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CHAPTER

11 The Impact of Compassion Meditation Training on the Brain and Prosocial Behavior

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Abstract

Compassion meditation is a form of mental training that cultivates compassion towards oneself and other people, and is thought to result in greater prosocial behavior in real-world settings. This framework views compassion as a quality that can be trained, rather than a stable trait, and scientists have started testing these hypotheses using neuroscientific and objective behavioral methods. How does this internal meditative practice translate to external behavioral changes? We propose an emotion-regulation model of compassion meditation, where responses to suffering may change through three processes: (1) increasing empathic responses, (2) decreasing avoidance responses, and (3) increasing compassionate responses to suffering. These altered responses to suffering may lead to behavioral transfer, where prosocial behavior is more likely to occur, even in a non-meditative state. We summarize the neuroscientific and behavioral literature that may provide early support for this model, and make recommendations for future research to further test the model.

Key Words: compassion meditation, mental training, emotion regulation, neuroscience, brain imaging, functional magnetic resonance imaging (fMRI), prosocial behavior, altruism, empathy

Recent collaboration between contemporary Western scientists and leading scholars from contemplative traditions has focused on the claim that compassion is instrumental to well-being, and that it is a skill that can be trained (Davidson & Harrington, 2001; Lama & Cutler, 1998; Salzberg, 1997). Furthermore, cultivation of compassion is believed to translate into greater prosocial behavior towards human suffering when it is encountered in the real world (Davidson & Harrington, 2001; Lama & Cutler, 1998; Salzberg, 1997). How does this emotional transformation occur from purely internal mental training to actual changes in external social behavior? Here, we present a body of research that has examined the impact of participation in programs designed to strengthen compassion, largely drawn from Buddhist contemplative practices. To objectively investigate the psychological and behavioral changes associated with compassion meditation training, investigators have used methods of functional neuroimaging and observable prosocial behavior to interrogate three stages from meditation to behavioral change: (1) neural states during compassion meditative states, (2) transfer of compassionate responses to non-meditative states, and (3) behavioral transfer of compassionate responses to increases in prosocial behavior. We integrate these findings using an emotion-regulation framework to theorize how compassionate states during meditation practice translate to altering compassionate responses to suffering outside of the meditation context and enhance prosocial behavior to relieve suffering.

Compassion Meditation

Compassion involves an emotional response that is sensitive to another's suffering, as well as a motivational response of wanting to relieve suffering (Goetz, Keltner, & Simon-Thomas, 2010). Compassion meditation practices aim to cultivate compassionate responses towards people who are suffering who vary in relational closeness to the meditator. In the compassion meditation we have studied (Weng, Fox, et al., 2013; Weng, Fox, Hessenthaler, Stodola, & Davidson, 2015)—a secularized practice drawn from the Drikung Kagyu tradition of Tibetan Buddhist meditation (see http://center-healthyminds.org/well-being-tools/compassion-training/ for audio file and script)—meditators first cultivate compassion towards targets who are closer (such as a loved one and the self), then practice with targets who are less close (such as a stranger and a "difficult person" with whom there may be conflict), and finally, cultivate compassion toward all living beings. This step-wise progression can be thought of exercising compassion like a muscle, first starting with the "lightest weight" of a loved one (for whom it is relatively easy to feel compassion) and working up to the heavier weight of a difficult person (with whom more challenging emotions may be evoked).

For each target of compassion meditation, three steps are practiced:

1. *Envisioning suffering*, or imagining a time each person has suffered;
2. *Mindful attention to reactions to suffering*, where nonjudgmental attention is brought to sensations, thoughts, and feelings that arise in response to envisioning suffering; and
3. *Cultivating compassion*, where feelings of care and concern for the target are practiced as well as a desire to relieve suffering (see Figure 11.1).

Meditators are instructed to use visualization to imagine others' suffering (Step 1), as well as to envision a golden light extending from their heart to the other's heart to relieve suffering (Step 3). They are also instructed to pay attention to internal visceral sensations (interoception), particularly around the heart, during the meditation (Steps 1–3). They are instructed to internally repeat phrases to help cultivate compassion, such as, "May you be free from suffering; May you experience joy and ease" (Step 3). (See other chapters in this volume for descriptions of other methods and courses for training compassion.)

With continued practice of compassion meditation, several changes are hypothesized to occur. Compassionate responses cultivated during the meditation period are thought to transfer to non-meditative states, so that when suffering is encountered in the real world, compassionate responses are more likely to occur. Cultivation of the desire to relieve suffering is hypothesized to result in greater prosocial behavior when suffering is encountered, even when individuals are not in a meditative state. In addition, compassionate responses towards more relationally distant targets (e.g., a stranger, a difficult person) are thought to become more like compassion towards more relationally close targets (e.g., loved one, the self).

An Emotion-Regulation Model of Compassion Meditation

Our group has studied compassion meditation from an emotion-regulation framework, which posits that compassion meditation changes emotional responses to suffering to be more compassionate and promote prosocial behavior (Lutz,

Compassion Meditation Step	Strategies	Response Component
Step 1. Envisioning Suffering	For each target, visually imagine suffering (physical, emotional)	Greater Empathic Response Affective experience sharing Cognitive perspective taking
Step 2. Mindful attention to reactions to suffering	Acceptance and nonjudgmental attention to thoughts, feelings, sensations evoked by suffering	Less Avoid Response Lessen cycle of emotions and thoughts that lead to self-focus and avoidance (personal distress)
Step 3. Cultivating Compassion	Visualize golden light Focus on caring, concern, desire to relieve suffering Repeat compassion phrases	Greater Approach Response Cultivate emotions and thoughts that lead to prosocial motivation and behavior (empathic concern)

Figure 11.1 Emotion regulation model of compassion meditation. Meditators cultivate compassion for each target: a loved one, the self, a stranger, and a difficult person (someone with whom there is conflict).

Brefczynski-Lewis, Johnstone, & Davidson, 2008; Weng, Fox, et al., 2013). Emotion regulation has been defined as "all of the conscious and nonconscious strategies we use to increase, maintain, or decrease one or more components of an emotional response", where the components are the feelings, behaviors, and physiological responses that make up the emotion (Gross, 2001). We propose a working model of how compassion meditation results in emotion regulation, where each step in compassion meditation (i.e., envisioning suffering, mindful attention to reactions to suffering, and cultivating compassion) impacts a different component of the emotional response to suffering in order to support subsequent prosocial behavior (see Figure 11.1). Although the meditation described in this chapter primarily uses visual and emotional strategies to cultivate compassion, this model acknowledges that compassionate responses to suffering may be cultivated through both cognitive and affective means (Dahl, Lutz, & Davidson, 2015, 2016; Engen & Singer, 2016; Weng, Fox, et al., 2013). This is consistent with psychological models where thoughts and emotions have bidirectional influences on each other, and both can affect behavior (Beck, Rush, Shaw, & Emery, 1987; Greenberg, 2004; Lazarus, 1991).

An emotion-regulation model of compassion meditation is outlined in Figure 11.1. Each step in compassion meditation impacts cognitive and affective processing of stimuli of suffering to support compassionate responses and subsequent prosocial behavior. In Step 1 of *envisioning suffering* (Figure 11.1, Step 1), meditators visually imagine a time when each target has suffered, such as from physical or emotional pain. In the case of relationally close targets (e.g., loved one and the self), this draws from memories of actual events when suffering has occurred. In the case of relationally distant targets (e.g., stranger or difficult person), meditators may need to imagine and construct a situation where these people may have suffered from physical or emotional pain. We hypothesize that this step uses visual imagery to enhance initial empathic responses to suffering, where meditators increase their understanding of others' internal states both through affective experience-sharing (triggered by visual and memory cues) and cognitive perspective-taking of others' states (Lamm, Decety, & Singer, 2011; Preston & de Waal, 2002; Zaki & Ochsner, 2012). Visualizing suffering may be particularly important for enhancing empathic responses towards strangers and difficult people, who are typically considered less relevant to the self and less deserving of compassion (Ashar, Andrews-Hanna, Yarkoni, Sills, Halifax et al., 2016; Ashar, Andrews-Hanna, Dimidjian, & Wager, 2016; Chiao & Mathur, 2010; Goetz et al., 2010). This step may therefore shift unconscious appraisals of how self-relevant and deserving of compassion each target is. We posit that enhancing empathic responses to suffering is *necessary* to increase awareness of another's suffering, but is *not sufficient* to result in a compassionate response and prosocial behavior (which the next two steps cultivate).

In Step 2 of compassion meditation, meditators bring *mindful attention to reactions to suffering* (Figure 11.1, Step 2) where they practice acceptance and nonjudgmental observation of challenging thoughts, feelings, and sensations (Halifax, 2012; Kabat-Zinn & Hanh, 2013; Salzberg, 1997) induced by empathic responses to suffering. This acceptance-based emotion-regulation strategy (Hayes, Luoma, Bond, Masuda, & Lillis, 2006; Kabat-Zinn & Hanh, 2013) is thought to break the cycle of ruminative thoughts and feelings that can be triggered by negative events, if they are present. In this step it is important to regulate reactions that may inhibit prosocial responses such as personal distress, which are negative emotions evoked by another's suffering (such as feeling alarmed, upset, and worried), and may result in self-focus and the desire to relieve one's own suffering (Batson, 1991; Batson, Fultz, & Schoenrade, 1987). Therefore, decreasing habitual reactivity to challenging emotions in response to another's suffering may be an important skill developed by compassion meditation, which may inhibit avoidance behavior. Learning these skills may support compassion-related appraisals such as perceived ability to cope with suffering (Goetz et al., 2010). We posit that this step is neither necessary nor sufficient for compassionate responses and behavior to occur; however, mitigating challenging emotions through mindful attention may decrease avoidance responses, and allow for more cognitive resources to be deployed on cultivating compassionate responses (Step 3).

In Step 3 of compassion meditation (Figure 11.1, Step 3), meditators *cultivate compassion* towards the targets who are suffering using visualization, emotion, and cognitive strategies (Salzberg, 1997; Weng, Fox, et al., 2013; Weng et al., 2015). Visualization is used to imagine a golden light extending from their heart to the other person's heart to relieve suffering. Emotion-based strategies are used to focus on feelings of caring and concern for the person's well-being, and on the desire for that person's suffering to be relieved (Batson, 1991; Salzberg, 1997). To aid emotional awareness, meditators are instructed to pay attention to visceral sensations in the body, particularly around the heart. Finally, cognitive strategies are used such as repeating compassion-generating thoughts such as "May you be free from suffering." Cultivating compassion is thought to also strengthen compassion-related appraisals, including each target's relevance to the self, their deservingness of compassion, as well as the meditator's ability to cope with suffering (Ashar et al., 2016a; Ashar et al., 2016b; Goetz et al., 2010). Due to these emotional and cognitive changes, cultivating compassion is hypothesized to enhance prosocial motivation and approach behavior when suffering is encountered in the real world.

Compassion Meditation Training: A Model of State-to-trait Changes and Behavioral Transfer

How does cultivating compassion during a meditative state (state-level change) result in greater compassion during non-meditative states (trait-level change), and increase real-world prosocial behavior (behavioral transfer)? Based on the state-level changes proposed during the three steps of compassion meditation in Figure 11.1, we propose a model of how these three emotional response components may function at baseline (before compassion meditation training), may change during meditative practice, and with continued practice may change compassionate responses during non-meditative states (see Figure 11.2). This model is based on principles of *affective chronometry* in emotion regulation (Davidson, 1998; Gross, 1998; Schuyler et al.,

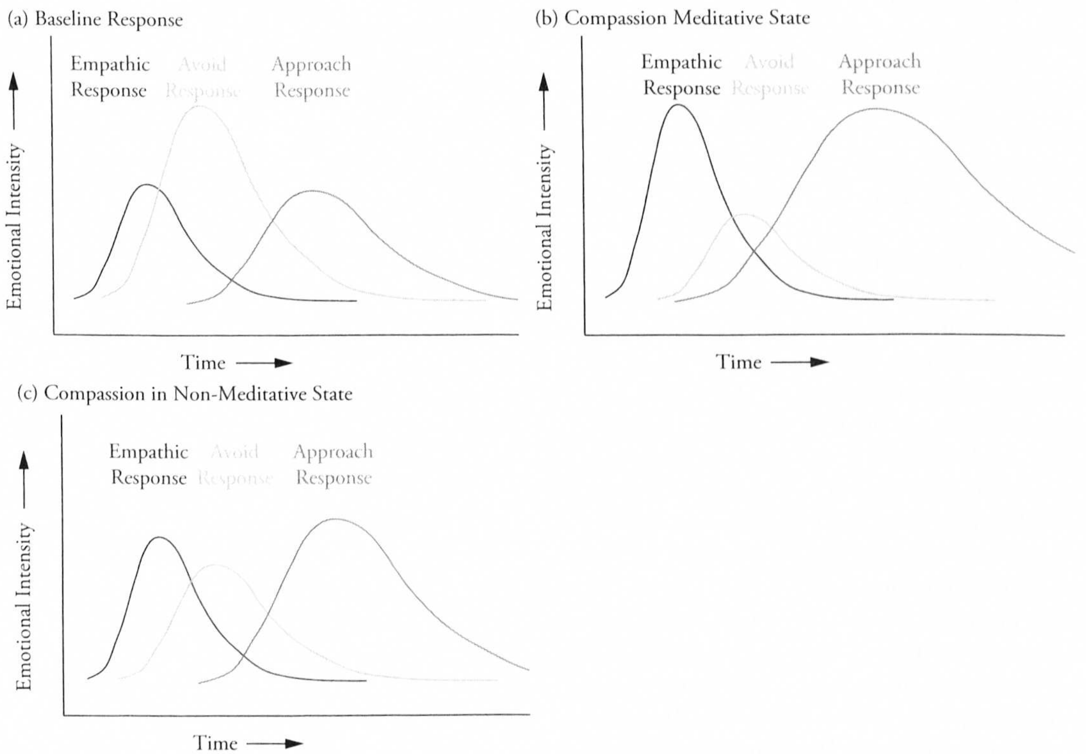

Figure 11.2 Theoretical model for compassion transfer within compassion meditation training from meditative to non-meditative states using an affective chronometry approach. We propose that responses to suffering that impact prosocial behavior involves three components: 1) empathic response to suffering, which signals the recognition of suffering necessary to cue subsequent prosocial responses, 2) avoidance responses that prevent prosocial behavior (if they are present, e.g., personal distress), and 3) approach responses that promote prosocial behavior (e.g., empathic concern). (a) Hypothetical baseline response within an untrained individual. Responses to suffering include a moderate empathic response, large avoid response, and moderate approach response. (b) Responses to suffering during a compassion meditative state. Compared to baseline, responses to suffering include a larger empathic response, decreased avoid response, and greater approach response. (c) Responses to suffering after compassion training during a non-meditative state, demonstration transfer of compassion. After compassion meditation practice, newly learned responses to suffering during a non-meditative state may fall between original baseline and meditative responses. The empathic response is increased from baseline and lower than meditation, the avoid response is decreased from baseline and greater than meditation, and the approach response is increased from baseline and lower than meditation.

2012), where each response component in compassion is conceptualized as a process that unfolds over time. Each response component includes a *rise time to peak*, or the time course of the speed and intensity of the response, and *recovery time*, or the time course of the response returning to baseline (due to both automatic and controlled emotion-regulation processes) (Davidson, 1998; Schuyler et al., 2012). For simplicity, we labeled the three response components as:

1. the *empathic response*, or the initial response that indicates recognition and understanding of another's suffering and is cultivated in Step 1 of compassion meditation;
2. the *avoid response*, or any cognitions and emotions that lead to avoidance of suffering and are mitigated in Step 2 of compassion meditation); and
3. the *approach response*, or any cognitions and emotions that promote compassion and prosocial behavior and are cultivated in Step 3 of compassion meditation (Figure 11.2).

In individuals who have not received compassion training, the baseline responses to suffering may show a moderate empathic response, a larger avoidance response, and a moderate approach response (Figure 11.2a). During a compassion meditative state, the empathic response may be enhanced, the avoidance response may be diminished, and the approach response may be enhanced for each target (Figure 11.2b). With continued practice, the compassionate responses during meditative states should begin to transfer to non-meditative states (demonstrating a form of emotional learning), which should shift the baseline responses to look more similar to meditative responses (*compassion transfer*). For example, compared to the baseline response, in a non-meditative state, the meditator may show a larger empathic response, a decreased avoidance response, and a greater approach response (Figure 11.2c); however, we posit that these responses are not as strong as meditative responses. Finally, after a period of training, compassionate responses during meditative and/or non-meditative states should lead to *behavioral transfer*, wherein cultivated emotional responses to suffering lead to greater prosocial behavior. The contemplative neuroscience field has started investigating components of this framework, and our group has specifically tested the hypothesis of behavioral transfer by examining the relationship between compassion meditative brain states and changes in prosocial behavior.

Empirical Evidence for the Emotion-Regulation Model of Compassion Meditation

In the following sections, we review and frame the behavioral and neuroscientific literature of compassion meditation within the emotion-regulation model. We first review evidence for the behavioral transfer hypothesis in which compassion meditation training may increase prosocial behavior towards those who are suffering. We then review evidence that each emotional response component of compassion (empathic responses, avoidance responses that may inhibit prosocial behavior, and approach responses that may promote prosocial behavior) may be altered by compassion meditation training. Finally, we make recommendations for future research to more rigorously and specifically test elements of the emotion-regulation model of compassion meditation.

Study Design to Test the Behavioral Transfer Hypothesis in Compassion Meditation

As far as we know, our work was the first to test the prosocial behavioral transfer hypothesis using both neural and behavioral measures. We tested whether compassion meditation training would increase prosocial behavior, and whether individual differences in behavior were related to changes in compassionate brain activity during a meditative state due to compassion training. We compared short-term online compassion training (meditation steps detailed heretofore) to cognitive reappraisal training. The compassion training was other-focused and aimed to increase empathic concern and prosocial motivation, while the reappraisal training was self-focused and designed to decrease personal negative emotions (Ochsner & Gross, 2005; Urry et al., 2006). (See Weng, Fox, et al., 2013, for more details, and http://centerhealthyminds.org/well-being-tools/compassion-training/ to download trainings.)

Participants were randomized to compassion training (n = 20) or reappraisal training (n = 21), and trainings were administered online for two weeks for 30 minutes a day. Participants were brain-scanned before and after the two weeks of training using an emotion-regulation paradigm, during which they were instructed to use their trainings (employing compassion or reappraisal strategies) towards images of people suffering. To measure altruistic behavior, we used behavioral economics methodology, which increased scientific rigor by systematizing social interactions into monetary exchanges, and requiring actual payment based on monetary decisions (decreasing the impact of social desirability). We designed the novel "Redistribution Game" wherein participants first witnessed an unfair interaction between two anonymous players, and then had the opportunity to spend personal funds to redistribute money from the unfair player to the other player. The game was administered after training. In order to directly test the behavioral transfer hypothesis, we investigated brain activity during compassion meditative states with individual differences in prosocial behavior.

Compassion Meditation Training Increases Prosocial Behavioral Responses to Suffering

We first tested whether compassion training resulted in greater prosocial behavior. We found that short-term compassion training increased redistribution behavior compared to reappraisal training (compassion trainees spent almost twice the amount as reappraisal trainees—Weng, Fox, et al., 2013). Within the same participants, economic paradigms that tested punishment of the unfair player and helping of the wronged player independently found that compassion training is associated more with helping than with punishment (Weng et al., 2015). These results demonstrated that even short-term training could result in greater prosocial behavior outside of the training context, confirming the behavioral transfer hypothesis that internal mental training could result in changes in external observable behavior. Interestingly, although the compassion group reported wanting to help the people in the images (on a scale from 1 = *Not at all* to 9 = *Very much*) more than the reappraisal group did (pre-training $t_{39} = 2.88, p < 0.01$; post-training $t_{39} = 3.54, p = 0.001$), and the compassion group showed increased reported desire to help after training (paired $t_{19} = 3.60, p < 0.01$), none of these reports (at pre, post, or the difference score) were associated with actual altruistic redistribution behavior (all p's > 0.33). Therefore, although subjective reports of a desire to help are increased by employing compassion and over time with compassion training, they are not necessarily associated with objective measures of altruistic behavior. Subjective report may be more influenced by social desirability (or the desire to look good to experimenters) than observable behavior, especially behavior that is costly to the participant. To most rigorously test the behavioral transfer hypothesis of compassion meditation training, we recommend that objective measures of prosocial behavior such as the Redistribution Game be used.

Other studies also support the hypothesis that compassion training increases observable prosocial behavior. For example, trainees were more likely than a wait-list control group to help an injured confederate after compassion training (Condon, Desbordes, Miller, & DeSteno, 2013; see Condon and DeSteno, this volume). Short-term compassion training also increased costly and non-costly helping of another player in a computerized game compared to a memory-training control group (Leiberg, Klimecki, & Singer, 2011; see Klimecki & Singer, this volume). In another study, four weeks of compassion meditation training via smartphone maintained the levels of charitable donations compared to decreased donations after a familiarity intervention control group (Ashar et al., 2016a; Ashar et al., 2016b). Long-term meditators of compassion meditation (LTMs; practitioners of the Nyingma tradition of Tibetan Buddhism who had engaged in meditation retreat for three or more years) showed greater recompensation of a player after an unfair exchange compared to novices, and demonstrated less punishment towards the unfair player (McCall, Steinbeis, Ricard, & Singer, 2014). Compassion training in children (e.g., Kindness Curriculum) may also enhance prosocial behavior compared to a wait-list control group, where children shared more stickers with most- and least-liked peers in their class, an unfamiliar child, and a child who was sick compared to a control group (Flook, Goldberg, Pinger, & Davidson, 2015). These studies provide early evidence that compassion training may exhibit behavioral transfer, where trait-level changes in compassionate responses to suffering encountered in the real world result in observable changes in prosocial behavior.

What neural and psychological changes contributed to this increase in prosocial behavior due to compassion training? To understand what contributes to these changes, we associated brain activity during voluntary generation of compassion (while viewing images of human suffering) to individual differences in redistribution behavior. We investigated whether redistribution was associated with changes in brain networks associated with (1) enhancing empathic responses to suffering, (2) decreasing responses that could lead to avoidance such as personal distress, and (3) increasing responses that promote prosocial behavior.

Compassion Meditation Training May Increase Empathic Responses to Suffering (Step 1)

In our work with compassion meditation novices, we found that greater redistribution behavior was associated with increases in activation in the right inferior parietal cortex (IPC) from pre- to post-compassion training (Weng, Fox, et al., 2013). This association between altruistic behavior and changes in IPC activation when viewing negative images (compared to neutral) was greater in the compassion vs. reappraisal group. The IPC is associated with an empathy network that is activated during shared representations of others' pain (Lamm et al., 2011), which supports the hypothesis that compassion training increases empathic responses to others' pain. The IPC was functionally correlated with the dorsolateral prefrontal cortex (DLPFC), which suggests that a fronto-parietal network may be engaged to support emotion regulation to enhance empathic responses (Vincent, Kahn, Snyder, Raichle, & Buckner, 2008). These data support the hypothesis of behavioral transfer due to compassion meditation, where training-related changes in neural activation and connectivity during a compassion meditative state were subsequently associated with behavioral changes that occurred during a non-meditative state.

What may have contributed to enhanced empathic neural responses? We examined eye-tracking data to test the hypothesis that compassion training increases visual attention to cues of suffering. We collected eye-tracking data during the fMRI task for each trial which was 12-seconds long, and computed the percentage of time when participants looked at emotional areas of interest (e.g., face of a woman crying) for negative vs. neutral images (see van Reekum et al., 2007, for methodological details). In a subset of participants with high-quality eye-tracking data (compassion n = 12, reappraisal n = 12), we found that at both pre- and post-training, the compassion group spent more time looking at the emotional parts of negative vs. neutral images when employing their training compared to the reappraisal group (t_{22} = 2.41, p < .05) (Davidson, 2010; Weng, 2014). Reappraisal may work to down-regulate negative emotions in part due to a behavioral strategy of averting eye gaze from emotional portions of images (van Reekum et al., 2007). These data suggest that compassion training may enhance visual attention to suffering, which may be one mechanism through which empathic neural responses are enhanced.

Other studies suggest that compassion meditation training may enhance empathic neural responses to human suffering during both meditative and non-meditative states. During a compassion meditative state, LTMs showed greater neural activation to sounds of human suffering in regions associated with experience-sharing and perspective-taking (Lamm et al., 2011; Zaki & Ochsner, 2012), including the insula, temporoparietal junction, and superior temporal sulcus, compared to novices (Lutz et al., 2008). In a non-meditative state after eight weeks of compassion training, neural networks associated with empathic accuracy of emotional eye expressions were longitudinally sustained, whereas they were decreased in a health discussion control group (Mascaro, Rilling, Negi, & Raison, 2013). These regions included the inferior frontal gyrus (IFG) and dorsomedial prefrontal cortex (dmPFC), which predicted performance in the empathic accuracy task (Mascaro et al., 2013; see Mascaro & Raison, this volume) and are associated with experience-sharing and mentalizing (Lamm et al., 2011; Zaki & Ochsner, 2012).

The amygdala was more highly activated in the LTMs (Lutz et al., 2008) during a compassion meditative state, which may reflect greater salience of emotional stimuli to detect suffering (Davis & Whalen, 2001). Similar to the finding in the LTMs, an eight-week compassion training enhanced activation in the right amygdala in response to images of suffering compared to a mindful-attention control group during a non-meditative state (Desbordes et al., 2012). This increase in amygdala activation was associated with functional benefits of decreased depression scores (Desbordes et al., 2012). Although amygdala responses can be associated with increased negative responses to negative stimuli (Ochsner & Gross, 2005; Zald, 2003), greater amygdala activation due to compassion training may represent a functional shift where suffering is more readily detected in order to respond prosocially. Because neural systems associated with the detection of suffering and empathic responses were engaged after compassion training in both meditative and non-meditative states, emotional transfer may be occurring where compassionate neural responses cultivated during meditative states may be transferring to non-meditative states.

However, this hypothesis has not been rigorously tested in any study, and different neural systems were engaged depending on the study and experimental paradigm.

Compassion Meditation Training May Decrease Responses That Promote Avoidance and Inhibit Prosocial Behavior (Step 2)

For some practitioners, greater empathic responses to others' suffering may provide an emotion-regulatory challenge. For example, greater awareness of another's suffering may lead to emotions that promote avoidance and inhibit prosocial behavior, such as personal distress (Batson, 1991), and therefore requires emotion regulation to mitigate these responses. By learning Step 2 of compassion meditation (Figure 11.1), mindful attention to negative emotional reactions to suffering may decrease withdrawal tendencies, and allow cognitive resources to be allocated to cultivating compassion (Step 3). Our data suggest that employing compassion is emotionally arousing, where compassion trainees reported greater arousal (how physiologically and psychologically activating the images are perceived to be) to both negative and neutral images compared to reappraisal ($F_{1,39} = 5.59$, $p < 0.05$; Weng, Motzkin, Stodola, Rogers, & Davidson, 2013). In response to images of suffering, we found a significant Group × Time interaction, where the compassion group reported greater arousal from pre- to post-training at trend level, and the reappraisal group did not change ($F_{1,39} = 5.47$, $p < 0.05$). Although at the group level, compassion training increased arousal to images of suffering, compassion trainees who were able to decrease arousal from pre- to post-training were the most altruistic in the redistribution game (Weng, Fox, et al., 2013). These findings suggest that compassion trainees who are able to regulate arousal after training may engage in an optimal level of arousal (Yerkes & Dodson, 1908), where they may affectively engage with others' suffering while maintaining cognitive resources to engage in prosocial motivation and planning.

Exploratory analyses within the amygdala also suggest that compassion training may decrease negative responses to suffering. We found that compassion trainees who were the most prosocial showed the most decreases in a region that encompassed the amygdala, as well as the hippocampal entorhinal cortex (Weng, Fox, et al., 2013), which are respectively implicated in emotional salience (Davis & Whalen, 2001) and social memory (Immordino-Yang & Singh, 2011). In addition, greater DLPFC activation due to training was correlated with decreased amygdala/hippocampal cortex activation across compassion and not reappraisal trainees (Weng, Fox, et al., 2013), which suggests that emotion regulatory systems were used to down-regulate activity in the amygdala. Compassion training, particularly mindful attention to reactions to suffering (Step 2), may cultivate more balanced emotional responses to suffering.

Several studies suggest that negative responses to suffering during non-meditative states may be decreased by compassion training. LTMs who practiced more compassion during a three-month meditation retreat showed less facial expressions of rejection emotions when watching videos of suffering compared to a waitlist control group (Rosenberg et al., 2015). After short-term empathy training, participants reported greater negative affect in response to suffering, but subsequent compassion training reversed this effect and negative affect was decreased (Klimecki, Leiberg, Ricard, & Singer, 2013). However, the effect is unclear, and it is unknown what would happen if compassion training had been implemented first. Parametric analyses demonstrated that decreases in negative affect after compassion training were mediated by the left supramarginal gyrus. In another study, after four weeks of using a smartphone-based compassion training app, participants experienced decreases in personal distress when viewing suffering due to training, and were associated with greater donations to charity (Ashar et al., 2016a; Ashar et al., 2016b). Personal distress as well as donation amounts were correlated with increased activity in an overlapping region of the ventromedial prefrontal cortex (vmPFC), which has been associated with constructing emotional meaning (Roy, Shohamy, & Wager, 2012). These findings suggest that compassion training may potentially decrease responses that inhibit prosocial behavior (such as personal distress) in response to suffering during non-meditative states. Because of the lack of studies examining these states during active meditation practice, it is currently unclear whether transfer of regulating inhibitory responses occurs from meditative to non-meditative states.

Compassion Meditation Training May Increase Responses That Promote Prosocial Behavior (Step 3)

We also found neural evidence that compassion training increases prosocial behavior through emotion-regulatory systems that enhance prosocial emotions. Greater changes in functional connectivity between the DLPFC and the nucleus accumbens (NAcc), a region implicated in social reward (Sanfey, 2007), were found to predict greater altruistic behavior in the compassion vs. reappraisal group (Weng, Fox, et al., 2013). This may suggest that emotion-regulation networks were recruited to up-regulate prosocial responses to suffering, including positive appraisals of aversive stimuli (Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008), enhancing affiliation (Depue & Morrone-Strupinsky, 2005) to people who are suffering, and increasing the reward value (Knutson & Cooper, 2005) of the victim's well-being. Greater DLPFC-NAcc connectivity was also associated with training-related decreases in reported arousal, which suggests that arousal may be indirectly decreased by promoting affiliative emotions rather than directly down-regulating arousal (Weng, Fox, et al., 2013).

Studies of compassion meditation training have also examined changes in prosocial responses to suffering during meditative and non-meditative states. Participants report greater positive affect during meditative states in LTMs (Engen & Singer, 2015), as well as non-meditative states in novices who view videos of suffering (Klimecki et al., 2013). During a non-meditative state, LTMs report greater *sympathy* (a term similar to *empathic concern* and *compassion*) towards suffering after a three-month retreat, and sympathy is associated with facial expressions of sadness (Rosenberg et al., 2015). Neural data consistently implicate regions associated with positive affect (Kringelbach & Berridge, 2009), affiliation (Strathearn, Fonagy, Amico, & Montague, 2009), and reward (Haber & Knutson, 2010), including the ventral striatum, ventral tegmental area, and the medial orbitofrontal cortex in both meditative (Engen & Singer, 2015; Klimecki, Leiberg, Lamm, & Singer, 2012) and non-meditative states (Klimecki et al., 2013). Another study found that training-related increases in reported tenderness (feelings of warmth and softness) when viewing suffering in a non-meditative state were associated with greater donations to charity (Ashar et al., 2016a; Ashar et al., 2016b), and that both tenderness and donations were correlated with increased activity in the vmPFC. However in our own dataset, we found that changes in a non-meditative state (where participants were instructed to simply attend to images of suffering) did *not* predict changes in altruistic redistribution (unpublished data, $p < 0.01$ whole-brain corrected). These studies suggest that transfer of compassionate responses from meditative states to non-meditative states may occur; however, this hypothesis has not been directly tested in any study. Behavioral transfer may be mediated by changes in both meditative non-meditative neural states in systems implicated in emotional meaning, emotion regulation, and reward processing.

Summary and Recommendations for Future Research

In recent years, an emerging field has studied the neural underpinnings of the cognitive and affective neural changes associated with compassion meditation training and resulting changes in prosocial behavior. During compassion meditative states, networks associated with emotional salience, experience-sharing, perspective-taking, emotion regulation, and positive affect and affiliation have been identified across studies. When suffering is encountered in a non-meditative state after compassion training, networks associated with empathic accuracy, emotional salience, and positive affect and affiliation are all enhanced across the studies discussed. These findings support the hypothesis that compassion training may enhance prosocial behavior by altering neural systems subserving response components to suffering: (1) increasing empathic neural responses, (2) decreasing avoidance responses that inhibit prosocial behavior, and (3) increasing approach responses that promote prosocial behavior. Furthermore, compassion transfer may occur where neural changes that occur during active meditative states transfer to non-meditative states when suffering is encountered; however, these hypotheses have not been directly tested. Similar networks appear to be activated during meditative and non-meditative states of compassion, but results varied depending on the population studied, the length of compassion training, and the fMRI paradigm.

Neural patterns representing compassionate brain states may be highly variable due to the complex psychological components of compassion, which may change at different rates, depending on how individuals respond to practices. For example, some individuals may need to focus on increasing initial empathic responses to suffering, while others may need to regulate avoidance responses and/or enhance prosocial responses. We expect highly variable patterns of neural activation, particularly in novices, whereas long-term practitioners may have more reliable and consistent patterns due to years of practice. Length of training may influence the strength and detectability of changes in neural activation due to training. For example, in our work, short-term compassion training did not produce any group-level differences in neural activation between compassion and reappraisal training that survived whole-brain correction for multiple comparisons (unpublished data); however, changes in activation due to training were associated with prosocial behavior, demonstrating that individual variability in brain responses was related to meaningful behavioral outcomes (Weng, Fox, et al., 2013). The behavioral transfer hypothesis is supported across several studies where prosocial behavior is enhanced by compassion training, and this change in behavior is predicted by neural activation during meditative and non-meditative states.

Future work should focus on testing more directly how compassionate neural states generated during meditation (representing the three response components to suffering) impact compassionate neural states during a non-meditative state, and how this subsequently increases prosocial behavior in response to suffering. We propose methodological advances here to better investigate these processes given the complex nature of compassion.

Understanding spatial and temporal variability of compassionate brain states: Because compassion training can affect processing at different levels (e.g., appraisals, emotional responses and regulation, prosocial motivation), and many tasks and populations are being studied, it is unlikely that we will identify a canonical compassionate brain response across studies. Supporting the hypothesis that compassionate neural states are highly variable in novices, analyses of shorter-term trainings (ranging from one day to eight weeks) often use region-of-interest (ROI)–based approaches and find that whole-brain analyses do not yield significant results. In addition, the development of compassionate neural states over time may not follow a linear pattern but may develop in qualitative and quantitative shifts. The neural representation of compassion in LTMs is unlikely to be similar to that of novices. Depending on the length and quality of their practice, people are likely to be at different stages in ability when trying to regulate distress, enhance prosocial feelings, and stay focused on another's suffering. People often have mixed responses to suffering, which are unlikely to be simply categorized as avoidant and/or prosocial, particularly if the suffering encountered is novel or involves highly evocative stimuli. This increases the likelihood that variability exists across individuals, particularly in novices who may not be able to consistently evoke a compassionate response. In addition, activation in one region may have different functional significance depending on the task and population studied. For example, during voluntary generation of compassion, LTMs show greater amygdala activation to distressing sounds (Lutz et al., 2008), whereas in non-meditative states, novices who undergo an eight-week course also show greater amygdala activation to negative images (Desbordes et al., 2012). However, during voluntary generation of compassion towards a similar image set, training-related decreases in the amygdala and hippocampal entorhinal cortex predicted greater altruistic behavior (Weng, Fox, et al., 2013). Many sources of variability potentially exist within neural representations of compassion training both within and between individuals, and neuroimaging methods that are able to harness and quantify this variability are needed.

Multivariate representation of compassionate brain states: Due to potential high variability within compassionate brain states, as well as regions being involved in more than one process (e.g., both personal distress and tenderness were associated with vmPFC activation in Ashar et al., 2016a), investigating neural states in compassion training using multivariate methods may be beneficial. Techniques such as multi-voxel pattern analysis (MVPA; Norman, Polyn, Detre, & Haxby, 2006) may be well suited to studying compassion training because it allows for: (1) spatial variability in the way complex mind states may be represented within individuals, which may be ideal for studying compassionate neural patterns both between and within subjects; and (2) temporal resolution to classify dynamic fluctuations of brain states through time (at each fMRI data time point). With this capacity, dynamic fluctuations of components of compassionate brain states (such as the empathic response, and responses that inhibit and promote prosocial behavior) may potentially be tracked as they wax and wane over time (Norman, Polyn, Detre, & Haxby, 2006). In MVPA, neural patterns may be analyzed at the individual level in native space (without norming to group-level templates), which produces individually derived metrics that can then be analyzed at the group level.

In preliminary analyses with our short-term compassion training dataset, we used classification accuracy, as determined by MVPA, as an indirect measure of stability and distinctiveness of compassionate brain states compared to other states (e.g., simply attending to the images). We found that compassion training specifically increased classification accuracy of compassionate brain states from pre-training (28.5%, where chance level is at 25%) to post-training (33.5%; $t_{167} = 3.77$, $p < 0.001$), and not the other three conditions. In addition, the greater the stability and distinctiveness of compassionate brain states (as indicated by classification accuracy), the more the participants subsequently donated their earnings to charity ($rho_{27} = 0.51$, $p = 0.005$; Weng, Lewis-Peacock, Stodola, & Davidson, 2012). Other groups also suggest applying multivariate methods to study neural representations of compassion training, such as using MVPA to examine neural patterns within the vmPFC that distinguish personal distress from tenderness (Ashar et al., 2016a).

Affective chronometry of compassionate neural responses to suffering: Compassionate responses to suffering can also be examined from an affective chronometry approach, examining how neural responses unfold over time through key information-processing points (Davidson, 1998; Gross, 2001; Figure 11.2). Investigators have examined the temporal dynamics of responses to emotional stimuli, comparing initial responses to stimuli to later responses. For example, amygdala responses to negative images may be analyzed in terms of an initial *reactivity* period compared to a later *recovery* period, and faster amygdala recovery (controlling for reactivity) is associated with decreased trait neuroticism (Schuyler et al., 2012).

Because compassionate responses encompass potentially both avoidant and prosocial responses to suffering, both frameworks can be used to examine how quickly compassion trainees can recover from stimuli of suffering as well as sustain or increase prosocial responses. Additionally, the strength of the initial empathic response to suffering may be enhanced through compassion training and can increase the emotional salience of human suffering. One study of long-term compassion meditators examined temporal dynamics of the amygdala and ventral striatum during a compassion-regulatory strategy compared to cognitive reappraisal (Engen & Singer, 2015). Comparing compassion to reappraisal strategies, they found that activity in both the amygdala and ventral striatum is sustained, suggesting that compassion involves greater emotional salience as well as positive responses to suffering compared to reappraisal. Both meditative and nonmeditative compassionate responses can be examined using affective chronometry approaches.

Objective measures of emotion: Self-reported ratings of emotions and appraisals have provided invaluable information about how people perceive stimuli of suffering. However, self-reported metrics are susceptible to demand characteristics and rely on accurate introspection. More objective metrics of emotions should be incorporated into experimental paradigms (either simultaneously measured with fMRI or outside the scanner), such as facial electromyography (Heller, Greischar, Honor, Anderle, & Davidson, 2011), facial action coding system (Rosenberg et al., 2015), heart rate (Lutz, Greischar, Perlman, & Davidson, 2009), and skin conductance (Schiller et al., 2010). These data can provide additional information regarding the valence, arousal, and type of emotions being experienced during compassion. In addition, psychophysiological data such as eye-tracking and pupillometry can also provide information on deployment of attentional resources and cognitive effort (Johnstone, van Reekum, Urry, Kalin, & Davidson, 2007; van Reekum et al., 2007).

Improvements in assessing prosocial behavior: Finally, the field has made strides in studying the prosocial outcomes of compassion training by measuring observable behavior outside of the training context. Ultimately, we want to test whether compassion training directly affects relationships, such as interactions with family, coworkers, and larger communities. Both the quality and the quantity of these interactions impact health and even mortality (Brown & Brown, 2015; Cohen, 2004; House, Landis, & Umberson, 1988). Preliminary evidence suggests that loving-kindness meditation enhances perceived social connection in daily life (Fredrickson, Cohn, Coffey, Pek, & Finkel, 2008; Kok & Fredrickson, 2010), which probably leads to more affiliative prosocial behaviors. More efforts should be made to combine neuroimaging measures with assessments in daily living, such as ecological momentary assessment (Shiffman, Stone, & Hufford, 2008), video and audio recorded interactions, as well as feedback from the potential recipients of compassion (second-person report). Compassionate behavior is not effective unless it is appropriate for the recipients of compassion, and this is a valuable source of information to assess the quality of prosocial behavior. The field can also draw from wisdom from the clinical psychology literature, where detailed assessments of empathic accuracy have been developed from the motivational interviewing literature (Miller & Rollnick, 2012). Well-designed tasks to assess prosocial (Ashar et al., 2016b) and empathic behavior (e.g., empathic accuracy in Zaki, Weber, Bolger, & Ochsner, 2009) should be administered within the scanner to associate with real-world assessments of prosocial behavior outside of the scanner. Dyadic interactions can be assessed inside the scanner using hyperscanning fMRI (pairwise data-acquisition) and related to real-world social behavior such as dyadic social network complexity (Bilek et al., 2015). Dyadic interactions can also be assessed outside of the scanner using psychophysiological linkage (Levenson

& Gottman, 1983) to associate them with compassionate neural responses. Tasks should also be designed that can be administered longitudinally that are less susceptible to demand characteristics, and studies should examine how long the training needs to be for behavioral effects to be sustained. Ultimately, these neural changes and behavioral outcomes should be related to mental and physical health outcomes of the participants (Fredrickson et al., 2008; Pace et al., 2009), as well as the people in their social networks, to test the hypotheses that compassion training positively influences both individual and systemic health (Davidson & Harrington, 2001; Lama & Cutler, 1998).

Targets of meditation: Studying specific targets of meditation may also be important in understanding the compassion transfer from close others (e.g., loved one, benefactor, the self) to more distant others (e.g., strangers, difficult people). Compassionate responses to each target may yield psychologically and clinically meaningful information. Compassionate responses to close others may represent a neural index of attachment security (Mikulincer & Shaver, 2005), and the quality of compassion evoked for close others may be associated with the ability to feel compassion for less close targets. We also recommend that investigators specifically study compassionate responses towards difficult people, where more complex emotions may be evoked, such as anger, annoyance, fear, and anxiety. More time may need to be spent focused on mindful attention to reactions to suffering, and empathy training (Klimecki et al., 2013) may be a necessary step before being able to practice compassion. These processes would be important to understand to apply to issues such as conflict resolution.

Finally, compassion training may be implemented to improve interactions between people of different group memberships. Researchers found that compassion training decreased implicit biases towards stigmatized out-group members (Kang, Gray, & Dovidio, 2013), even when those targets were not explicitly engaged during practice. These questions provide fruitful paths for future research in the impact of compassion training on neural and social behavioral functioning.

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