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Mindfulness meditation-related pain relief: Evidence for unique brain mechanisms in the regulation of pain

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Abstract

The cognitive modulation of pain is influenced by a number of factors ranging from attention, beliefs, conditioning, expectations, mood, and the regulation of emotional responses to noxious sensory events. Recently, mindfulness meditation has been found attenuate pain through some of these mechanisms including enhanced cognitive and emotional control, as well as altering the contextual evaluation of sensory events. This review discusses the brain mechanisms involved in mindfulness meditation-related pain relief across different meditative techniques, expertise and training levels, experimental procedures, and neuroimaging methodologies. Converging lines of neuroimaging evidence reveal that mindfulness meditation-related pain relief is associated with unique appraisal cognitive processes depending on expertise level and meditation tradition. Moreover, it is postulated that mindfulness meditation-related pain relief may share a common final pathway with other cognitive techniques in the modulation of pain.

Keywords

Mindfulness; Meditation; Pain; Neuroimaging

The advent of contemporary neuroimaging techniques has contributed greatly to our understanding of the neural mechanisms underlying pain perception and, importantly, how pain can be modulated. Increases in experienced pain are reliably associated with increased brain activity in a set of regions including the anterior cingulate cortex (ACC), anterior insula and sensory areas such as primary and secondary somatosensory cortices (SI/SII), thalamus and posterior insula [1,13,14,19,56].

A variety of factors are now known to either increase or decrease pain-related brain activation, including: predictive cues [3], distraction [5,58], attention [52,58,63] expectation [41,55], beliefs [68], placebo [54,67], hypnosis [57], stress, anxiety, mood and emotional state [51,65]. Many of these factors, however, are difficult for an individual to engage in a self-directed and volitional fashion. By contrast, there is growing evidence that mindfulness

meditation, a volitionally initiated cognitive act, can significantly attenuate the subjective experience of pain. Although mindfulness meditation has only recently been the subject of scientific investigation, the emerging data indicate that it shares important common neural substrates engaged by other cognitive factors known to modulate pain. Nevertheless, some facets of mindfulness meditation-related pain relief appear to engage brain mechanisms distinct from those engaged by other cognitive factors and thus may provide novel insights into how the subjective experience of pain is produced and modulated.

1. What is mindfulness?

Mindfulness has been described as a “non-elaborative, non-judgmental awareness” of present moment experience [36]. Operational definitions of mindfulness expand on this description by regarding it as including: (a) regulated, sustained attention to the moment-to-moment quality and character of sensory, emotional and cognitive events, (b) the recognition of such events as momentary, fleeting and changeable (past and future representations of those events being considered cognitive abstractions), and (c) a consequent lack of emotional or cognitive appraisal and/or reactions to these events. This latter aspect highlights the assumption that our normal experiences are typically, but perhaps unnecessarily, framed as enduring due to insufficient mindfulness and thus augmenting mindfulness could have significant positive effects. Taken together, mindfulness is simultaneously a process of cognitive control, emotional reappraisal or reduced judgment, and existential insight. Although there are individual differences in trait mindfulness [15,20], this characteristic can be developed by mental training such as meditation.

2. Mindfulness meditation practices: focused attention and open monitoring

There are a variety of different meditative practices that are subsumed under the general rubric of “*mindfulness*”. This ambiguity has led to confusion within the literature because the specific meditation technique being employed is not always adequately defined and operationalized [20,42,59]. Because the mechanisms involved in meditation-induced pain-related changes may be dependent on the specific technique being investigated (see below), it is critical that the specifics of the practice being taught or employed be recognized. In general, mindfulness techniques can be divided into two styles, namely, focused attention and open monitoring [42] (see Lutz et al. [42] for a comprehensive review).

Focused attention (FA), also known as Samatha or Shamatha (from Sanskrit), is associated with maintaining focus on a specific object, often the changing sensation or flow of the breath or an external object [42]. When attention drifts from the object of focus to a distracting sensory, cognitive or emotional event, the practitioner is taught to acknowledge the event and to disengage from it by gently returning the attention back to the object of meditation. Along with training stability and flexibility of one’s attention, the FA practitioner likely engages in cognitive reappraisal by repeatedly reinterpreting distracting events as fleeting or momentary and doing so with acceptance.

By contrast, open monitoring (OM), or Vipassana (Sanskrit translation), is associated with a non-directed acknowledgement of any sensory, emotional or cognitive event that arises in the mind. Zen meditation is considered to be one form of OM practice [4]. While practicing OM, the practitioner experiences the current sensory or cognitive ‘event’ without evaluation, interpretation, or preference. OM practice is associated with a non-evaluative and non-elaborative mental stance whereas FA practice places less emphasis on refraining from appraisal or elaboration. Unlike FA, which likely involves reappraisal, OM ultimately would involve a complete lack of higher order appraisal. Traditionally it is taught that training in

focused attention, prior to open monitoring, stabilizes one's attention and emotions allowing insight, into the changeability of experience, to occur during OM practice.

3. Mindfulness meditation and health

Mindfulness meditation has been found to improve a wide spectrum of cognitive and health outcomes [29]. Training in mindfulness meditation improves anxiety [25,38], depression [6,61], stress [2,10,11,39], and cognition [33,42–44,70]. Mindfulness-related health benefits are associated with enhancements in cognitive control, emotion regulation, positive mood, and acceptance, each of which have been associated with pain modulation [29]. Thus, it seems reasonable to hypothesize that mindfulness meditation itself would attenuate pain through some of these mechanisms.

4. Mindfulness meditation and pain

For thousands of years, contemplatives have reported that the practice of mindfulness meditation attenuates the experience of pain by modulating expectations, the nature and orientation of attention toward the experience, and the corresponding emotional response [7]. In 1980, Clark and Clark reported that “devout Buddhist” porters from Nepal exhibited higher pain tolerance and lower subjective pain reports when compared to other, age-matched, ethnic groups [12]. Although these researchers suggested that religious practices (i.e., meditation) were associated with greater pain tolerance, it was not clear if mindfulness-based practice itself could reduce pain [12].

In the early 1980s, clinical studies of mindfulness began with Jon Kabat-Zinn's seminal work with chronic pain patients. It was hypothesized that training in mindfulness would attenuate pain by altering emotional responses to pain and enhancing acceptance-related coping strategies [35,37]. Over the course of a five year study, it was found that chronic pain patients who completed an eight-week Mindfulness-Based Stress Reduction (MBSR) program significantly improved their pain symptoms and overall quality of life, even up to four years after completion of this initial training. In other work, eight weeks of mindfulness training was shown to improve pain acceptance in lower back pain patients [47]. More recently, [64] administered a dot-probe task of pain-related threat words to fibromyalgia (FM) patients. Increased engagement to pain-related threat, as measured by dot-probe performance, is associated with slower response times to a neutral probe where a pain-related stimulus was previously presented. It was noted that participation in the MBSR program reduced avoidance of pain-related threat words when compared to FM patients without meditation training [64]. These results are consistent with the work of Grossman showing positive influences of the MBSR program on FM patients [30]. Garland and colleagues recently determined that eight weeks of mindfulness training significantly improved pain symptoms in irritable bowel syndrome (IBS) patients, even after three months of training [23,24]. Multivariate path analyses revealed that mindfulness meditation reduced pain symptoms by reducing anxiety and emotional reactions to IBS symptoms [23]. Taken together, these findings provide evidence for the *effectiveness* of mindfulness meditation in the treatment of clinical pain. However, the degree to which these effects are due to the meditation practices themselves (i.e., the *efficacy* of mindfulness to reduce pain) is less clear.

Addressing this question requires the ability to isolate and study the ‘active ingredients’ of meditation by eliminating potential placebo or regression-to-the-mean effects. Unfortunately, there has been a lack of controlled clinical trials that have achieved this aim. An alternative approach has been to explore the effects of mindfulness-related pain modulation in highly controlled experimental settings.

5. Behavioral studies of meditation-related pain relief

The first attempts to evaluate the effects of mindfulness meditation on experimentally induced pain compared highly trained meditators with meditation-naïve controls. Grant and Rainville noted that long-term Zen meditation practitioners required higher temperatures to report moderate pain [28]. During a focused attention condition, where subjects directed their attention toward the pain, pain ratings increased in meditation-naïve controls whereas meditation practitioners had a non-significant reduction in pain. Conversely, during a mindful attention condition, both sensory and affective pain ratings were reduced in experienced practitioners, whereas no effect was seen in meditation-naïve controls. Importantly, the largest pain reductions were observed in the most advanced practitioners. A similar study contrasted focused attention and open monitoring in long-term Tibetan practitioners [50]. Perlman et al. [50] reported that adept meditators practicing OM had lower pain unpleasantness, but not pain intensity ratings. No significant differences were found between meditators and controls during the FA condition and, in contrast to Grant and Rainville's findings [28], no differences in baseline pain sensitivity were observed. While differences exist between these two studies, the findings suggest that different meditative traditions (i.e., Zen, Vipassana) employing mindfulness practice, particularly the OM style of mindfulness, are associated with pain reduction. While these reports were important in advancing the concept of meditation-related analgesia, they did not account for potential pre-existing differences between meditators and controls and, therefore, do not allow causal inferences to be made. However, data from longitudinal studies suggesting that even short-term training in mindfulness can have substantial pain-relieving effects.

Short-term meditation training studies have utilized a within subject design to track changes in pain responses over time, as a result of training. Kingston et al. found that six, 1-h mindfulness meditation training sessions (twice weekly) effectively increased pain tolerance on the cold pressor test as compared to a control group that underwent 2 h of visual imagery training [40]. Subjects were taught both body awareness (i.e., FA) and aspects of OM meditation. In line with these techniques, the authors postulated that mindfulness modifies the subjective pain experience by enhancing acceptance and coping [37,40].

Mindfulness-related pain reduction may also involve divided attention, distraction or non-specific changes in relaxation or mood [9]. To address this issue Zeidan et al. examined the effects of brief mindfulness meditation training on pain, compared to both math distraction and relaxation [69]. The authors found that three days (20 min/day) of mindfulness meditation training (incorporating both FA and OM) significantly reduced ratings of "high" and "low" pain when compared to math distraction and relaxation. Although math distraction reduced "high" pain ratings in response to noxious electrical stimulation, it did not significantly reduce "low" pain ratings. Relaxation had no effect on pain. Surprisingly, three days of meditation training significantly decreased pain sensitivity compared to the control group, with the newly trained meditators requiring significantly higher levels of electrical stimulation to report moderate pain [69]. Zeidan et al. [69] postulated that even short-term training in mindfulness meditation could reduce pain above and beyond the effects of distraction and relaxation.

Taken together, the behavioral studies discussed above provide evidence that mindfulness meditation practice can change the manner in which noxious stimuli are experienced. While the nature of these changes remains unclear, brain imaging studies are beginning to delineate the mechanisms involved in mindfulness-related pain relief, allowing them to be distinguished from effects such as placebo, expectation and belief.

6. The neural substrates of mindfulness meditation-related pain relief

The subjective experience of pain is constructed by interactions among sensory, cognitive, and affective processes. Mindfulness meditation is associated, via enhanced cognitive control and emotion regulation, with the modulation of sensory representations. This raises the question, which of these specific mechanisms are involved, if any, in mindfulness-related pain relief? Secondly, we might ask, to what extent are these mechanisms unique to meditative practices and to what extent are they shared by other cognitive/affective modulators of pain?

7. Trait effects of prior meditation practice on pain

Studies of long-term meditation practitioners on pain processing have necessarily employed case-control designs to assess differences in pain sensitivity during basal states (i.e., non-meditation). Using electroencephalography (EEG) and noxious laser stimulation, Brown and Jones examined the influence of long-term mindfulness practice on pain and pain anticipation [8] and postulated that mindfulness meditators would have reduced electrophysiological [event related potentials (ERP)] markers of anticipation. In line with previous findings of Grant and Rainville [28], they determined that greater meditation experience was associated with lower pain unpleasantness ratings [8]. When compared to controls, the meditation group exhibited smaller anticipation-evoked potentials in right inferior parietal cortex and mid-cingulate cortex, indicating less anticipation to the noxious stimuli. Lower mid-cingulate cortex activation during anticipation further predicted lower pain unpleasantness ratings in the meditation group but not in controls. Importantly, ACC/ventromedial-PFC (vmPFC), which was more strongly activated in meditators, correlated positively with pain unpleasantness in controls and negatively in meditators (i.e., greater activity associated with less unpleasantness, see Fig. 1). These findings are noteworthy, as the meditation group was not formally meditating, thereby suggesting that practitioners have undergone persistent changes that allow them to process nociceptive information in a unique manner. The authors postulated that mindfulness meditation-related pain reduction is associated with increased cognitive and emotional control (as reflected by activation of ACC/vmPFC) produced by cultivating an attitude of acceptance towards impending stimuli. The anticipation or expectation reductions were postulated to be some of the active mechanisms of meditation-related pain relief [8].

In a follow up to their behavioral study of Zen meditators [28], Grant et al. investigated the brain mechanisms involved in mindfulness-related pain reduction using functional and structural MRI [27]. It was hypothesized that even during a non-meditative state, Zen practitioners would differ from controls in a manner reflective of open monitoring meditation, that is, with reduced evaluative or elaborative-related brain activity. During pain, meditators exhibited greater activation in brain areas responsible for encoding sensory aspects of noxious stimulation [insula, thalamus, mid-cingulate cortex] (Fig. 2). At the same time, brain activity decreases were observed for meditators in regions involved in emotion, memory and appraisal [medial-PFC (mPFC), OFC, amygdala, caudate, hippocampus] (Fig. 2). Within these areas, the most advanced practitioners had the largest activation decreases, accompanied by the lowest pain ratings. Importantly, it was found that the baseline pain sensitivity of meditators, but not controls, was predicted by reduced functional connectivity between DLPFC and mid-cingulate cortex regions during pain. These results were interpreted as reflecting a mental state wherein the meditators were fully attentive to the sensory properties of the stimuli (highly activated pain areas) but simultaneously inhibiting appraisal, elaboration and emotional reactivity (deactivated DLPFC, OFC, med-PFC, amygdala, hippocampus). The authors postulated that Zen practitioners learn to adopt such a mental stance following extensive training. In the accompanying structural imaging study, it

was found that, compared to age-matched controls, Zen practitioners exhibited thicker gray matter in pain-related regions which overlapped with the functional effects. More specifically, meditators had thicker cortex in mid-cingulate cortex and bilateral SII that, in the case of the mid-cingulate cortex area, was correlated with the number of years of experience in practitioners. These regional structural differences, which overlapped with the functional results and correlated with meditation experience, were interpreted as further evidence for long lasting changes stemming from meditative practice and are consistent with other structural imaging studies of meditation [31,32].

The studies summarized in this section extend the preceding behavioral studies by demonstrating that the effects of meditation are not limited to a meditative state. Further, they provide the first potential neural mechanisms underlying mindfulness-related pain reduction. Surprisingly, however, the two studies report nearly opposite results: Grant and Rainville [28] found meditators to be less sensitive to pain at baseline whereas Brown and Jones [8] found no difference between groups. In contrast, whereas Brown and Jones [8] noted mindfulness-related pain relief to be associated with reductions in anticipation, Grant et al. [27] observed no difference during a cue period preceding pain. Furthermore, during the receipt of pain, Grant et al. [27] found *stronger* activation for meditators in pain-related cortices (mid-cingulate cortex, insula, SII, and thalamus) whereas Brown and Jones [8] observed *reduced* activation for meditators in SII and insula. Similarly, whereas Brown and Jones [8] found *stronger* activation for meditators in cognitive and emotion-related brain regions (ACC, vmPFC), Grant et al. [27] found it was quite dramatically reduced in (DLPFC, mPFC, OFC, amygdala and hippocampus). Such contradictory findings emphasize the importance of acknowledging differences in dependent measures (fMRI vs. EEG), meditation traditions, meditator experience level, experimental directives and stimulus type (heat vs. laser) which likely account for some of these differences. Clearly, more work is necessary to understand these discrepancies.

8. State effects of active meditation during pain

While the results discussed above suggest that meditation-related effects are not necessarily dependent upon a meditative state, little is actually known about the effects of active mindfulness meditation on pain. Gard et al. have recently examined the influence of Vipassana meditation on pain perception with fMRI [22]. They found that during meditation, long-term mindfulness practitioners had significant reductions in pain unpleasantness ratings to noxious electrical stimulation compared to a control group. Consistent with Brown and Jones [8] and Perlman et al. [50] but not Grant et al. [26,27], Gard et al. found that meditators and controls did not differ in reported pain intensity [8,50] and did not have baseline sensitivity differences. While meditating during pain, the meditation group exhibited greater activation of contralateral SII and posterior insula [22], regions implicated in the sensory dimension of pain processing. Change in activity of this region (from mindfulness to baseline) correlated negatively with changes in unpleasantness in meditators (from baseline to mindfulness) but positively in controls. The authors interpret this as an increase in sensory processing during meditation, which is accompanied by pain reduction. This reversed relationship between meditators and controls mirrors the correlations of vmPFC and ACC with unpleasantness during anticipation in the Brown and Jones study [8]. In fact, Gard and colleagues also report rACC and vmPFC activation for meditators in the anticipation phase. Thus, these studies converge to show increased activation of brain regions implicated in cognitive/emotional control during anticipation of pain (rACC, vmPFC). Gard et al. [22] interpret their findings as reflecting decreased cognitive control while Brown et al. suggested that increased ACC and vmPFC activity reflects increased cognitive flexibility [8].

The results described thus far provide strong confirmatory evidence for an influence of mindfulness practice on pain processing. However, each study discussed in the previous section featured a cross-sectional or case-control design. As such, these reports are limited in their ability to make causal claims due to the myriad differences that may exist between meditators and controls, above and beyond the specific meditative practice utilized.

Given these differences, a critical question that must be addressed is how much mindfulness training is necessary to have an influence on pain perception? Surprisingly, the answer appears to be very little. Zeidan et al. [71] recently examined the brain mechanisms involved in meditation-related pain relief with a brief mindfulness training protocol in previously meditative-naïve participants. Using arterial spin labeling (ASL) fMRI, a technique that provides a quantifiable measure of cerebral blood flow while controlling for respiratory confounds, they examined the effects of four days (20 min/day) of mindfulness meditation training on pain-related brain processing. Training consisted of a combination of FA and OM techniques. In session 1 (before training), subjects were stimulated with noxious heat for 6 min at 49 °C (12 s OFF/ON) in a rest condition and an attention to breath condition (ATB) where subjects were instructed to “focus on the changing sensations of the breath.” The ATB condition served as a divided attention control. Prior to meditation training, although ATB did not reduce pain intensity ratings, there was a trend towards significance in reducing pain unpleasantness ratings ($p = .06$). After meditation training, subjects were reassessed in a rest and meditation condition. Meditating in the presence of noxious heat stimulation significantly reduced pain intensity (average reduction 40%) and pain unpleasantness (average reduction 57%) ratings compared to rest.

When compared to rest, meditation significantly reduced activation in contralateral SI, corresponding to the stimulation site (Fig. 3). Regression analyses revealed that mindfulness meditation reduced pain through multiple brain mechanisms. Increased activation in the rACC during meditation and pain predicted reductions in pain intensity (Fig. 3). The rACC is associated with the cognitive modulation of pain, cognitive control, and the regulation of emotions [49,66] (Fig. 3). Interestingly, greater activity in the right anterior insula during meditation and noxious heat stimulation was associated with greater reductions in pain intensity ratings. This area links somatosensory processing areas with brain regions such as the PFC, amygdala, and ACC [21,48]. The anterior insula may be involved in shaping afferent nociceptive processing by providing a substrate for the integration of cognitive information [60] and has been shown to contribute to interoceptive evaluation [17,18,46]. Furthermore, greater activity in areas involved in the contextual evaluation of pain (OFC) was directly related to pain unpleasantness decreases during meditation and noxious stimulation.

Greater reductions in thalamic activity during meditation and noxious stimulation predicted reductions in pain unpleasantness ratings (Fig. 3). Crick and colleagues [16,45] proposed a model in which shifts in executive attention, mediated by activation in higher order brain regions (PFC), can regulate lower level sensory processes, specifically in the thalamic reticular nuclei. In accordance with this model, Zeidan et al. [71] proposed that meditation-related reductions in pain unpleasantness are associated with OFC regulation of thalamic reticular nuclei (TRN). Existing anatomical connections between SI and TRN [16,34] provide support for a theory in which meditation-related shifts in executive attention (focusing on the changing sensations of the breath) produce increased activity in the OFC that inhibit lower level nociceptive processing in the thalamus. This process could attenuate the elaboration of nociceptive information in the cortex, evidenced by decreased activity in the thalamus and SI. Taken together, these findings contribute to the existing literature by demonstrating that brief mindfulness-based mental training reduces pain through multiple mechanisms including cortico-cortical and cortico-thalamic interactions.

9. An integrated perspective on meditation-based pain relief

Understanding the literature reviewed thus far requires evaluating the data in the context of the different meditation practices used (focused attention, open monitoring), different levels of expertise (i.e., meditation naive, short-term or long-term practitioners), and different experimental designs (state effects, trait effects, case-control, longitudinal). Inconsistencies and apparent discrepancies among studies may be partially explained by considering the complex interactions among these factors, for which we will here attempt to gain a flavor (Table 1).

Given the differences in the neural processes, which undoubtedly underlie the differences in the mental processes with different forms of mindfulness meditation (see above), it is likely that FA and OM practices would influence pain in different ways. Specifically, FA is proposed to involve repetitive cognitive reappraisal and to promote sustained attention whereas OM is proposed to involve non-judgmental appraisal of salient sensory events [42]. While the studies of Grant and colleagues were able to show a FA condition did not significantly reduce pain in Zen practitioners (or increase pain, as it did in controls), Perlman et al. [50] found that differences between adept and novice meditators in pain reduction were only exhibited with OM practices. Thus, OM meditations seem more suited to analgesia than FA when taking into account meditation experience. That is, OM is more effective at reducing pain after extensive meditation training, as compared to FA. Support for this can be found in Grant et al.'s 2009 study which reports that the analgesic effect in advanced meditators, performing an OM-style of attention, did not arise until ~2000 h of practice. On the other hand, approaches combining elements of both FA and OM are effective at reducing behavioral and neural mechanisms of pain after brief mental training [69,71]. These findings suggest that cognitive practices employing attentional stability (focused attention) in conjunction with non-evaluative awareness of sensory events (open monitoring) can reduce pain, even after brief mental training.

10. Common final pathway to the cognitive modulation of pain

Cognitive techniques, such as placebo, distraction or changes in expectation, likely employ similar brain mechanisms in the modulation of pain [62]. In each case, the ACC has been postulated to attenuate pain by employing cognitive control mechanisms to modulate pain through activation of the descending opioid system via the periaqueductal gray. Based on the studies reviewed above, we suggest that mindfulness operates through an overlapping network but by unique mechanisms. More specifically, placebo analgesia is typically preceded by greater activation of DLPFC during anticipation of pain, an effect that predicts reductions in pain perception and activity in pain-related brain regions [53,67]. Mindfulness, on the other hand, does not appear to involve DLPFC activation. Long-term training in Zen as well as Vipassana, both forms of OM meditation, is associated with deactivation in DLPFC during pain, and in the case of Zen, reduced connectivity between this region and pain-related mid-cingulate cortex activation [27]. It is not yet clear however, to what extent this altered relationship of DLPFC with pain processing regions might be related to differences in anticipatory processing. Concerning DLPFC, we postulate that: where placebo effects exert top-down modulatory effects on pain by initiating positive expectations via the PFC, mindfulness meditation seems to reduce the influence of expectancy on pain, possibly through decreased elaboration (i.e., a state of reduced- or non-appraisal) of nociceptive information. In support of this interpretation, the reductions in DLPFC in Zen practitioners are accompanied by 'deactivation' of memory- and appraisal-related brain regions, including the hippocampus and OFC, respectively. This is again in contrast to placebo effects (associated with activation of the OFC) that are dependent on conditioning, expectation and beliefs. Interestingly, the OFC pain-related effects in meditators vary depending on

experience level. Newly trained practitioners [71] showed OFC activation *increases* that are associated with pain reduction whereas long-term Zen practitioners showed activation *decreases* associated with reduced pain [27]. We suggest this reflects the transition one undergoes, during meditative training, from cognitive reappraisal at early phases to a more appraisal-free state as one advances. However, it is clear that further studies are needed to help characterize mindfulness-related pain reduction and its relation to other pain modulatory techniques.

In this review we have surveyed the rapidly emerging field of meditation-related pain reduction. The data indicate that, like other cognitive factors that modulate pain, prefrontal and cingulate cortices are intimately involved in the modulation of pain by mindfulness meditation. Mindfulness meditation, like other cognitive manipulations, alters the contextual evaluation of pain but is likely to do so dynamically over time and experience, such that beginners reappraise events and the most advanced practitioners may refrain from elaboration/appraisal entirely. Admittedly, many of these interpretations are based on reverse inference and assumptions derived from traditional claims and require more scrutiny in future research. Nonetheless, mindfulness-related pain reduction promises to be an important tool for understanding how our awareness of sensory events occurs as well as a potentially important adjunct to current treatment options for acute and chronic pain.

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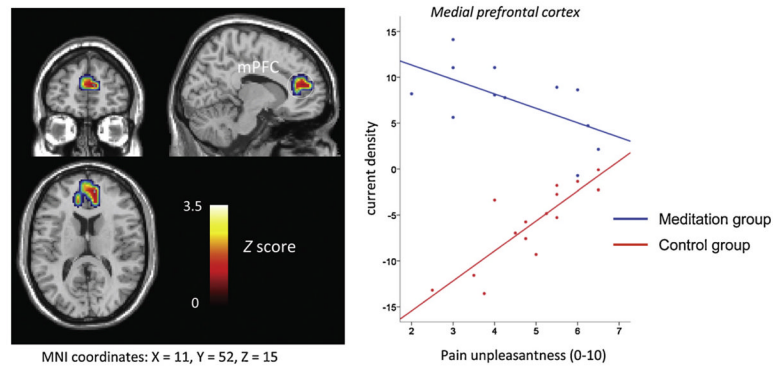


Fig. 1. Inverse correlations of pain unpleasantness with anticipatory neural activity in mPFC/rACC in meditators and controls. In a study comparing neural responses during anticipation of pain between a group with meditation experience and a control group with no meditation experience, a region in mPFC/rACC was more greatly activated in the meditation group, with greater activation predicting reducing pain unpleasantness ratings. In the control group, the opposite correlation was found with overall lower activity. From Brown and Jones [8].

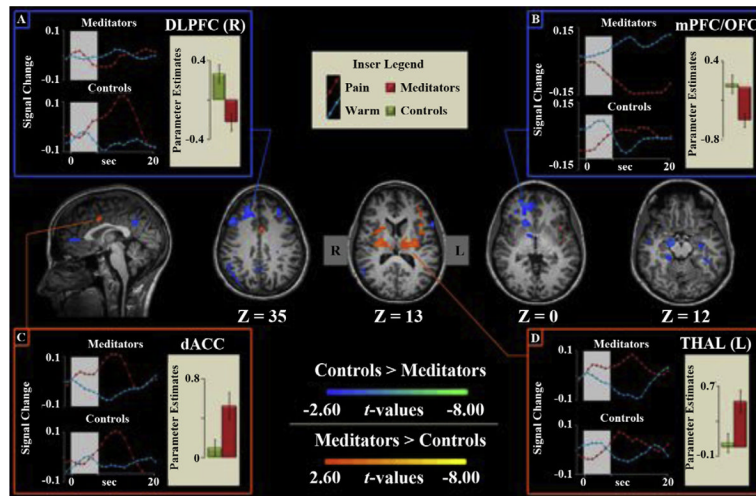


Fig. 2. Brain areas showing higher and lower activity in meditators compared to controls, during pain, in a non-meditative state. Activation is higher for meditators in pain-related regions such as dorsal anterior cingulate cortex (dACC), insula (INS) and thalamus (Thal) but is dramatically reduced (particularly on inset B) in areas involved in appraisal, emotion and memory: medial prefrontal cortex (mPFC)-orbitofrontal cortex (OFC), amygdala, and dorso-lateral prefrontal cortex (DLPFC).

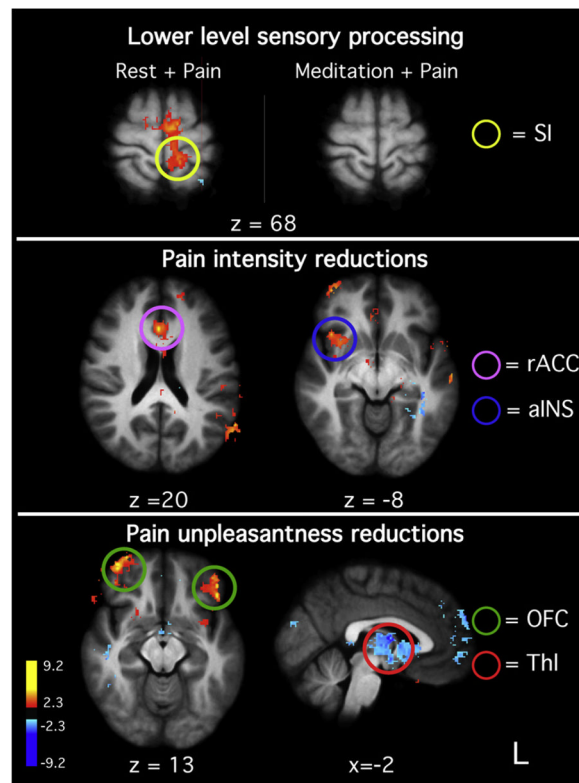


Fig. 3. Mindfulness meditation significantly reduced pain through a number of brain mechanisms. In the presence of noxious heat, meditation significantly reduced lower level afferent processing in the primary somatosensory cortex (SI) corresponding to the stimulation site (top). Regression analyses revealed that meditation-related pain intensity reductions were associated with greater activity in the rostral anterior cingulate cortex (rACC), an area involved in cognitive control (middle). Greater right anterior insula (aINS) activity also predicted pain intensity reductions during meditation, an area associated with interoceptive awareness (middle). Greater orbitofrontal cortex (OFC) activity was associated with greater decreases in pain unpleasantness ratings (bottom). Moreover, thalamic (Thl) deactivation was associated with reductions in pain unpleasantness (bottom).

Table 1

Studies assessing the effects of mindfulness meditation on pain.

Study	Methodology	Meditation practices	Novice or adept meditators	Noxious stimuli	Baseline difference/change	Intensity/unpleasantness reduction	Activation during mindful/pain-related contrasts	Mindful brain activity correlating with pain experience
Kingston (2007)	Psychophysiology	FA/OM	Trained Novices	Cold	Increased tolerance for meditators	NA	NA	NA
Grant (2009) ^b	Psychophysiology	Attention: focused Attention: mindful	Adepts	Heat	Lower sensitivity for meditators	Focused – no/no Mindful – yes/yes	NA	NA
Brown (2010)	EEG/ERP	Non-meditative Anticipation State	Adepts	Laser	No difference: meditators vs controls	No/yes	↓ INS & SII	↓ MCC, ↑ rACC = ↓ UNP
Zeidan (2010)	Psychophysiology	FA/OM	Trained Novices	Electrical	Decreased sensitivity for meditators	Yes/not tested	NA	NA
Perlman (2010)	Psychophysiology	FA and OM (separately)	Adepts + trained novices	Heat	No difference: adepts vs novices	FA – no/no OM – no/yes	NA	NA
Grant (2010) ^b	Structural MRI	Zen FA/OM	Adepts	Heat	Lower sensitivity for meditators	NA	NA	↑ MCC, SI/SII = ↓ sensitivity ^a
Grant (2011) ^b	fMRI (BOLD)	Zen FA/OM	Adepts	Heat	Lower sensitivity for meditators	NA	↓ DLPCF, AMG, HIP ↑ MCC, Thal, INS	↓ DLPCF = ↓ INT
Zeidan (2011)	fMRI (ASL)	FA/OM	Trained novices	Heat	Not tested	Yes/yes	↓ SI stimulation site	↑ aINS, MCC = ↓ INT ↑ OFC, ↓ Thal = ↓ UNP
Gard (2012)	fMRI (BOLD)	OM	Adepts	Electrical	No difference: control vs meditation group	No/yes	↑ pINS, rACC ↓ PFC	↑ pINS/SII = ↑ UNP

Abbreviations: aINS, anterior insula; AMG, amygdala; FA, focused attention; INT, pain intensity; OFC, orbitofrontal cortex; OM, open monitoring; MCC, mid cingulate cortex; OM, open monitoring; MCC, mid cingulate cortex; PFC, prefrontal cortex; pINS, posterior insula; rACC, rostral anterior cingulate cortex; SI/SII, primary and secondary somatosensory cortices; Thal, thalamus; UNP, pain unpleasantness.

^aThis is a structural MRI study where greater cortical thickness of MCC, SI/SII in meditators was also related to lower pain sensitivity and meditation experience.

^bThese studies had an overlapping sample and should not be considered completely independent.