Differential Effects on Pain Intensity and Unpleasantness of Two Meditation Practices

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Pain is an unpleasant sensory and emotional experience that can be regulated by many different cognitive mechanisms. We compared the regulatory qualities of two different meditation practices during noxious thermal stimuli: Focused Attention, directed at a fixation cross away from the stimulation, which could regulate negative affect through a sensory gating mechanism; and Open Monitoring, which could regulate negative affect through a mechanism of nonjudgmental, nonreactive awareness of sensory experience. Here, we report behavioral data from a comparison between novice and long-term meditation practitioners (long-term meditators, LTMs) using these techniques. LTMs, compared to novices, had a significant reduction of self-reported unpleasantness, but not intensity, of painful stimuli while practicing Open Monitoring. No significant effects were found for FA. This finding illuminates the possible regulatory mechanism of meditation-based clinical interventions like Mindfulness-Based Stress Reduction (MBSR). Implications are discussed in the broader context of training-induced changes in trait emotion regulation.

Keywords: pain regulation, emotion regulation, attention, meditation, mindfulness, long-term meditators

Pain has been defined as "an unpleasant sensory and emotional experience" (Merskey & Bogduk, 1994; see also Melzack & Casey, 1968). Research on pain perception has come to overlap with emotion regulation as paradigms have been developed to study the affective component of pain perception and to modulate pain perception through purely cognitive manipulations. Attention (Bantick et al., 2002; Wiech, Ploner, & Tracey, 2008), anticipation (Ploghaus et al., 1999), the placebo effect (Wager et al., 2004), perceived control (Salomons, Johnstone, Backonja, Shackman, & Davidson, 2007), hypnosis (Rainville, Carrier, Hofbauer, Bushnell, & Duncan, 1999; Rainville, 2008), and other processes have all been shown to affect pain perception. Of particular relevance, theory and research on catastrophizing and pain suggest that catastrophizing, "a tendency to magnify or exaggerate the threat value

or seriousness of . . . pain sensations" (Sullivan, Thorn, et al., 2001), can greatly increase the severity of pain and its functional consequences (Edwards, Bingham, Bathon, & Haythornthwaite, 2006).

Recently, research on mindfulness-based interventions like Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, Lipworth, & Burney, 1985) raise the possibility of a mechanism by which training in a very general cognitive process, mindfulness,[1] can lead to beneficial changes in emotion regulation during distress or physical suffering. In the relevant framework, similar to pain catastrophizing theory, the aversive quality of *any* experience is enhanced, or in some cases created entirely, by elaborative or ruminative processes that build on the sensory and primary affective response to the aversive stimulus. Thus, the training emphasizes the cultivation of an open, nonjudgmental, nonreactive form of awareness termed mindfulness, which purportedly allows one to reduce the elaboration and thus improve the quality of one's experience overall (Baer, 2003; Bishop et al., 2004; Kabat-Zinn, 1982). Research over many years on MBSR and related clinical programs has shown beneficial effects on pain conditions. In a series of seminal papers, Kabat-Zinn et al. showed clinically significant reduction in pain indices and number of medical symptoms, as well as various measures of psychological well-being, in 51 (Kabat-Zinn, 1982) and, later, 90 (Kabat-Zinn et al., 1985) treatment-resistant chronic pain patients after participation in a 10-week Stress Reduction & Relaxation Program (SR&RP), an early version of MBSR. Long-term follow-up of 225 participants

[1] The term "mindfulness" is used in many different ways, which can lead to confusion in the literature. Here, for simplicity, we focus on mindfulness as conceptualized in the foundational literature for the MBSR program. See Lutz, Slagter, Dunne, & Davidson (2008) and Lutz, Dunne, Davidson, and Thompson (2007) for a more in-depth discussion of meditation- and mindfulness-related terminology.

showed lasting improvements up to 4 years after the intervention (Kabat-Zinn, Lipworth, Burncy, & Sellers, 1986). More recently, Kinsgston et al. (Kingston, Chadwick, Meron, & Skinner, 2007) tested the effects of mindfulness training on an acute cold-pressor pain stimulus, finding decreased pain ratings and increased ability to tolerate the pressor after training. Also, Morone, Greco, and Weiner (2008) reported improvements in Chronic Pain Acceptance and Physical Function, but not measures of pain intensity, in 37 older adults after an 8-week program modeled on MBSR and at 3-month follow-up. This result is particularly interesting in that it suggests differential effects of mindfulness training on the affective and sensory aspects of pain.

Despite this pattern of clinical benefits for mindfulness-based interventions on pain conditions and measures, conclusive establishment of the mechanisms by which mindfulness leads to these benefits, or indeed of whether mindfulness per se is the active factor at all, remains elusive. Most clinical studies are not well-suited to establishing these mechanisms, since MBSR and related programs are complex and multifaceted, incorporating elements of various mindfulness-related techniques, such as breath awareness, body scans, and walking meditation, as well as physical exercise and stretching and training in cognitive reappraisal (Kabat-Zinn, 1982). In addition, there are hard-to-quantify social factors relating to the group setting and the interactions with the teacher. Even considering only the most directly mindfulness-related components of MBSR, two different aspects of attentional control can be identified (Bishop et al., 2004; Kabat-Zinn, 1982), described by Lutz, Slagter, et al. (2008) as Focused Attention (FA) and Open Monitoring (OM). Focused Attention refers to maintaining selective attention on a chosen object and is exemplified by Kabat-Zinn's (1982) instructions, "Bring your attention to the primary object of observation. Be aware of it from moment to moment," as well as Bishop et al.'s (2004) component of self-regulation of attention. Open Monitoring refers to attentive, nonreactive awareness of whatever is occurring in the present moment, without focusing on any particular object, and is exemplified by their instructions, "Distinguish between observation of the experience itself and thoughts and interpretations of the experience. Observe the thinking process itself . . . Treat all thoughts as equal in value and neither pursue them nor reject them," as well as Bishop et al.'s (2004) component of orientation to experience in the present moment.

In order to investigate the mechanisms by which mindfulness-based interventions affect pain perception, it would be helpful to study pain perception in an experimental paradigm that separates the FA and OM processes as much as possible. Although there is some overlap between the attentional processes of FA and OM and the techniques used to develop them and, indeed, FA may naturally lead to OM, expert practitioners may be able to voluntarily separate the two states to some degree. Recently Grant and Rainville (2009) studied perception of painful thermal stimuli by novices and long-term meditators (LTMs) in the Zen Buddhist tradition. All participants received painful stimuli in three conditions: resting; focusing attention exclusively on the stimulation; and focusing on the stimulation while maintaining nonjudgmental, moment-by-moment observation, a condition they describe as mindfulness, and which falls in the category of OM (Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008). They report that intensity of pain was increased during concentration for novices, and both intensity

and unpleasantness of pain were decreased during mindfulness for LTMs. Furthermore, the reduction of intensity for LTMs was significantly correlated with lifetime hours of practice, and only LTMs with greater than 2000 hours of experience showed clinically significant changes in pain intensity ratings (more than 2 on the 0–10 scale). These results support the idea that different attentional strategies can have different effects on sensory and affective aspects of pain perception and also support the premise of using expert practitioners to differentiate these attentional strategies.

We report here behavioral results[2] from a study comparing pain perception in novices and long-term Tibetan Buddhist meditation practitioners, which is similar to Grant and Rainville (2009) but differs in several important ways. We have published results from several other paradigms with this population of practitioners (Brefczynski-Lewis, Lutz, Schaefer, Levinson, & Davidson, 2007; Khalsa et al., 2008; Lutz et al., 2008; Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). For this study, we collected ratings of pain intensity and unpleasantness from novices and long-term meditation practitioners performing Focused Attention, with attention directed on a visual target, and an Open Monitoring-type practice, consisting of nonjudgmental, nonreactive awareness of sensory experience similar to mindfulness (see Methods: Meditation practices). These two conditions broadly parallel the Focused Attention and mindfulness conditions in Grant and Rainville (2009) but differ in important ways. First, whereas Grant and Rainville instructed participants to direct their attention at the stimulus itself, we instructed participants to direct attention *away* from the stimulus, toward a visual fixation cross. This presents an obvious parallel with research on distraction and pain. Several studies have found that direction of attention away from painful stimuli led to reductions in reports of both pain intensity and unpleasantness. Villemure, Slotnick, and Bushnell (2003) found that pain intensity and unpleasantness ratings were lower when participants were instructed to attend to an odor rather than the painful stimuli. Bantick et al. (2002) measured only pain intensity and found decreases in participants' ratings, as well as decreases in neural activity in many brain areas, during a cognitively demanding task. Miron, Duncan, and Bushnell (1989) found that both intensity and unpleasantness were rated lower when participants were instructed to attend to a visual discrimination task instead of painful stimuli (but not during conditions of divided attention) and proposed that this is due to gating of sensory input by modulation of nociceptive neurons in the dorsal horn of the spinal cord by attention, a phenomenon their group had previously demonstrated (Bushnell, Duncan, Dubner, & He, 1984).

In accordance with this theory and research, we expected that the LTMs practicing FA would experience a larger attentional gating effect on pain perception than novices, leading to a reduction in both intensity and unpleasantness. In contrast, the expected effects of OM are more specific. According to the mindfulness framework discussed above, we would expect painful stimuli presented during a strong OM state to be perceived with normal or even increased intensity, due to the emphasis on open receptivity to sensory input, but with reduced unpleasantness, due to the

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[2] The experiment was run in the MRI scanner; analysis of fMRI data is awaiting a larger sample size.

emphasis on reduction of cognitive and affective elaboration of sensory input.

In summary, we predict:

I. Group (Novice or LTM) × Practice (FA or OM) × Rating type (Intensity or Unpleasantness) interaction, and Group (Novice or LTM) × Rating Type (Intensity or Unpleasantness) interaction during OM only. This would result from differential effects of OM on intensity and unpleasantness but reduction of both intensity and unpleasantness in FA for experts but not novices.

II. Main effect of Group (Novice or LTM) during FA only, with both intensity and unpleasantness ratings lower for LTMs than novices. This would result from attentional gating of painful sensory input by FA in LTMs but not novices.

Methods

Participants

Nine long-term meditation practitioners (8 Caucasian, 1 Tibetan) and 10 age-, sex-, and stimulus-temperature-matched controls (9 Caucasian, 1 Hispanic) participated in the experimental procedure (Table 1.) Long-term meditation practitioners were selected based on a criterion of at least 10,000 hours of formal meditation practice in the Kagyu and Nyingma traditions of Tibetan Buddhism, which have closely similar styles of practice. Some of them have been practicing since early childhood; others came to the lab from up to 11 years of meditation retreat. The largest lifetime accumulation of formal practice hours was 45,000. Ten control participants were recruited from the local community and had no previous experience with any type of meditation but generally expressed interest in learning meditation. They were given instructions in the practices written by a scholar who is familiar with the practices[3] (see footnote 3) and then told to practice at home 30 minutes a day for 7 days prior to the experiment. To reduce effects of likely motivational differences between novices and LTMs, control participants were told that the four novices who demonstrated the largest reduction in pain-induced brain activity (i.e., BOLD signal) during meditation would receive a $50 bonus payment (cf. Brefczynski-Lewis et al., 2007). We hoped that a bonus based on neural activity would motivate them to exert themselves in the meditation practices while not incentivizing them to misrepresent their ratings. Control subjects were screened for pain-related disorders and use of analgesic or psychiatric medication. One long-term practitioner reported a diagnosis of fibromyalgia nearly 20 years ago but considered him/herself mostly improved and would likely no longer meet the diagnostic criteria for FM. Analysis of data excluding this practitioner did not change significance of any tests, so he or she was included in the analysis due to the difficulty recruiting participants in this population.

Meditation Practices

See sidebar for the actual instructions given to participants for both practices. All participants performed Focused Attention (FA) practice (Tib. "*gzhi gnas*," pronounced "shiné," similar to "shamatha" in Sanskrit) and a meditation practice specific to the LTMs' tradition (Tib. "*rig pa cog gzhag,*" pronounced "rigpa chok shak") whose instructions fit the classification of Open Monitoring (OM) in (Lutz et al., 2008).[4] For more on shiné and shamatha, see Lutz, Dunne, Davidson, and Thompson (2007) and Thrangu and Johnson (2004); for more on the traditional account of *rig pa cog gzhag,* see Lutz et al. (2007), Chagme (2000), and Norbu and Shane (2000); and for a more detailed discussion of the relationships among FA, OM and mindfulness, see Lutz et al. (2008).

Procedure

Painful stimuli were provided by a TSA-2001 thermal stimulator (Medoc Advanced Medical Systems, Haifa, Israel) with a 30 mm × 30 mm flat thermode, which was applied to the inside of the left wrist. All participants first underwent a calibration procedure for stimulus temperature. Temperature was increased from 32 °C to 49 °C at 0.7 °C/sec and then held for 5 seconds before returning to baseline at the maximum slew rate, approximately 4 °C/sec. Participants were instructed to hit a key to indicate when the pain level had reached 8 on a scale of 0–10, where 0 indicates no pain at all, and 10 indicates unbearable pain. At the indicated time the temperature returned to the 32 °C baseline at the maximum rate. The temperature remained at the 32 °C baseline for 30 seconds before beginning again. There were 10 trials; the average temperature reached over the last five trials was used for that participant in the protocol. If a participant did not indicate the pain level had reached 8, 49 °C was used for that participant. Temperatures used ranged from 46 °C–49 °C (see Table 1).

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[3] Instructions for the two meditative practices:

1. Training for Concentration: This state is better known as the Buddhist practice of "one-pointed concentration." This is a state in which one tries to focus all one's attention upon one object, keep it on that object, and bring it back to that object when one finds that one has been distracted (by outer perceptions or inner thoughts).

   During the training session, the participant should focus his or her attention on a small object (coin, shirt stud, etc.). For this experiment, it is important that the object on which one focuses is visual, rather than focusing on the breath, mantra, or a mental image.

   Ideally, this "one-pointed concentration" should be clear (vivid) and unwavering (calm and stable), free from all types of distraction, the main types being sinking into dullness and being carried away by mental agitation.

2. Cultivation of Open Presence: Generate a state of total openness, in which the mind is vast like the sky. Maintain a clear awareness and presence open to the surrounding space. The mind is calm and relaxed, not focused on something particular, yet totally present, clear, vivid and transparent. When thoughts arise, simply let them pass through your mind without leaving any trace in it. When you perceive noises, images, tastes, or other sensations, let them be as they are, without engaging into them or rejecting them. Consider that they can't affect the serene equanimity by your mind.

[4] Previous literature (e.g., Lutz et al., 2007) has translated *rig pa cog gzhag* as "Open Presence," and this name was used in our conversations with the LTMs and the instructions for the novices (see footnote 3).

Table 1
Participant Matching Characteristics

Group	N	Male gender, N	Age		Temperature used	
			Mean	SD	Mean	SD
Experts	9	5	48.1	10.7	48.1	0.78
Novices	10	5	47.1	11.8	48.2	0.79
t-test			$t(17) = 0.19, p = .85$		$t(17) = 0.27, p = .79$	

The experiment consisted of 32 trials, broken up into 8 runs of 4 trials each, with a resting period and comfort check between each run. In each trial, participants were presented with a cue for either FA or OM meditation, and then given 45 seconds to settle into the meditation state. Then there was a 12-s warm period at 38 °C, followed by 10 seconds at that participant's painful temperature, or a nonpainful temperature six degrees cooler. All temperature changes occurred at the device's maximum slew rate of approximately 4 °C/sec. Order of FA/OM and hot/warm was counterbalanced across runs. At the end of each painful stimulus, a blank screen was presented for 10 seconds, then participants were asked to rate the stimulus for "intensity—how hot was it," and then "unpleasantness—how much did it bother you," each on a scale of 0 to 10. Each rating screen appeared for 5 seconds, with 1 second blank in between. The overall time between the beginning of one stimulus and the next was 93.3 seconds. Ratings were analyzed in a $2 \times 2 \times 2$ mixed ANOVA, with between-subjects factor Group (Novice or LTM) and within-subject factors Practice (FA or OM) and Rating Type (intensity or unpleasantness). Ratings were also examined for trends over time.

Results

As predicted in Hypothesis I, the Group (Novice or LTM) × Practice (FA or OM) × Rating type (Intensity or Unpleasantness) interaction was significant, $F(1, 17) = 10.623, p = .005, \eta_p^2 = 0.39$ (see Figure 1). This was primarily driven by the LTM's
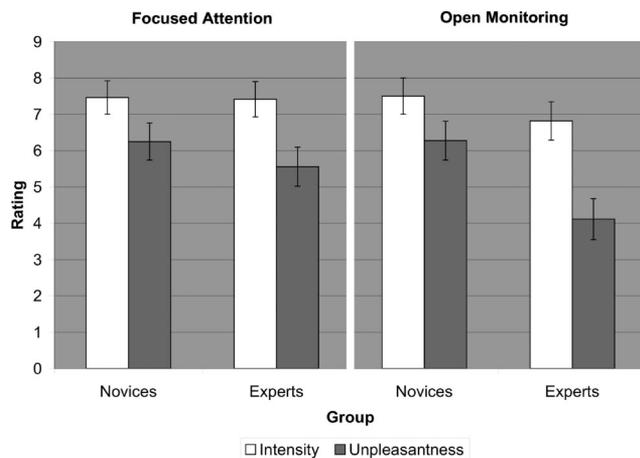

Focused Attention   **Open Monitoring**

Figure 1. Pain intensity and unpleasantness ratings for novices and long-term meditators performing Focused Attention and Open Monitoring meditation practices. Error bars are ±SEM.

ratings of unpleasantness during OM. These ratings were lower for the LTMs than for the novices during OM, $F(1, 17) = 7.71, p = .013, \eta_p^2 = 0.31$, and lower in OM than during FA for the experts, $F(1, 8) = 46.62, p = .0001, \eta_p^2 = 0.85$. The Group (Novice or LTM) × Practice (FA or OM) interaction for unpleasantness ratings was significant, $F(1, 17) = 37.618, p < .0001, \eta_p^2 = 0.69$. The Practice (FA or OM) × Rating type (Intensity or Unpleasantness) interaction was significant within the LTMs' group, $F(1, 8) = 11.531, p = .009, \eta_p^2 = 0.59$. Also, the Group (Novice or LTM) × Rating Type (Intensity or Unpleasantness) interaction during OM approached significance, $F(1, 17) = 3.381, p = .083, \eta_p^2 = 0.17$.

The Group (Novice or LTM) × Practice (FA or OM) interaction for intensity ratings was also significant, $F(1, 17) = 8.262, p = .011, \eta_p^2 = 0.33$, but much less so than the corresponding interaction for unpleasantness (consistent with the significant three-way interaction.) These ratings were lower for the LTMs during OM than FA, $F(1, 8) = 8.494, p = .019, \eta_p^2 = 0.52$.

Hypothesis II was not supported. We expected reduced intensity and unpleasantness ratings in the FA condition for LTMs relative to novices. Instead, we found no main effect of Group (Novice or LTM) for both rating types during FA, $F(1, 17) = 0.35, p = .56, \eta_p^2 = 0.02$. The intensity ratings for both groups were virtually identical, $F(1, 17) = 0.005, p = .95, \eta_p^2 < 0.001$, and the unpleasantness ratings were not significantly different, $F(1, 17) = 0.87, p = .36, \eta_p^2 = 0.05$.

We also found a significant main effect of rating type, $F(1, 17) = 23.135, p = .0002, \eta_p^2 = 0.58$. Ratings for unpleasantness were lower than ratings for intensity overall and in each condition individually. This is consistent with the general finding in the literature that thermal pain results in lower ratings of unpleasantness than intensity, for example, Grant and Rainville (2009) and Miron et al. (1989).

There was a slight indication of habituation to the stimulus for the unpleasantness ratings for the novices during both practices, linear trend over time, $F(1, 9) = 5.37, p = .046, \eta_p^2 = 0.37$, but not in any other conditions or for the other group. This trend was the same for both FA and OM, linear × Practice interaction $F(1, 9) = 0.001, p = .97, \eta_p^2 < 0.001$.

Discussion

The specific reduction in unpleasantness ratings for the LTMs in OM accords with our prediction. Our results appear to support the interpretation that reducing the cognitive elaboration of a sensory experience through deliberate application of a trained nonjudgmental attentional stance can reduce the perceived unpleasantness, which is consistent with the theoretical framework of mindfulness

meditation. The significance of this framework extends beyond the area of pain perception. The literature on catastrophizing theory has already pointed out the parallel between cognitive elaboration of pain sensation and cognitive theories of psychopathology, such as depression and anxiety (Sullivan, Rodgers, & Kirsch, 2001; Sullivan, Thorn, et al., 2001). These theories also posit a role for elaboration of sensory or other experience, which develops into rumination, in the development of the overarching negative affect comprising these conditions (Abramson et al., 2002; Dozois & Beck, 2008). Based on these cognitive theories, well-established interventions, such as Cognitive-Behavioral Therapy (CBT), identify specific thought patterns purported to lead to psychopathology and provide specific training to clients to change these patterns. Mindfulness-based techniques, such as MBSR (Kabat-Zinn, 1982) and Mindfulness Based Cognitive Therapy (MBCT; Teasdale et al., 2000), suggest that training of the much more general cognitive process mindfulness, or addition of mindfulness to a more specific cognitive training, can also be beneficial, because of the relationship between mindfulness and the cognitive elaboration process at the core of these theories. These interventions have been explored in both pain and psychopathology, but there is not currently a consensus in the literature as to whether mindfulness per se can prevent or treat psychopathology or to what extent it enhances other treatments. Our current differential result supports a view that different forms of attentional training can have specific effects on different aspects of sensory and affective experience, which is relevant to this question. There is clearly a need for continuing theoretical and empirical work to tease apart these different effects and to see whether and how they generalize across different emotional domains, such as pain perception and psychopathology.

Based on previous results involving distraction of attention away from painful stimuli, we expected reduced intensity and unpleasantness ratings in the FA condition for LTMs relative to novices, but this hypothesis was not supported. There are a number of possible flaws in our reasoning that led to this hypothesis. First, it may be that our assumption of expertise in the practice was incorrect. The strong effect seen for OM described above, as well as our previous findings with many of the same participants (e.g., Brefczynski-Lewis et al., 2007; Lutz et al., 2004) argue against this possibility; however, it could still be that the experts were more skilled in OM than FA. Other paradigms examining FA in more detail in this population would be necessary to clarify this. Second, the focusing of attention may not have been as complete as we were expecting. Miron et al. (1989) found that pain ratings were *not* effectively reduced by distraction when attention is divided. Pain is inherently demanding of attention (Melzack & Casey, 1968). In many previous studies of distraction and pain (e.g., Bantick et al., 2002; Longe et al., 2001), the distracter itself was salient or even cognitively demanding; in contrast, in our study, the potential restriction of attention away from pain would depend entirely on the strength of the experts' attentional control. In addition, there are at least three subtle factors that could have worked to maintain some component of attention on the pain. Participants knew in advance that they would be asked to rate the pain intensity after each trial, which may have created an intention to maintain some component of attention on the painful sensation. Also, the analysis of FA practice presented by Lutz et al. (2008) suggests that the practice explicitly involves recognition of distracters as part of the disengagement from distraction and reen-

gagement with the target. Finally, posttesting inquiries regarding what LTMs were doing during the meditation states revealed that some teachers in their tradition taught that the best way to regulate pain during Focused Attention practice would be to deliberately move the focus onto the affective response to the stimulus. This suggests that the practitioners might have been accustomed to that strategy, which might have interfered with precise compliance with our instructions. In light of all this, future studies are needed using a more nuanced differentiation of attentional strategies. Wiech et al. (2008) propose that studies of attentional modulation of pain need to consider at least three conditions: attention directed at pain, attention directed away from pain, or neutral attention. To encompass the possibilities raised in this and other studies of meditation and pain, future studies would also need to include a condition where attention was directed at the affective response to pain and one or more conditions relating to OM or mindfulness styles of open, nonreactive awareness.

Grant and Rainville (2009) recently reported results from a similar experiment, also comparing novices to LTMs, that showed a pattern of changes in ratings of pain intensity and unpleasantness that was broadly consistent with our results, although some details were different, likely due to methodological differences between their study and ours. While both studies included a meditation condition consisting of nonjudgmental observation of stimulus (OM or mindfulness), in our study the other condition was attention focused *away* from the pain, while in their study the other condition was attention focused *on* the pain. Overall, as expected, both studies found no evidence of analgesic effects of meditation in novices. Also as expected, both studies found that OM/mindfulness meditation in experts led to reduced ratings of pain unpleasantness relative to other conditions. Both studies also found significant reductions of pain *intensity* ratings for experts practicing OM/mindfulness, although Grant and Rainville found this effect to be comparable to the effect on unpleasantness, while we found a considerably smaller effect on intensity than unpleasantness. Grant and Rainville suggest that mindfulness may interact with the sensory processing of pain in addition to the emotional reaction; the difference in relative effect sizes between the two studies may be due to subtle differences between the specific practices used. Finally, Grant and Rainville found increased pain ratings when novices directed their attention toward the pain, while we found no effect whatsoever in novices. This is likely due to the difference in attentional focus: it is reasonable to expect that even (or especially) without training, increased attention given to painful sensations would increase their impact in awareness. Together, the results of the two studies support the implication in the existing mindfulness literature that the higher-order regulatory processes in OM/mindfulness may be more important to meditation-based pain reduction than specific effects of attentional control.

We considered the possibility of differential demand characteristics between groups. In particular, the LTMs likely have a greater motivation to demonstrate effectiveness of the meditation practices due to their long-term personal investment in them. To provide some motivation for the novices, we offered a bonus of $50 to the four novices who demonstrated the largest reduction in pain-induced brain activity (i.e., BOLD signal) during meditation, but we acknowledge that this is unlikely to match the motivation of lifelong practitioners. Additionally, the issue of motivation is complicated because many types of meditation instructions include

an aspect of "nonstriving"; because of this, in some cases the novices may have paradoxically exerted *more* effort, or a different kind of effort, than the LTMs. It is important to note that we found that expertise-related group effects were restricted to one type of practice, OM, only, even though we expected an analgesic effect of both practices; indeed, in the meditation traditions, both practices are said to have the potential for this effect (Chagme, 2000; Gunaratana, 2002). The selectivity of our finding makes it unlikely that it merely reflects a group difference in demand characteristics or motivation; nevertheless, the self-report data described here must be corroborated by further data before any strong claims can be made. For these reasons, as well as a wide range of other factors resulting from the self-selection of the LTM group, conclusive establishment of the effectiveness of these practices will require future studies with random assignment of novices to meditation and control groups and longitudinal monitoring as expertise develops.

The presence of a significant indication of habituation, together with the fact that the order of conditions was not counterbalanced across participants, raises the possibility that the results could have been influenced by order effects. The trial structure presented the first stimulus during FA and the last during OM. To investigate this possibility, data were reanalyzed excluding the first FA trial and the last OM trial, leaving a data set where the first trial was OM and the last was FA. All significance tests remained unchanged, indicating that results were not due to confounding order effects.

One notable limitation of the current study is the lack of a baseline, that is, nonmeditation, condition. Our original decision was driven by two considerations. Our discussions with scholars of these practices led us to believe that practitioners with this much experience would tend to revert to some meditation practice when no task was otherwise demanded of them, which complicates the determination of a baseline against which to measure the practices. Also, the study was designed for functional MRI; constraints on MRI scanner time and the experts' schedules made it difficult to fit in any other conditions. The long-term meditators in our study had at least 10,000 and up to 45,000 hours of meditation practice. This level of experience is comparable to or greater than experience levels considered characteristic of "expertise" in previous studies (e.g., with musicians: Koelsch, Fritz, Schulze, Alsop, & Schlaug, 2005), which suggests that these practitioners should be able to successfully apply the attentional strategies of the practices. In contrast, with only one week of practice, the novices are expected to enter only superficially into the meditation states. Accordingly, the effect of each practice is characterized as the difference between the LTMs' ratings and the novices' during the same practice. Finally, both groups underwent a thermal pain threshold calibration procedure to determine the stimulation temperature that they would rate 8 on a scale of 10. This procedure was performed while not practicing any kind of meditation. Consultation with scholars of these practices suggested that the attentional demand of the calibration task would be sufficient to prevent automatic reversion to meditation practice; thus, to the best of our knowledge, the calibration task was performed during a baseline mental state for both groups. Although it is not a direct test, the fact that there was virtually no difference between the temperatures chosen by the LTM and novice groups (see Table 1) suggests that the groups were comparable at baseline. To the extent that this is true, it

supports the validity of interpreting group differences in the practice conditions as measures of the effect of the practice. However, more direct tests of the effects of practice relative to a baseline are required in future studies.

Conclusion and Future Directions

These results support the hypothesis that training of specific cognitive strategies can affect the subjective unpleasantness of a sensory experience separately from the intensity, while raising questions about contrasting effects of different directions and degrees of attention. Intriguing parallels between theories of sensory unpleasantness and psychopathology suggest that similar training might affect larger-scale emotion regulation through parallel mechanisms. It is well known that trait-like qualities of emotion regulation can change over time, as evidenced by a wealth of developmental literature (e.g., Cole & Michel, 1994; Goldsmith, Pollak, & Davidson, 2008). Also, at a given point in time, these processes can be altered intentionally, as in studies where participants are instructed to use specific strategies to enhance or suppress affective responses (e.g., Jackson, Malmstadt, Larson, & Davidson, 2000). The current widespread interest in various forms of mental training, including both classic cognitive therapies and more recent meditation-based interventions, raises the question: to what extent, and by what mechanisms, can trait changes be implemented intentionally through training? In other words, how can state changes intentionally become trait changes in emotion regulation? We hope to contribute to this investigation with our current work with experts highly trained in specific regulatory strategies. In addition, random controlled longitudinal studies of training of these mental states are warranted to examine the extent to which such voluntarily produced states produce trait-like change. Finally, studies comparing effects of training on different modalities of emotion regulation, such as pain perception, anxiety, and depression, are necessary to determine to what extent attentional, elaborative, and ruminative mechanisms are common to these different domains.

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