Differential effects on pain intensity and unpleasantness of two meditation practices

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Abstract:

Pain is an unpleasant sensory and emotional experience, which 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 a practice called Open Presence, which could regulate negative affect through a mechanism of non-judgmental, non-reactive awareness of sensory experience. Here we report behavioral data from a comparison between expert and novice meditation practitioners using these techniques. Experts, compared to novices, had a significant reduction of self-reported unpleasantness, but not intensity, of painful stimuli, while practicing Open Presence. No significant effects were found for FA. This finding illuminates the possible regulatory mechanism of meditation-based clinical interventions such as Mindfulness-Based Stress Reduction (MBSR). Implications are discussed in the broader context of training-induced changes in trait emotion regulation.

Keywords: meditation, mindfulness, attention, pain, intensity, unpleasantness
Introduction:

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 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 such as 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, non-judgmental, non-reactive 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; 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's group 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 showed lasting improvements up to 4 years after the intervention (Kabat-Zinn, Lipworth, Burncy, & Sellers, 1986). More recently, Morone, Greco, & 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

\(^1\) 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, & Thompson, 2007) for a more in-depth discussion of meditation- and mindfulness-related terminology.
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 (Kabat-Zinn, 1982), described by (Lutz & Slagter et al., 2008) as Focused Attention (FA) and Open Monitoring (OM). Focused Attention involves 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.” Open Monitoring involves attentive, non-reactive 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.”

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 & Rainville (2009) studied perception of painful thermal stimuli by novices and long-term expert practitioners 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 non-judgmental, moment-by-moment observation, a condition they describe as mindfulness. They report that intensity of pain was increased during concentration for novices, and both intensity and unpleasantness of pain were decreased during mindfulness for experts. Furthermore, the reduction of intensity for experts was significantly correlated with lifetime hours of practice, and only experts 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 expert Tibetan Buddhist meditation practitioners which is similar to Grant & 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, Greischar, Rawlings, Ricard, & Davidson, 2004; Lutz, Brefczynski-Lewis, Johnstone, & Davidson, 2008). For this study, we collected ratings of pain intensity and unpleasantness from novice and expert practitioners performing Focused Attention, with attention directed on a visual target, and Open Presence, a practice specific to this tradition which involves non-judgmental, non-reactive awareness of sensory experience similar to mindfulness (for more discussion of Open Presence see Methods: Meditation practices). These two conditions broadly parallel the Focused Attention and mindfulness conditions in Grant & Rainville (2009) but differ in important ways. First, whereas Grant & Rainville instructed participants to direct their attention at the stimulus itself, we instructed participants to direct attention away from the stimulus, towards a visual fixation cross. This presents an obvious parallel with research on distraction and pain. Several studies have found that

\(^2\) The experiment was run in the MRI scanner; analysis of fMRI data is awaiting a larger sample size.
direction of attention away from painful stimuli led to reductions in reports of both pain intensity and unpleasantness. Villemure, Slotnick, & 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, & 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, 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 experts 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 OP are more specific. According to the mindfulness framework discussed above, we would expect painful stimuli presented during a strong OP 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 emphasis on reduction of cognitive and affective elaboration of sensory input.
In summary, we predict:

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

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

Methods:

Participants:
Nine long-term meditation practitioners (8 Caucasian, 1 Tibetan) and ten age-, sex-, and stimulus-temperature-matched controls (8 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 directly to the lab from up to eleven 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, (see sidebar) 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 experts, 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 diagnosis of fibromyalgia but was included anyway, since increased pain sensitivity in the expert group would only tend to weaken predicted effects.
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 "shi ney") and a meditation practice specific to the experts' tradition, called Open Presence (Tib. "rig pa cog gzhag", pronounced "rigpa chok shak"). The traditional description of Open Presence is complex, but the basic instructions of the practice indicate that it shares common qualities with Open Monitoring-type practices that are relevant to the purported effects on pain perception discussed above. We believe the present results from Open Presence to be relevant to the larger body of research on OM-type practices such as mindfulness. For more on FA see (Gunaratana, 2002); for more on the traditional account of OP see (Lutz et al., 2007) and (Karma Chagme, 2000); and for a more detailed discussion of the relationships among FA, OM and mindfulness, see (Lutz & Slagter 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 slowly increased until participants indicated the pain level had reached 8 on a scale of 0-10, where 0
indicates no pain at all, and 10 indicates unbearable pain. The average temperature reached over five trials was used for that participant in the protocol. If a participant did not indicate the pain level had reached 8, the temperature stopped at 49°C and this was used for that participant. Temperatures used ranged from 46°C-49°C.

The experiment consisted of 32 trials, broken up into 8 runs of 4 trials each, with a resting period and comfort check in between. In each trial, participants were presented with a cue for either FA or OP meditation, and then given 45 seconds to settle into the meditation state. Then there was a 12-second warm ramp-up temperature, followed by 10 seconds at that participant's painful temperature, or a non-painful temperature six degrees cooler. Order of FA/OP and hot/warm was counterbalanced across runs. At the end of each painful stimulus, 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. Ratings were analyzed in a 2 × 2 × 2 mixed ANOVA, with between-subject factor Group (novice or expert) and within-subject factors Practice (FA or OP) and Rating Type (intensity or unpleasantness). Ratings were also examined for trends over time, but sample size is currently too small to provide adequate power to test these trends.

Results.
As predicted in Hypothesis I, the Group (Experts or Novices) × Practice (FA or OP) × Rating type (Intensity or Unpleasantness) interaction was significant, $F(1,17) = 10.623, p = 0.005$ (Figure 1). This was primarily driven by the experts’ ratings of unpleasantness during OP. These ratings were lower for the experts than for the novices during OP ($t(17) = 2.77, p = 0.013$), and lower in OP than during FA for the experts (paired $t(8) = 6.8, p < 0.0001$). The Group (Experts or Novices) × Practice (FA or OP) interaction for unpleasantness ratings was significant, $F(1,17) = 37.618, p < 0.0001$. The Practice (FA or OP) × Rating type (Intensity or Unpleasantness) interaction was significant within the experts’ group, $F(1,8) = 11.531, p = 0.009$. Also, the Group (Experts or Novices) × Rating Type (Intensity or Unpleasantness) interaction during OP approached significance, $F(1,17) = 3.381, p = 0.083$, while the Group (Experts or Novices) × Rating Type (Intensity or Unpleasantness) interaction during FA was not significant, $F(1,17) = 0.9334, p = 0.347$.

Hypothesis II was not supported. We expected reduced intensity and unpleasantness ratings in the FA condition for experts relative to novices. Instead, we found no main effect of Group (Experts or Novices) for both rating types during FA, $p = 0.56$. The intensity ratings for both groups were virtually identical, $p = 0.94$, and the unpleasantness ratings were not significantly different, $p = 0.36$.

We also found a significant main effect of rating type, $F(1,17) = 23.135, p = 0.0002$. Ratings for unpleasantness were lower than ratings for intensity overall and in each
condition individually. In this sample, the main effect of ratings was more powerful than any differential effects of group or condition on ratings, making unambiguous interpretation difficult. Nevertheless, the Group × Rating Type interaction during OP approached significance, suggesting that OP in particular may have specific effects on the unpleasantness of pain rather than the intensity, which may have attained significance with a larger sample size.

Discussion.

The specific reduction in unpleasantness ratings for the experts in OP accords with our prediction. Interestingly, Grant & Rainville (2009) reported results from a similar experiment that showed a different pattern of changes in ratings of pain intensity and unpleasantness. One major difference is that whereas we found a trend for a greater reduction in unpleasantness than intensity for experts compared to novices in OP meditation, they showed greater reductions in intensity than unpleasantness, for experts compared to novices, during mindfulness meditation practice. It is not clear why their findings contrast with ours. Our results appear to support the interpretation that reducing the cognitive elaboration of a sensory experience 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 et al., 2001; Sullivan, Rodgers, & Kirsch, 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 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 with selective reduction of unpleasantness for experts 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 experts relative to novices, but this hypothesis was not supported. There are a number of possible reasons for this. First, it may be that our assumption of expertise in the practice was incorrect. The clear effect seen for OP 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 OP than FA. Other paradigms examining FA in more detail in this population would be necessary to clarify this.

This unexpected result also highlights complexities of attention direction and magnitude that must be addressed in future studies of attention and pain (Wiech et al. 2008). Pain is inherently demanding of attention (Melzack & Casey, 1968). In many previous studies of distraction and pain (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 two 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 and Slagter et al. (2008) suggests that the practice explicitly involves recognition of distracters as part of the disengagement from distraction and re-engagement with the target. Finally, subsequent informal discussion with some of the practitioners 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, non-reactive awareness.

Given the likely awareness of the long-term practitioners of the purported effects of meditative states on pain, it cannot be entirely ruled out that the observed effects may be due in part to demand characteristics. The fact that significant changes in
the experts’ ratings were found during OP but not FA, despite traditional accounts of an analgesic effect of both practices (Gunaratana, 2002; Karma Chagme, 2000) argues that these effects are selective and not a simple result of demand characteristics. Nevertheless, corroborating measures such as fMRI data are needed to clarify the interpretation of results.

One notable limitation of the current study is the lack of a baseline, i.e. non-meditation, 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 magnetic resonance imaging; constraints on MRI scanner time and the experts’ schedules made it difficult to fit in any other conditions. The long-term practitioners 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 experts’ 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; given this calibration, it seems likely that experts’ and novices’ ratings would have been similar during a non-meditating condition during the experiment. For these reasons, we believe that despite the lack of a baseline condition, our use of a calibrated between-groups design with experts and novices provides validly interpretable results.

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,
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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and enhancement of emotional responses to unpleasant pictures.


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/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 my 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 of your mind.
Table 1. Participant matching characteristics.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>N (Males)</th>
<th>Age</th>
<th>Temperature Used</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Experts</td>
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<td>5</td>
<td>48.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Novices</td>
<td>10</td>
<td>5</td>
<td>47.1</td>
<td>11.8</td>
</tr>
<tr>
<td>T-Test</td>
<td></td>
<td></td>
<td>t (17) = 0.19, p = 0.85</td>
<td>t (17) = 0.27, p = 0.79</td>
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T-Test: t (17) = 0.19, p = 0.85; t (17) = 0.27, p = 0.79
Figure 1. Pain intensity and unpleasantness ratings for novices and expert meditators performing Focused Attention and Open Presence meditation practices.


http://brainimaging.waisman.wisc.edu/~perlman/0903-EmoPaper/IURatingsChartFinal.eps