engen, H. G., & Singer, T. (2015). Compassion-based emotion regulation up-regulates experienced positive affect and associated neural networks. *Social Cognitive and Affective Neuroscience*, *10*(9), 1291–1301. https://doi.org/10.1093/scan/nsv008

Farb, N. A. S., Anderson, A. K., & Segal, Z. V. (2012). The mindful brain and emotion regulation in mood disorders. *The Canadian Journal of Psychiatry*, *57*(2), 70–77. https://doi.org/10.1177/070674371205700203

Favre, P., Kanske, P., Engen, H., & Singer, T. (2021). Decreased emotional reactivity after 3-month socio-affective but not attention- or meta-cognitive-based mental training: A randomized, controlled, longitudinal fMRI study. *NeuroImage*, *237*, Article 118132. https://doi.org/10.1016/j.neuroimage.2021.118132

Ferguson, A. M., Cameron, C. D., & Inzlicht, M. (2020). Motivational effects on empathic choices. *Journal of Experimental Social Psychology*, *90*, Article 104010. https://doi.org/10.1016/j.jesp.2020.104010

Fredrickson, B. L., Cohn, M. A., Coffey, K. A., Pek, J., & Finkel, S. M. (2008). Open hearts build lives: Positive emotions, induced through loving-kindness meditation, build consequential personal resources. *Journal of Personality and Social Psychology*, *95*(5), 1045–1062. https://doi.org/10.1037/a0013262

Garland, E. L., Farb, N. A., Goldin, P., & Fredrickson, B. L. (2015). Mindfulness broadens awareness and builds eudaimonic meaning: A process model of mindful positive emotion regulation. *Psychological Inquiry*, *26*(4), 293–314. https://doi.org/10.1080/1047840X.2015.1064294

Gavazzeni, J., Andersson, T., Bäckman, L., Wiens, S., & Fischer, H. (2012). Age, gender, and arousal in recognition of negative and neutral pictures 1 year later. *Psychology and Aging*, *27*(4), 1039–1052. https://doi.org/10.1037/a0027946

Gethin, R. (1998). *The foundations of Buddhism*. Oxford University Press.

Goetz, J. L., Keltner, D., & Simon-Thomas, E. (2010). Compassion: An evolutionary analysis and empirical review. *Psychological Bulletin*, *136*(3), 351–374. https://doi.org/10.1037/a0018807

Goldstein, J., & Kornfield, J. (1987). *Seeking the heart of wisdom: The path of insight meditation*. Shambhala.

Gomez, P., & Danuser, B. (2010). Cardiovascular patterns associated with appetitive and defensive activation during affective picture viewing. *Psychophysiology*, *47*(3), 540–549. https://doi.org/10.1111/j.1469-8986.2009.00953.x

Graham, F. K., & Clifton, R. K. (1966). Heart-rate change as a component of the orienting response. *Psychological Bulletin*, *65*(5), 305–320. https://doi.org/10.1037/h0023258

Hoffman, L. (2015). *Longitudinal analysis: Modeling within-person fluctuation and change*. Routledge.

Ingram, R. E. (1990). Self-focused attention in clinical disorders: Review and a conceptual model. *Psychological Bulletin*, *107*(2), 156–176. https://doi.org/10.1037/0033-2909.107.2.156

Jinpa, T. (2015). *A fearless heart: How the courage to be compassionate can transform our lives*. Avery.

Kang, Y. (2019). Examining interpersonal self-transcendence as a potential mechanism linking meditation and social outcomes. *Current Opinion in Psychology*, *28*, 115–119. https://doi.org/10.1016/j.copsyc.2018.12.007

Kaplan, S., & Berman, M. G. (2010). Directed attention as a common resource for executive functioning and self-regulation. *Perspectives on Psychological Science*, *5*(1), 43–57. https://doi.org/10.1177/1745691609356784

King, B. G., Conklin, Q. A., Zanesco, A. P., & Saron, C. D. (2019). Residential meditation retreats: Their role in contemplative practice and significance for psychological research. *Current Opinion in Psychology*, *28*, 238–244. https://doi.org/10.1016/j.copsyc.2018.12.021

King, B. G., Zanesco, A. P., Skwara, A. C., & Saron, C. D. (2023, February 10). *Cultivating concern for others: Meditation training and motivated engagement with human suffering* [Data set]. https://osf.io/e3g5m/

Kirmayer, L. J. (2015). Mindfulness in cultural context. *Transcultural Psychiatry*, *52*(4), 447–469. https://doi.org/10.1177/1363461515598949

Knight, M., & Ponzio, A. (2013). The effects of emotion regulation on explicit memory depend on strategy and testing method. *Emotion*, *13*(6), 1041–1054. https://doi.org/10.1037/a0033533

Koopmann-Holm, B., Sze, J., Ochs, C., & Tsai, J. L. (2013). Buddhist-inspired meditation increases the value of calm. *Emotion*, *13*(3), 497–505. https://doi.org/10.1037/a0031070

Kral, T. R. A., Schuyler, B. S., Mumford, J. A., Rosenkranz, M. A., Lutz, A., & Davidson, R. J. (2018). Impact of short- and long-term mindfulness meditation training on amygdala reactivity to emotional stimuli. *NeuroImage*, *181*, 301–313. https://doi.org/10.1016/j.neuroimage.2018.07.013

Krebs, D. (1975). Empathy and altruism. *Journal of Personality and Social Psychology*, *32*(6), 1134–1146. https://doi.org/10.1037/0022-3514.32.6.1134

Kveraga, K., Boshyan, J., Adams, R. B., Mote, J., Betz, N., Ward, N., Hadjikhani, N., Bar, M., & Barrett, L. F. (2015). If it bleeds, it leads: Separating threat from mere negativity. *Social Cognitive and Affective Neuroscience*, *10*(1), 28–35. https://doi.org/10.1093/scan/nsu007

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International Affective Picture System (IAPS): Affective ratings of pictures and instruction manual* (Technical Report A-8). University of Florida. https://www.csea.phhp.ufl.edu

Levenson, R. W., & Ruef, A. M. (1992). Empathy: A physiological substrate. *Journal of Personality and Social Psychology*, *63*(2), 234–246. https://doi.org/10.1037/0022-3514.63.2.234

Levine, L. J., & Edelstein, R. S. (2009). Emotion and memory narrowing: A review and goal-relevance approach. *Cognition & Emotion*, *23*(5), 833–875. https://doi.org/10.1080/02699930902738863

Lim, D., Condon, P., & DeSteno, D. (2015). Mindfulness and compassion: An examination of mechanism and scalability. *PLoS ONE*, *10*(2), Article e0118221. https://doi.org/10.1371/journal.pone.0118221

Lindahl, J. R. (2015). Why right mindfulness might not be right for mindfulness. *Mindfulness*, *6*(1), 57–62. https://doi.org/10.1007/s12671-014-0380-5

Lindsay, E. K., Chin, B., Greco, C. M., Young, S., Brown, K. W., Wright, A. G. C., Smyth, J. M., Burkett, D., & Creswell, J. D. (2018). How mindfulness training promotes positive emotions: Dismantling acceptance skills training in two randomized controlled trials. *Journal of Personality and Social Psychology*, *115*(6), 944–973. https://doi.org/10.1037/pspa0000134

Loewenstein, G., & Small, D. A. (2007). The scarecrow and the tin man: The vicissitudes of human sympathy and caring. *Review of General Psychology*, *11*(2), 112–126. https://doi.org/10.1037/1089-2680.11.2.112

Luberto, C. M., Shinday, N., Song, R., Philpotts, L. L., Park, E. R., Fricchione, G. L., & Yeh, G. Y. (2018). A systematic review and meta-analysis of the effects of meditation on empathy, compassion, and prosocial behaviors. *Mindfulness*, *9*(3), 708–724. https://doi.org/10.1007/s12671-017-0841-8

Lutz, A., Brefczynski-Lewis, J., Johnstone, T., & Davidson, R. J. (2008). Regulation of the neural circuitry of emotion by compassion meditation: Effects of meditative expertise. *PLoS ONE*, *3*(3), Article e1897. https://doi.org/10.1371/journal.pone.0001897

Lutz, A., Jha, A. P., Dunne, J. D., & Saron, C. D. (2015). Investigating the phenomenological matrix of mindfulness-related practices from a neurocognitive perspective. *American Psychologist*, *70*(7), 632–658. https://doi.org/10.1037/a0039585

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods*, *7*(1), 83–104. https://doi.org/10.1037/1082-989X.7.1.83

MacLean, K. A., Ferrer, E., Aichele, S. R., Bridwell, D. A., Zanesco, A. P., Jacobs, T. L., King, B. G., Rosenberg, E. L., Sahdra, B. K., Shaver, P. R., Wallace, B. A., Mangun, G. R., & Saron, C. D. (2010). Intensive meditation training improves perceptual discrimination and sustained attention. *Psychological Science*, *21*(6), 829–839. https://doi.org/10.1177/0956797610371339

Makransky, J. (2007). *Awakening through love: Unveiling your deepest goodness*. Wisdom.

Maratos, F. A., & Pessoa, L. (2019). What drives prioritized visual processing? A motivational relevance account. In N. Srinivasan (Ed.), *Progress in brain research* (Vol. 247, pp. 111–148). Elsevier. https://doi.org/10.1016/bs.pbr.2019.03.028

McArdle, J. J. (2009). Latent variable modeling of differences and changes with longitudinal data. *Annual Review of Psychology*, *60*, 577–605. https://doi.org/10.1146/annurev.psych.60.110707.163612

McMahan, D. L. (2017). How meditation works: Theorizing the role of cultural context in Buddhist contemplative practices. In D. L. McMahan & E. Braun (Eds.), *Meditation, Buddhism, and science* (pp. 21–46). Oxford University Press.

Miller, S. B., & Ditto, B. (1991). Exaggerated sympathetic nervous system response to extended psychological stress in offspring of hypertensives. *Psychophysiology*, *28*(1), 103–113. https://doi.org/10.1111/j.1469-8986.1991.tb03395.x

Montagrin, A., Brosch, T., & Sander, D. (2013). Goal conduciveness as a key determinant of memory facilitation. *Emotion*, *13*(4), 622–628. https://doi.org/10.1037/a0033066

Monteiro, L. M., Musten, R. F., & Compson, J. (2015). Traditional and contemporary mindfulness: Finding the middle path in the tangle of concerns. *Mindfulness*, *6*(1), 1–13. https://doi.org/10.1007/s12671-014-0301-7

Mor, N., & Winquist, J. (2002). Self-focused attention and negative affect: A meta-analysis. *Psychological Bulletin*, *128*(4), 638–662. https://doi.org/10.1037/0033-2909.128.4.638

Nhat Hanh, T. (1998). *The heart of the Buddha's teaching: Transforming suffering into peace, joy, and liberation*. Broadway Books.

Ochsner, K. N. (2000). Are affective events richly recollected or simply familiar? The experience and process of recognizing feelings past. *Journal of Experimental Psychology: General*, *129*(2), 242–261. https://doi.org/10.1037/0096-3445.129.2.242

Öhman, A., & Mineka, S. (2001). Fears, phobias, and preparedness: Toward an evolved module of fear and fear learning. *Psychological Review*, *108*(3), 483–522. https://doi.org/10.1037/0033-295X.108.3.483

Oveis, C., Horberg, E. J., & Keltner, D. (2010). Compassion, pride, and social intuitions of self-other similarity. *Journal of Personality and Social Psychology*, *98*(4), 618–630. https://doi.org/10.1037/a0017628

Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *Trends in Cognitive Sciences*, *6*(2), 93–102. https://doi.org/10.1016/S1364-6613(00)01845-3

Papies, E. K., Pronk, T. M., Keesman, M., & Barsalou, L. W. (2015). The benefits of simply observing: Mindful attention modulates the link between motivation and behavior. *Journal of Personality and Social Psychology*, *108*(1), 148–170. https://doi.org/10.1037/a0038032

Pilarczyk, J., Sterna, R., Schwertner, E., Pacula, B., Bartoszek, M., & Kuniecki, M. (2022). Physiological reactions at encoding selectively predict recognition of emotional images. *Biological Psychology*, *175*, Article 108429. https://doi.org/10.1016/j.biopsycho.2022.108429

Preston, S. D., & Hofelich, A. J. (2012). The many faces of empathy: Parsing empathic phenomena through a proximate, dynamic-systems view of representing the other in the self. *Emotion Review*, *4*(1), 24–33. https://doi.org/10.1177/1754073911421378

Purser, R. E. (2015). Clearing the muddled path of traditional and contemporary mindfulness: A response to Monteiro, Musten, and Compson. *Mindfulness*, *6*(1), 23–45. https://doi.org/10.1007/s12671-014-0373-4

Rosenberg, E. L., Zanesco, A. P., King, B. G., Aichele, S. R., Jacobs, T. L., Bridwell, D. A., MacLean, K. A., Shaver, P. R., Ferrer, E., Sahdra, B. K., Lavy, S., Wallace, B. A., & Saron, C. D. (2015). Intensive meditation training influences emotional responses to suffering. *Emotion*, *15*(6), 775–790. https://doi.org/10.1037/emo0000080

Rosseel, Y. (2012). Lavaan: An R package for structural equation modeling. *Journal of Statistical Software*, *48*(2), 1–36. https://doi.org/10.18637/jss.v048.i02

Sahdra, B. K., MacLean, K. A., Ferrer, E., Shaver, P. R., Rosenberg, E. L., Jacobs, T. L., Zanesco, A. P., King, B. G., Aichele, S. R., Bridwell, D. A., Mangun, G. R., Lavy, S., Wallace, B. A., & Saron, C. D. (2011). Enhanced response inhibition during intensive meditation training predicts improvements in self-reported adaptive socioemotional functioning. *Emotion*, *11*(2), 299–312. https://doi.org/10.1037/a0022764

Sakaki, M., Niki, K., & Mather, M. (2012). Beyond arousal and valence: The importance of the biological versus social relevance of emotional stimuli. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(1), 115–139. https://doi.org/10.3758/s13415-011-0062-x

Salzberg, S. (1995). *Lovingkindness: The revolutionary art of happiness*. Shambhala.

Scheffer, J. A., Cameron, C. D., & Inzlicht, M. (2022). Caring is costly: People avoid the cognitive work of compassion. *Journal of Experimental Psychology: General*, *151*(1), 172–196. https://doi.org/10.1037/xge0001073

Schumer, M. C., Lindsay, E. K., & Creswell, J. D. (2018). Brief mindfulness training for negative affectivity: A systematic review and meta-analysis. *Journal of Consulting and Clinical Psychology*, *86*(7), 569–583. https://doi.org/10.1037/ccp0000324

Schupp, H., Cuthbert, B., Bradley, M., Hillman, C., Hamm, A., & Lang, P. (2004). Brain processes in emotional perception: Motivated attention. *Cognition & Emotion*, *18*(5), 593–611. https://doi.org/10.1080/02699930341000239

Shields, G. S., Skwara, A. C., King, B. G., Zanesco, A. P., Dhabhar, F. S., & Saron, C. D. (2020). Deconstructing the effects of concentration meditation practice on interference control: The roles of controlled attention and inflammatory activity. *Brain, Behavior, and Immunity*, *89*, 256–267. https://doi.org/10.1016/j.bbi.2020.06.034

Shiota, M. N., Keltner, D., & John, O. P. (2006). Positive emotion dispositions differentially associated with Big Five personality and attachment style. *The Journal of Positive Psychology*, *1*(2), 61–71. https://doi.org/10.1080/17439760500510833

Shrout, P. E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, *7*(4), 422–445. https://doi.org/10.1037/1082-989X.7.4.422

Skwara, A. C., King, B. G., & Saron, C. D. (2017). Studies of training compassion: What have we learned; what remains unknown? In E. M. Seppälä, E. Simon-Thomas, S. L. Brown, M. C. Worline, C. D. Cameron, & J. R. Doty (Eds.), *The Oxford handbook of compassion science* (pp. 219–236). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190464684.013.17

Slagter, H. A., Davidson, R. J., & Lutz, A. (2011). Mental training as a tool in the neuroscientific study of brain and cognitive plasticity. *Frontiers in Human Neuroscience*, *5*, Article 17. https://doi.org/10.3389/fnhum.2011.00017

Smith, C. A., & Kirby, L. D. (2009). Putting appraisal in context: Toward a relational model of appraisal and emotion. *Cognition & Emotion*, *23*(7), 1352–1372. https://doi.org/10.1080/02699930902860386

Smith, P. L., & Little, D. R. (2018). Small is beautiful: In defense of the small-N design. *Psychonomic Bulletin & Review*, *25*(6), 2083–2101. https://doi.org/10.3758/s13423-018-1451-8

Smith, T. W., Houston, B. K., & Zurawski, R. M. (1984). Finger pulse volume as a measure of anxiety in response to evaluative threat. *Psychophysiology*, *21*(3), 260–264. https://doi.org/10.1111/j.1469-8986.1984.tb02932.x

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers*, *31*(1), 137–149. https://doi.org/10.3758/BF03207704

Stellar, J. E., Cohen, A., Oveis, C., & Keltner, D. (2015). Affective and physiological responses to the suffering of others: Compassion and vagal activity. *Journal of Personality and Social Psychology*, *108*(4), 572–585. https://doi.org/10.1037/pspi0000010

Steptoe, A., Godaert, G., Ross, A., & Schreurs, P. (1983). The cardiac and vascular components of pulse transmission time: A computer analysis of systolic time intervals. *Psychophysiology*, *20*(3), 251–259. https://doi.org/10.1111/j.1469-8986.1983.tb02152.x

Tashi Tsering, G. (2005). *The four noble truths: The foundation of Buddhist thought* (Vol. 1). Wisdom.

Todd, R. M., Cunningham, W. A., Anderson, A. K., & Thompson, E. (2012). Affect-biased attention as emotion regulation. *Trends in Cognitive Sciences*, *16*(7), 365–372. https://doi.org/10.1016/j.tics.2012.06.003

Vila, J., Guerra, P., Muñoz, M. A., Vico, C., Viedma-del Jesús, M. I., Delgado, L. C., Perakakis, P., Kley, E., Mata, J. L., & Rodríguez, S. (2007). Cardiac defense: From attention to action. *International Journal of Psychophysiology*, *66*(3), 169–182. https://doi.org/10.1016/j.ijpsycho.2007.07.004

Wadlinger, H. A., & Isaacowitz, D. M. (2011). Fixing our focus: Training attention to regulate emotion. *Personality and Social Psychology Review*, *15*(1), 75–102. https://doi.org/10.1177/1088868310365565

Wallace, B. A. (2004). *The four immeasurables: Cultivating a boundless heart*. Snow Lion.

Wallace, B. A. (2006). *The attention revolution: Unlocking the power of the focused mind*. Wisdom.

Weng, H. Y., Lapate, R. C., Stodola, D. E., Rogers, G. M., & Davidson, R. J. (2018). Visual attention to suffering after compassion training is associated with decreased amygdala responses. *Frontiers in Psychology*, *9*, Article 771. https://doi.org/10.3389/fpsyg.2018.00771

Weng, H. Y., Schuyler, B., & Davidson, R. J. (2017). The impact of compassion meditation training on the brain and prosocial behavior. In E. M. Seppälä, E. Simon-Thomas, S. L. Brown, M. C. Worline, C. D. Cameron, & J. R. Doty (Eds.), *The Oxford handbook of compassion science* (pp. 133–146). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190464684.013.11

Wielgosz, J., Goldberg, S. B., Kral, T. R. A., Dunne, J. D., & Davidson, R. J. (2019). Mindfulness meditation and psychopathology. *Annual Review of Clinical Psychology*, *15*(1), 285–316. https://doi.org/10.1146/annurev-clinpsy-021815-093423

Wilson-Mendenhall, C. D., Dunne, J. D., & Davidson, R. J. (2022). Visualizing compassion: Episodic simulation as contemplative practice. *Mindfulness*. Advance online publication. https://doi.org/10.1007/s12671-022-01842-6

Yaden, D. B., Haidt, J., Hood, R. W., Vago, D. R., & Newberg, A. B. (2017). The varieties of self-transcendent experience. *Review of General Psychology*, *21*(2), 143–160. https://doi.org/10.1037/gpr0000102

Zaki, J. (2014). Empathy: A motivated account. *Psychological Bulletin*, *140*(6), 1608–1647. https://doi.org/10.1037/a0037679

Zaki, J., & Cikara, M. (2015). Addressing empathic failures. *Current Directions in Psychological Science*, *24*(6), 471–476. https://doi.org/10.1177/0963721415599978

Zanesco, A. P., King, B. G., MacLean, K. A., & Saron, C. D. (2018). Cognitive aging and long-term maintenance of attentional improvements following meditation training. *Journal of Cognitive Enhancement*, *2*(3), 259–275. https://doi.org/10.1007/s41465-018-0068-1

Zanesco, A. P., King, B. G., Powers, C., De Meo, R., Wineberg, K., MacLean, K. A., & Saron, C. D. (2019). Modulation of event-related potentials of visual discrimination by meditation training and sustained attention. *Journal of Cognitive Neuroscience*, *31*(8), 1184–1204. https://doi.org/10.1162/jocn_a_01419

Zanesco, A. P., Skwara, A. C., King, B. G., Powers, C., Wineberg, K., & Saron, C. D. (2021). Meditation training modulates brain electric microstates and felt states of awareness. *Human Brain Mapping*, *42*(10), 3228–3252. https://doi.org/10.1002/hbm.25430

(*Appendix follows*)

Appendix

List of Images Used in the Studies

Image pairs were matched on thematic content and presented in counterbalanced sets (A and B) across the pre- and postassessments of Studies 1 and 2. Memory foils were then added to some image pairs for inclusion in the long-term follow-up assessment of Study 3. All threat and suffering images used in the studies are listed in Table A1. For illustration, only the subset of pleasant stimuli that were used as memory test items in Study 3 are indicated.

Table A1

Thematic Content, IAPS Number, and Memory Accuracy for Image Stimuli

		IAPS number			Memory accuracy		
Category	Theme or semantic content	Set A	Set B	Foil	Set A	Set B	Foil
Threat	Aimed gun	6230	6260	2811	.57	.48	.71
	Carjacking/assault	6821	6571	—	—	—	—
	Dog attack	1525	1300	1301	.19	.29	.67
	Gun assault	3500	3530	9425	.38	.24	.71
	Gun violence/threat	2683	9423	6830	.33	.38	.71
	Human skulls/skeleton (†)	9490	9440	9480	.14	.57	.67
	Physical assault	6530	6360	6315	.14	.33	.81
	Creepy animal	1280	1617	—	—	—	—
	Riot/street violence	9427	2691	9424	.33	.43	.71
	Roaches (†)	1274	1275	—	—	—	—
	Shark (†)	1932	1930	1931	.24	.24	.67
	Snake	1019	1070	1090	.43	.19	.67
	Snake	1050	1052	1120	.52	.29	.62
	Spider (†)	1205	1200	1201	.43	.43	.62
	Terror/violence (†)	9635	6213	6370	.33	.29	.81
Suffering	Accident scene/disaster (†)	9050	9435	9254	.19	.14	.86
	Battered woman	3180	3181	3225	.29	.29	.90
	Critical injury/condition	3230	3030	3261	.19	.19	.95
	Drug addiction (†)	2717	9102	2710	.29	.43	.71
	Frail or elderly person	2590	2490	—	—	—	—
	Grief or distress expression	2900	9421	9429	.24	.52	.90
	Loss/mourning the dead	2141	2799	9220	.19	.38	.67
	Medical or hospital scene	2205	3220	9432	.48	.38	.90
	Physical restraint	9419	9426	—	—	—	—
	Poverty/material need	2375	2703	9520	.43	.38	.90
	Sad or distressed child	2095	2800	2276	.48	.48	.86
	Severe injury (†)	9250	3101	9921	.43	.33	.90
	Severe injury of child	3170	3301	3266	.38	.29	1.00
	Sick or elderly person	2520	2491	—	—	—	—
	Starvation/helplessness (†)	9040	3350	3300	.38	.24	.95
Pleasant	Baby	2070	2040	2071	.48	.19	.76
	Blue sky/clouds	5551	5600	5891	.33	.14	.81
	Butterfly	1604	1602	1603	.33	.43	.43
	Cave/mountains (†)	5661	5611	5660	.33	.19	.86
	Cute animals (†)	1460	1610	1750	.24	.10	1.00
	Cute animals	1710	1463	1722	.24	.57	.67
	Cute child (†)	2655	2650	2332	.24	.38	.95
	Father with baby (†)	2165	2057	2160	.38	.19	.62
	Flowers	5849	5779	5811	.14	.19	.90
	Smiling faces	2550	2395	2340	.33	.43	.86
	Social gathering	7502	5833	5910	.29	.48	.90
	Sports	8205	8032	8031	.43	.48	.76

Note. Image themes with a dagger (†) were not included in physiological analyses (see Footnote 6). Memory accuracy is the proportion of correct memory judgments across 21 participants. IAPS = International Affective Picture System.

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