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Mindfulness meditation is related to sensory-affective uncoupling of pain in trained novice and expert practitioners

Jelle Zorn | **Oussama Abdoun** | **Romain Bouet** | **Antoine Lutz**

Lyon Neuroscience Research Centre, INSERM U1028, CNRS, UMR5292, Lyon 1 University, Bron Cedex, Lyon, France

Correspondence
Antoine Lutz, Director of Research at the Lyon Neuroscience Research Center, DYCOG Team, INSERM U1028 - CNRS UMR5292, Centre Hospitalier Le Vinatier (Bât. 452), 95 BdPinel, 69675 BronCedex, France.
Email: antoine.lutz@inserm.fr

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Abstract

Background: Mindfulness meditation can alleviate acute and chronic pain. It has been proposed that mindfulness meditation reduces pain by uncoupling sensory and affective pain dimensions. However, studies to date have reported mixed results, possibly due to a diversity of styles of and expertise in mindfulness meditation. Furthermore, the interrelations between mindfulness meditation and pain catastrophizing during acute pain remain little known.

Methods: This cross-sectional study investigated the effect of a style of mindfulness meditation called Open Monitoring (OM) on sensory and affective pain experience by comparing novice (2-day formal training; average ~20 hr practice) to expert practitioners (>10.000 hr practice). We implemented a paradigm that was designed to amplify the cognitive-affective aspects of pain experience by the manipulation of pain anticipation and uncertainty of stimulus length (8 or 16 s thermal pain stimuli). We collected pain intensity and unpleasantness ratings and assessed trait pain catastrophizing with the Pain Catastrophizing Scale (PCS).

Results: Across groups, mindfulness meditation reduced unpleasantness, but not intensity ratings compared to attentional distraction. Experts reported a lower score on PCS, reduced amplification of unpleasantness by long painful stimuli, and larger sensory-affective uncoupling than novices particularly during long painful stimuli. In experts, meditation-induced uncoupling spilled over the control condition. Across groups and task conditions, a higher score on PCS predicted lower sensory-affective uncoupling during long painful stimuli and higher ratings of pain intensity during short painful stimuli.

Conclusion: These findings suggest that mindfulness meditation specifically down-regulates pain affect as opposed to pain intensity, and that pain catastrophizing undermines sensory-affective uncoupling of pain.

Significance: In this study, we found that a style of mindfulness meditation referred to as OM reduced unpleasantness but not intensity ratings compared to attentional distraction in trained novice (state effect) and expert meditators (state and trait effects). We also observed that trait pain catastrophizing scores predicted this sensory-affective uncoupling. These findings advance our understanding of the cognitive mechanisms underlying mindfulness meditation and can inform treatment strategies for chronic pain.

1 | INTRODUCTION

Pain includes partly dissociable sensory and affective-motivational components. Sensory qualities relate to pain intensity, location and duration, whereas the affective-motivational component refers to pain unpleasantness that produces a motivation to avoid pain and seek relief (Melzack & Casey, 1968). The affective-motivational component is intertwined with cognitive-evaluative processes that can exacerbate or reduce pain (Sullivan et al., 2001). One such factor is pain catastrophizing, 'an exaggerated negative "mental set" brought to bear during actual or anticipated pain experience' (Sullivan et al., 2001), which predicts increased pain in healthy and clinical populations (Quartana, Campbell, & Edwards, 2009; Sullivan et al., 2001), as well as the maintenance and exacerbation of chronic pain (Edwards, Dworkin, Sullivan, Turk, & Wasan, 2016; Gatchel, Peng, Peters, Fuchs, & Turk, 2007).

A process designed to undermine or oppose effects of pain catastrophizing is mindfulness, which has been defined as a 'nonelaborative, nonjudgemental, present-centred awareness' (Bishop et al., 2004). Contrary to pain catastrophizing, a mindful stance is thought to deflate the negative cognitive-affective elaboration of pain, by becoming aware of distressing thoughts and automatic emotional reactivity and by observing them as mere mental events. Opening up to sensory experience is thought to support this process (Bernstein et al., 2015; Hayes, Strosahl, & Wilson, 2012; Kabat-Zinn, 2013; Lutz, Jha, Dunne, & Saron, 2015).

Mindfulness meditation can indeed alleviate acute and chronic pain (Zeidan, Grant, Brown, McHaffie, & Coghill, 2019). In line with the cognitive stance cultivated by mindfulness meditation, one of the most consistent findings has been a reduction in pain affect as opposed to intensity (Gard et al., 2012; Hilton et al., 2017; Perlman, Salomons, Davidson, & Lutz, 2010). This suggests that mindfulness meditation reduces pain by 'uncoupling' sensory and affective/evaluative pain dimensions. However, despite that some meditation studies have reported neural substrates for sensory-affective uncoupling (as reviewed by Grant 2014), this notion remains debatable, as some studies have reported marked overall pain reductions for novice (Zeidan et al., 2011, 2015, 2016) and expert meditators (Grant & Rainville, 2009). This discrepancy may arise from the diversity of styles of and expertise in mindfulness meditation. Furthermore, interrelations between mindfulness and pain catastrophizing during acute pain remain little known.

In the present work, we implemented a paradigm that was designed to amplify the cognitive-affective aspects of pain while participants performed Open Monitoring (OM) meditation (Lutz, Slagter, Dunne, & Davidson, 2008), a style of mindfulness meditation known to impact sensory-affective uncoupling of pain (Perlman et al., 2010). Specifically, we collected pain intensity and unpleasantness ratings, while novices (2-day formal training; average ~20 hr home practice) and expert practitioners (>10.000 hr practice) performed OM meditation, or a distraction control condition, during the anticipation and reception of short (8 s) and long (16 s) thermal pain stimuli.

We expected that long painful stimuli in particular would exacerbate pain catastrophizing related processes, which would be counteracted by meditation state and expertise. In line with the cognitive attitude cultivated by mindfulness meditation, we expected this regulation to be mainly reflected in a reduction in pain unpleasantness as opposed to pain intensity. Specifically, we hypothesized that mindfulness meditation would reduce pain unpleasantness but not pain intensity compared to attentional distraction (state effect); and to a larger degree for long compared to short painful stimuli and experts compared to novices. Furthermore, we expected that experts would rate painful stimuli as overall less unpleasant but equally intense compared to novices (trait effect). We also expected that experts would be more resilient to pain amplification by long painful stimuli than novices, as reflected in a lower increase in unpleasantness but not intensity between short and long painful stimuli and larger sensory-affective uncoupling for long painful stimuli in particular. Finally, we expected that the latter two effects could be explained by lower pain catastrophizing for experts compared to novices.

2 | MATERIAL AND METHODS

2.1 | Participants

Participants were recruited for the Brain and Mindfulness ERC-funded project, which includes a cross-sectional observational neuroscientific study on the effect of mindfulness meditation on experiential, cognitive and affective processes conducted in the city of Lyon from 2015 to 2018. Participants included novice and long-term meditation practitioners (experts), who were recruited through multiple screening stages which are reported in detail elsewhere (see the Brain & Mindfulness Project Manual, Abdoun et al., 2018). Inclusion criteria were as follows: aged between 35 and 65 years, no psychotropic drug use, no neurological or psychiatric disorder, a Beck Depression Inventory (BDI) score below 20, no family history of epilepsy, no severe hearing loss, MRI compatibility (the experiment was carried out in an MRI scanner) and affiliation to the social security system. Pregnant and breastfeeding women were also excluded. Experts needed to have a minimum of 10.000 hr of formal practice in the Kagyu or Nyingma school of Tibetan Buddhism, followed at least one traditional 3-year meditation retreat, a regular daily practice in the year preceding inclusion. They also had to be able to distinguish between OM meditation and Open

Presence (OP) meditation, a more advanced nondual form of OM (see Meditation practices below for details) and to be familiar with the practice of OP. Novices were included if they did not have significant experience with meditation or other mind-body training techniques and a pain sensitivity above 47°C comparable to experts in our previous study (Lutz, McFarlin, Perlman, Salomons, & Davidson, 2013). Long-term meditation practitioners under a tradition comparable to the one in this study also exhibited very low pain sensitivity (~50°C to elicit moderate pain), further speaking to the need to match controls and experts on pain sensitivity. The study by Lutz et al. (2013) was also used in a power-analysis to determine the optimum sample size for this study. While the power analysis for the fMRI data was based on a group size of 25 participants (plus 3 participants to accommodate for artifactual data), we oversampled the novice group to increase our power for correlation analyses with questionnaire measures. A total of 37 novices and 27 expert practitioners were included. Two novices were excluded from the analyses because of a technical error with the log file and noncompliance with task instructions. One expert was excluded because of poor control task performance (33% correct responses only). Hence, the final sample included 35 novices (52.3 ± 7.5 years old, 16 females) and 26 expert practitioners (52.2 ± 8.1 years old, 12 females). No significant group differences were present in age, gender and temperature of painful stimuli used during the experiment (see Table 1). Experts had an average lifetime meditation experience of 41,357 hr (±17,999 *SD*; range: 13110–94535, missing data for one participant). All participants provided written informed consent before participating in the study. The study was approved by the regional ethics committee on Human Research (CPP Sud-Est IV, 2015-A01472-47).

2.2 | Meditation practices

As has been discussed elsewhere (Lutz et al., 2013), states of openness and acceptance central to Mindfulness-Based Interventions (MBI, Kabat-Zinn, 1982; Kabat-Zinn, Lipworth, & Burney, 1985; Kabat-Zinn, Lipworth, Burney, & Sellers, 1986) and Acceptance Commitment Therapy (ACT, Hayes, 2004) are also at the heart of mindfulness-related meditation practices labeled here OM (Chambers, Gullone, & Allen, 2009; Dunne, 2011; Hayes, 2004; Lutz, Dunne, & Davidson, 2006; Lutz et al., 2015). OM practices aim to cultivate a nonreactive, open and accepting awareness of present moment experience. Traditionally, initial training in focused attention (FA) meditation is considered a prerequisite for OM practice (Lutz et al., 2008). Hence, novices also received training in FA (for details on the training protocol see Abdoun, Zorn, Poletti, Fucci, & Lutz, 2019). Specifically, novices may still frequently 'grasp' mental objects, causing them to become absorbed in experiential content, resulting in a reduction or loss of moment-to-moment attention and observation. FA, which involves sustained FA on a selected object of choice, increases the capacity to detect distractions and sustain attention, which is said to stabilize the mind (Lutz et al., 2008). The resulting improved monitoring capacity supports OM practice, which involves the nonselective, nonjudgemental and nonelaborative monitoring of all ongoing sensory, affective and cognitive experience (Chambers et al., 2009; Lutz et al., 2008; see Methods S1 for OM instructions provided during the experiment). It has been suggested that the cultivation of such a meta-cognitive perspective allows one to become aware of subtle distressing thoughts that may accompany the perception of a nociceptive stimulus (e.g. thoughts such as 'It is killing me' or 'this lasts forever') that may otherwise go unnoticed. This awareness, together with the realization that thoughts are simply mental events and not accurate reflections of reality—a process known as 'cognitive defusion' or 'dereification' assumed integral to OM—is thought to cut subsequent emotional reactivity and pain amplification (Bishop et al., 2004; Hayes, 2004; Kabat-Zinn, 1982; Lutz et al., 2008, 2015). As a result of these two processes, it has been proposed that, during a state of OM, sensory pain dimensions might be perceived with equal or increased vividness, without the affective distress that usually accompanies such experience (Lutz et al., 2013; Perlman et al., 2010), leading to an 'uncoupling' of sensory and affective pain dimensions (Kabat-Zinn, 1982).

Novices and experts differ in the way of practicing objectless meditation. Specifically, with expertise the capacity to sustain an OM state becomes increasingly effortless, at which point it becomes possible to make awareness an object of meditation itself (Chambers et al., 2009; Lutz et al., 2008). Expert practitioners were intensively trained in this advanced style of OM labeled OP (Tib. rig pa) (Lutz et al, 2006) and

TABLE 1 Group characteristics

	Novices	Experts	*p*-value
Age (years)	52.3 (7.5)	52.2 (8.1)	$p = 0.95$
Temperature (experiment)	47.89 (0.49)	47.79 (0.49)	$p = 0.45$
Sex	35 (16 F/19 M)	26 (12 F/14 M)	$p = 0.97$

Note:: Continuous variables are presented as mean (standard deviation), and *p*-values were calculated using Welch's *t* test. For categorical variables, *p*-values were calculated using chi-squared test.

were explicitly asked to do it. In this state, theoretically at least, the phenomenological qualities of effortlessness, openness and acceptance are vividly experienced and control-oriented elaborative processes reduced to a minimum. A suspension of subject-object duality (nonduality) is also reportedly involved (Dunne, 2011; Lutz et al, 2006). As this state is considered a relatively advanced one, even expert practitioners might not be able to sustain it for more than a short time (Lutz et al, 2006). For the sake of simplicity, we will use the term OM for both novices and experts below, acknowledging that for experts actual meditation might also have qualified as OP.

2.3 | Meditation training novices

An important aim of the Brain and Mindfulness project was to have a high-quality control group for expert practitioners. To this end, meditation naïve participants underwent a weekend-long formal meditation training program (see Abdoun et al., 2019 for in depth information on the novice training protocol), that was provided by a qualified MBSR teacher, with 13 years of practice and 8 years of teaching experience in the meditation tradition under study and 3 years of experience as a teacher of a 18-month meditation-based intervention (Poisnel et al., 2018). The training included teachings with the support of instruction videos, guided meditations and experiential exercises, question and answer sessions, as well as sufficient time to reflect and share within the group. During the weekend, novices were introduced to various styles of meditation, including FA and OM practice: two complementary styles of meditation (see section 2.2), also extensively practiced by expert practitioners. One specific exercise involved switching between FA on, and OM of, pain. During such exercises, novices were additionally familiarized with several experiential dimensions relevant to mindfulness meditation (e.g. absorption vs. meditative awareness). Through this approach, we aimed to assure that novices gained an adequate understanding of the practices, while simultaneously addressing another issue in the literature, namely that studies that did not include formal meditation training failed to observe effects for meditation-naïve control participants (Gard et al., 2012; Grant & Rainville, 2009; Perlman et al., 2010). After the training weekend, novices were invited to keep up a daily practice of minimum 20 min a day until the day of the last experiment, to balance FA, OM and compassion meditations (relevant to other experiments, and also practiced by the experts), and to keep track of their practice with a logbook (n = 29). Novices had on average 63.2 days (±31.8 *SD*) to practice before participating to the experiment (range: 15–124 days), during which they engaged for a daily average of 18.3 min (±7.8 *SD*, range: 6.4–36.7 min) in the three meditations, including in OM practice for a daily average of 7.7 min (±3.8 *SD*; range: 1.4–15.1 min). Total meditation practice at the day of the experiment was 19.4 hr (±12.9 *SD*; range: 2.2 to 49.2 hr), including 8.1 (±6.1 *SD*; range: 0.4–26.5 hr) of OM.

2.4 | Pain calibration procedure

Painful stimuli were provided by a TSA 2001-II thermal stimulator (Medoc Advanced Medical Systems) with a 30 × 30 mm flat thermode applied to the palmar side of the left wrist. All participants underwent a calibration procedure for stimulus temperature. Using the method of limits (Fruhstorfer, Lindblom, & Schmidt, 1976), the temperature was increased from 32 to 50°C maximum at 0.7°C/s. Participants were instructed to indicate with a button press when the pain level reached a 7 on a scale of 0 ('no pain')—10 ('the worst pain imaginable'). At button press, temperature returned to the 32°C baseline at maximum rate. The temperature remained at baseline for 5 s before rising again. Subjects received 10 stimulations. The average temperature over the last five trials was used as an indication of that participant's pain sensitivity (except when 50°C was reached at three consecutive trials in which case the procedure was stopped and pain sensitivity set at 50°C; 3 novices, 2 experts). A second, finer calibration procedure was performed on the day of the experiment to determine the optimal temperature for a 16-s-long heat stimulation that would be used during the experiment itself. This calibration started with the temperature that best matched the participant's previously determined pain sensitivity, but was confined to a limited range of four possible temperatures: 47.0, 47.5, 48.0 and 48.5°C. Subjects received the best matching temperature for 16 s, after which they were asked to rate their pain using the same scale as before. If rating was at 7, temperature was kept at that level; else the temperature was adapted until the targeted pain level of 7 was reached (see Methods S2 for more details on the results of the two calibration procedures).

2.5 | Experimental design, pain stimuli and task instructions

Visual stimuli were presented using Psychopy v1.83.04 (Peirce, 2009). The experimental design is presented in Figure 1. Temporal jitters in the presentation of the stimuli were introduced to reduce collinearity of regressors in the fMRI-based general linear models. A fixation cross was displayed on the screen when no other visual stimuli were presented. Each trial started with a 5-to 8-s introductory period. A 2-s predictive cue then indicated whether the upcoming stimulation would be warm or hot and was followed by a 5- to 8-s anticipatory period. A thermal stimulation was then

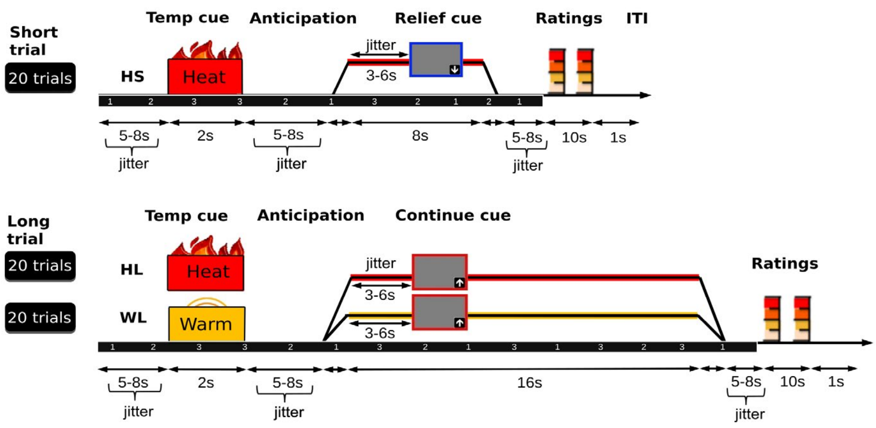

FIGURE 1 Schematic illustration of the experimental paradigm. Each trial started with a 5- to 8-s-introductory period. A 2-s predictive cue then indicated the temperature of the upcoming stimulation (warm or hot) and was followed by a 5- to 8-s-anticipatory period. A thermal stimulation (to the palmar side of the left wrist) was then delivered that was either short (8 s) or long (16 s). After 3–6 s of thermal stimulation, a second visual cue informed subjects about the duration of the stimulation. Nonpainful warm stimuli were always long and served as baseline control for the fMRI. Following stimulus offset, a 5- to 8-s-rest period preceded the presentation of two rating scales (5 s each). Rating scales probed pain intensity, unpleasantness, relief and task performance. During each trial, a single-digit number (1–3) was presented every 2 s from the start of the trial until rating scales were shown (see black horizontal bars). Subjects randomly alternated between two task conditions: Distraction, involving the mental addition of the numbers and the blocking of all pain experience; or OM involving the cultivation of an open attitude to pain (and no mental addition). Subjects received a total of 60 thermal stimuli: 20 short hot (SH), 20 long hot (LH) and 20 long warm (LW) equally distributed across the two task conditions. ITI, intertrial interval; OM, Open Monitoring

delivered which was either hot, at the participant's painful temperature, or warm, at a nonpainful temperature 6 degrees cooler. 3–6 s after stimulus onset, a second cue indicated whether the stimulation would be short (8 s, relief) or long (16 s, nonrelief). Warm stimuli were always long (16 s) and served as a baseline control condition for the MRI. Hence, they will not be analysed for the current work. Five to eight seconds after the thermal stimulation ended, two rating scales were presented for 5 s each (see Rating scales section below). After 1 s the next trial started. Baseline temperature for the thermode was 32°C. Ramp-up and ramp-down periods were 1.5 s for the warm and 2.5 s for hot stimuli. Temperature of the long hot stimuli dropped slightly by 1°C (0.5°C/s) after 2 s of stimulation (not depicted) as initial pilot sessions revealed they would otherwise be unbearable. Subjects received a total of 60 thermal stimuli; 20 short hot (SH), 20 long hot (LH) and 20 long warm (LW), applied to the palmar side of the left wrist. All thermal stimuli were delivered during one experimental session consisting of six blocks of ten trials each. Subjects rested 1.5 min between the blocks. Each block was further subdivided into two subblocks, one for each state condition, in randomized order: OM or a control addition task (Distraction). Each trial type (SH, LH, LW) was set to occur at least once during each subblock. Each subblock started with a 20 s auditory and visual state induction during which participants received instructions for the experimental condition. For OM, participants were instructed to keep an open and accepting awareness (see Methods S1 for full instructions). Experts specifically were also told that the OM instructions referred to the practice of OP. For Distraction, subjects were instructed to mentally add simple single-digit numbers (1–3) that were presented on the centre of the screen (replacing the fixation cross) from the start of each trial until rating scales were shown (see Figure 1). Numbers were presented for 1 s with a variable interval of 3, 4 or 5 s between numbers. Subjects were asked to maintain a tight focus on the screen in order not to miss any numbers, while blocking all pain-related sensations, emotions and thoughts. In order to minimize visual differences between task conditions, numbers were also presented on the screen during OM. However, subjects were instructed to abstain from mental addition, but to nonetheless keep their gaze fixed at the screen at all times, in a relaxed manner, in order to not miss any visual cues. Prior to the experiment, participants were familiarized with the task and performed one full block of trials using nonpainful stimuli only.

2.6 | Rating scales

Throughout the blocks, we collected ratings of pain intensity and unpleasantness using 1–9 Likert items. Similarly, we collected ratings of pain relief (how relieved were you when the stimulation stopped) which will not be analysed here, but in a future publication in the context of studying reward-related activity in the neuroimaging analysis. We further checked task performance by regularly asking the total sum of the addition task in the Distraction condition, or, in case of OM, to what degree participants were able to follow meditation instructions. After each trial, two different rating scales were presented in randomized order (see Methods S3 for the specific questions and frequency of presentation).

2.7 | Questionnaires and other measurements

To characterize interindividual trait differences in cognitive and affective processes involved in our paradigm, we measured the Pain Catastrophizing Scale (PCS) (Sullivan, Bishop, & Pivik, 1995). 33 novices and 26 experts completed the PCS before participating in the experiment. Other measurements relevant to the current experiment were collected. These included the Drexel Defusion Scale which measures cognitive defusion (see the Brain & Mindfulness project manual, Abdoun et al., 2018, for all questionnaires collected), several phenomenological scales collected at the end of the fMRI session (e.g. openness, avoidance, vividness) and a qualitative interview about worldview and pain and suffering coping strategies. These will be the subject of a future publication.

2.8 | Statistical analysis

We used R 3.3.2 for statistical analyses (R core team, 2017).

Group comparisons: Welch's *t* test was used to compare group means for age, pain sensitivity, experimental temperature, task performance and trait pain catastrophizing. Chi-squared test was used to test for differences in categorical variables between groups.

Outlier removal pain ratings: We first removed no-response trials and subsequently removed extreme outlier points that were more than 3.5 standard deviations away from the median for each grouping of Subject by Rating Type (Intensity, Unpleasantness).

Linear mixed models (LMMs): LMMs were fitted to the data using lme4 (Bates, Maechler, Bolker, & Walker, 2015). The main advantage of these models is that they are able to handle missing data and complex unbalanced designs (e.g. different ratings being asked at different trials as in this study) (Bates et al., 2015; Molenberghs & Lesaffre, 2014). Another characteristic of LMMs is that they contain a fixed and random effects structure. Usually, the fixed effects structure estimates the explanatory variables (i.e. effects of interests or covariates), whereas the random effects structure estimates subject-level effects for repeated measures, thus accounting for heterogeneity between subjects and nonindependence within subjects (Singmann & Kellen, 2019). Fixed effect terms for each model are specified in the results section. Time (different blocks) was additionally included as fixed effect covariate in all models. We kept the random effects structures maximal, by including subject-level random intercepts and random slopes for each within-subject fixed effect (including the Time covariate) (Barr, Levy, Scheepers, & Tily, 2013). Models were fitted using restricted maximum likelihood, and type II Wald chi-square tests were used to assess significance of fixed effects (Bates et al., 2015; Bolker et al., 2019; Luke, 2017). Post hoc tests were performed using the emmeans package version 1.2.2, using Tukey multiple comparison corrections.

Effects size calculations: For informative, replicative and meta-analytic purposes, we provide effect size measures for the effects of interest. As of yet, no generally accepted method exists for the calculation of effect sizes within LMMs. As a workaround for estimation of the effect sizes for interaction and post hoc effects observed within LMMs, we fitted simpler models to the data and calculated effect sizes on them. More specifically, for LMM interaction effects, we fitted the equivalent ANOVA model, that included the factors involved in the interaction, and data averaged per subject for each possible combination of the factor levels (as usual for ANOVA). We subsequently calculated the partial eta-squared (ηp^2) effect-size measure for the interaction term (Maher, Markey, & Ebert-May, 2013). For the estimation of effect sizes of post hoc LMM pairwise comparisons, we grouped data according to the levels under comparison, and averaged data per subject. We subsequently calculated Cohen's (d) effect-size measure (Maher et al., 2013). Cohen's (d) was also calculated for group differences in pain catastrophizing analysed with a t test.

3 | RESULTS

3.1 | Manipulation check

The percentage of correct responses on the Distraction task did not differ between experts ($M = 0.87$, $SD = 0.13$) and novices ($M = 0.88$, $SD = 0.11$), ($t(49.9) = 0.6$, $p = 0.57$), suggesting equal control task compliance between groups. However, when participants were asked to what degree they could follow meditation instructions, experts ($M = 7.46$, $SD = 1.21$) provided significantly higher ratings than novices ($M = 6.66$, $SD = 1.38$), $t(57.3) = 2.4$, $p = 0.020$; $d = 0.61$), potentially reflecting differing levels of expertise.

3.2 | Effects of meditation state and expertise on pain experience

We tested the effect of meditation state and expertise on pain experience with a model that included Group (Experts, Novices), State (OM, Distraction), Rating Type (Intensity, Unpleasantness) and Trial Type (Short, Long) as fixed effects (see Figure 2a for an overview of the data). We observed a

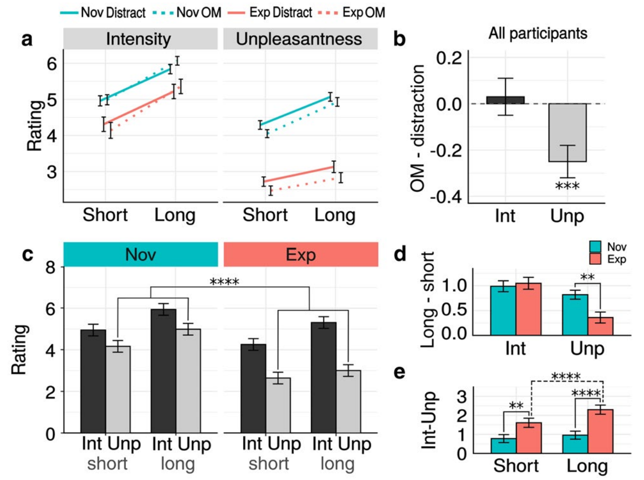

FIGURE 2 Effect of meditation state and expertise on subjective pain experience. (a) Overview of pain self-report data. (b) Relative to Distraction, OM reduced the unpleasantness but not intensity of pain, across groups (Novices and Experts) and trial types (Short, Long); Subsequent results are averaged across the levels of states (OM, Distraction). (c) Compared to novices, experts rated painful stimuli as less unpleasantness but equally intense across trial types (Short, Long). (d) Experts, compared to novices, reported a comparable increase in pain intensity but a lower increase in pain unpleasantness between short and long painful stimuli. (e) Experts, compared to novices, reported larger sensory-affective uncoupling of pain, already during short, but particularly during long painful stimuli (solid lines). Experts additionally reported larger sensory-affective uncoupling of pain for long compared to short painful stimuli (dashed lines). Pain ratings were provided on 1–9 Likert scales. Results are model-derived estimates. Int, Intensity; OM, Open Monitoring; Unp, unpleasantness. Error bars are standard errors. Significance levels *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; ****: $p < 0.0001$

State x Rating Type (χ^2 (1) = 1.0, $p = 0.001$; $\eta p^2 = 0.11$), a Group x Rating Type interaction (χ^2 (1) = 1.3, $p < 0.001$; $\eta p^2 = 0.18$) and a Group x Rating Type x Trial Type interaction (χ^2 (1) = 8.6, $p = 0.003$; $\eta p^2 = 0.08$).

First, we conducted post hoc tests on the State x Rating Type interaction (Figure 2b). In line with what was predicted, we observed an overall state effect across groups (Novices, Experts) and trial types (Short, Long). Interpreting the overall state effect, we found that relative to Distraction, OM significantly reduced the unpleasantness but not intensity of pain across all participants (unpleasantness: estimate = −0.25, 95% CI = [−0.39, −0.11], $t(102) = -3.5$, $p < 0.001$, $d = -0.14$; intensity: estimate = 0.03, 95% CI = [−0.19, 0.13], $t(173) = 0.3$, $p = 0.74$). To test whether this effect of state was also present in each group, we performed follow-up tests on the novice and expert groups separately. We found that the state effect was present in both novice and expert groups (novices: State x Rating Type (χ^2 (1) = 6.36, $p = 0.012$, $\eta p^2 = 0.12$; unpleasantness: estimate = −0.21, 95% CI = [−0.38, −0.04], $t(65) = -2.4$ $p = 0.018$, $d = -0.15$; intensity: estimate = 0.08, 95% CI = [−0.11, 0.28], $t(118) = 0.8$, $p = 0.43$), (experts: State x Rating Type (χ^2 (1) = 3.85, $p = 0.05$, $\eta p^2 = 0.10$; unpleasantness: estimate = −0.29, 95% CI = [−0.53, −0.05], $t(39) = -2.4$, $p = 0.021$, $d = -0.18$; intensity: estimate = −0.03, 95% CI = [−0.29, 0.24], $t(60) = -0.19$, $p = 0.85$). Additional supplementary analyses revealed that, for novices, none of the usual practice metrics could predict the state effect. Instead, time elapsed since the meditation weekend was found to be a significant predictor, such that novices who participated in the experiment closer to the meditation weekend reported larger state effects (see Results S1). The significance of this finding will be further detailed in the discussion.

Next, we performed post hoc tests on the Group × Rating Type interaction of the main model (Figure 2c). Across the different task conditions (OM, Distraction) and trial types (Short, Long), experts rated painful stimuli as significantly less unpleasant compared to novices (estimate = −1.75, 95% CI = [−2.45, −1.05], $t(59) = -5.0$, $p < 0.0001$; $d = -1.33$), whereas averaged reports of pain intensity did not differ between groups (estimate = −0.66, 95% CI = [−1.38, 0.05], $t(59) = -1.8$, $p = 0.070$). Thus, in line with our predictions expert practitioners reported a larger reduction in the unpleasantness, but not intensity of pain compared to novices during OM meditation, but contrary to our predictions, this effect also extended to a nonmeditative control state.

Finally, we examined the Group × Rating Type × Trial Type interaction of the main model (Figure 2d,e). A first post hoc test revealed that, as predicted, experts, reported a significantly lower increase in pain unpleasantness between short and long painful stimuli compared to novices (estimate = −0.46, SE = 0.15, $t(103) = -3.2$, $p < 0.01$; $d = -0.98$), whereas the reported increase in pain intensity did not differ between groups (estimate = 0.05, SE = 0.16, $t(172) = 0.3$, $p = 0.74$) (Figure 2d). Second, we performed post hoc tests to examine group differences in the reported degree of sensory-affective uncoupling of pain; operationalized as the within-subject difference between sensory intensity and unpleasantness ratings of pain (intensity-unpleasantness). As predicted, experts, compared to novices, reported significantly larger sensory-affective uncoupling of pain, already during short (estimate = 0.83, SE = 0.32, $t(70) = 2.6$, $p = 0.01$; $d = -0.73$) but most pronouncedly during long painful stimuli (estimate = 1.3, SE = 0.32, $t(70) = 4.2$, $p = 0.0001$; $d = -1.02$) (see solid lines Figure 2e). Expert, but not novice practitioners, additionally reported larger sensory-affective uncoupling of pain for long compared to short painful stimuli (experts: estimate = 0.69, SE = 0.13, $t(2078) = 5.2$, $p < 0.0001$; $d = 0.40$; novices: estimate = 0.18, SE = 0.11, $t(2075) = 1.5$, $p = 0.12$) (see dashed lines Figure 2e). Collectively, these results confirmed our hypotheses on meditation state and expertise related sensory-affective uncoupling of pain.

We also anticipated a modulation of the state-effect by meditation-expertise and trial type, such that experts would report larger OM-related sensory-affective uncoupling than novices, particularly during long painful stimuli, which we failed to observe. This could have been due to cross-over effects between task conditions, as it has been previously observed that a meditation state can affect the postmeditative baseline (Lutz, Greischar, Rawlings, Ricard, & Davidson, 2004). Specifically, experts' larger sensory-affective uncoupling of pain cultivated during meditation might have lingered on to the control state: thereby attenuating overall differences between states in this group. To test this possibility, we performed an exploratory analysis to examine whether the magnitude of reported sensory-affective uncoupling of pain, for the two different task conditions, depended on the order of task performance within blocks. We fitted a model that included Group (Experts, Novices), State (OM, Distraction), Subblock (First, Second) and Block (1–6) as fixed effect terms and an Uncoupling index (within-subject difference intensity-unpleasantness for long painful stimuli) as dependent variable. Consistent with this hypothesis, we observed a Group x State x Subblock interaction (χ^2 (1) = 4.44, p = 0.035). Post hoc tests revealed an order effect for experts only, who reported increased sensory-affective uncoupling of pain for OM relative to Distraction, during first but not second experimental subblocks after resting breaks (first subblock: estimate = 0.73, 95% CI = [0.06, 1.39], $t(137) = 2.2$, $p = 0.032$; second subblock: estimate = −0.15, 95% CI = [−0.82, 0.51], $t(122) = -0.45$, $p = 0.65$) (see Figure 3). No such order effect was present for novices (first subblock: estimate = 0.11, 95% CI = [−0.43, 0.66], $t(125) = 0.4$, $p = 0.68$; second subblock: estimate = 0.51, 95% CI = [−0.09, 1.10], $t(142) = 1.7$, $p = 0.094$). The fact that experts reported larger sensory-affective uncoupling of pain for OM compared to Distraction during first but not second experimental subblocks after 2 min during resting breaks, suggests that a spillover effect of OM within blocks, that attenuated overall state differences, was present for the expert group specifically.

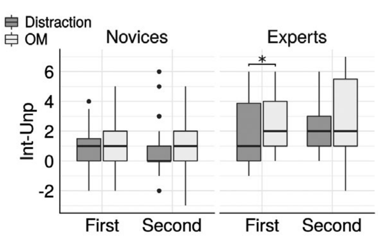

FIGURE 3 Effect of task order within blocks on reported sensory-affective uncoupling of pain. A state-effect specific to experts was present when controlling for task order within blocks, with experts but not novices reporting increased sensory-affective uncoupling of pain for OM compared to Distraction for first but not second subblocks after resting breaks. OM, Open Monitoring

3.3 | Relationship between pain catastrophizing and meditation expertise

Next, we tested for group differences in trait pain catastrophizing as measured by the PCS. As predicted, experts had significantly lower trait pain catastrophizing compared to novices (experts: $M = 6.96$, $SD = 5.39$; novices: $M = 18.27$, $SD = 9.35$, $t(52.7) = -5.8$, $p < 0.0001$, 95% CI = [−15.20, −7.42]; $d = -1.44$) (see Results S2 for figure). To explore the relationship of this expertise effect to meditation practice, we tested whether experts' lifetime meditation experience could predict pain catastrophizing scores, which was not the case (r(23) = −0.08, $p = 0.70$). This might have been due to nonlinearity of training, or a ceiling effect introduced by the high level of experience of expert practitioners (~40.000 hr).

3.4 | Relationships between pain catastrophizing and pain experience

Finally, and as hypothesized, we examined whether the group difference in trait pain catastrophizing could explain the observed group differences in increase in pain unpleasantness between short and long painful stimuli, as well as in reported degree of sensory-affective uncoupling for long painful stimuli. To test this, we divided participants in a low (Low PCS) and high (High PCS) pain catastrophizing subgroup (median split), and examined whether the newly created PCS subgroups showed similar group differences in the specified effects. The Low PCS group included 22 experts and 7 novices, whereas the High PCS group included 26 novices and four experts (see blue (novices) and red (experts) dots in upper panels Figure 4a). Groups did not differ in mean pain sensitivity (low PCS: $M = 47.5$, $SD = 2.1$, high PCS: 47.8, $SD = 1.5$, $t(50) = -0.7$, $p = 0.49$, 95% CI = [−1.30, 0.63]) or experimental pain temperature (low PCS: $M = 47.9$, $SD = 0.49$, high PCS: 47.8, $SD = 0.50$, $t(57) = 0.48$, $p = 0.63$, 95% CI = [−0.20, 0.32]). We fitted a model that included PCS (Low PCS, High PCS), Trial Type (Short, Long), State (OM, Distraction) and Rating Type (Intensity, Unpleasantness) as fixed effects, and observed a PCS × Rating Type interaction (χ^2 (1) = 7.1, $p < 0.01$; $\eta p^2 = 0.11$), and a PCS × Rating Type × Trial Type interaction (χ^2 (1) = 1.7, $p < 0.001$; $\eta p^2 = 0.17$).

First, we conducted post hoc tests on the PCS x Rating Type interaction (Figure 4a). Across the different task conditions (OM, Distraction) and trial types (Short, Long), the Low PCS group rated painful stimuli as significantly less unpleasant than the High PCS group (estimate = −1.54, SE = 0.37, $t(57) = -4.2$, $p < 0.0001$, 95% CI = [−2.29, −0.80]; $d = -1.12$), whereas averaged reports of sensory pain intensity did not differ between PCS groups (estimate = −0.70, SE = 0.36, $t(57) = -1.9$, $p = 0.057$, 95% CI = [−1.42, 0.02]).

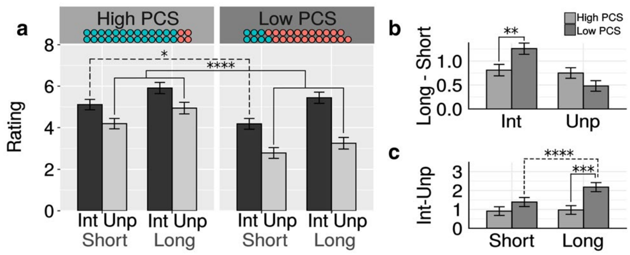

FIGURE 4 Effect of pain catastrophizing on subjective pain experience. Results are averaged across the levels of states (OM, Distraction). (a) The low (right panel) compared to high PCS group (left panel) rated painful stimuli as less unpleasant (solid lines) across trial types (Short, Long). However, the high compared to low PCS group rated painful stimuli as more intense only when they were short (dashed lines). Dots in upper panels represent the composition in novices (blue) and experts (red) of each PCS group. (b) The increase in pain unpleasantness between short and long painful stimuli did not differ between groups. Instead the low PCS group reported a higher increase in pain intensity. (c) The low compared to high PCS group reported larger sensory-affective uncoupling of pain, specifically during long painful stimuli (solid lines), as well as a larger increase in sensory-affective uncoupling of pain between short and long painful stimuli (dashed lines). Pain ratings were provided on 1–9 Likert scales. Results are model-derived estimates. Int, Intensity; OM, Open Monitoring; PCS, Pain Catastrophizing Scale; Unp, unpleasantness. Error bars are standard errors. Significance levels *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; ****: $p < 0.0001$

This result was conceptually similar to that of the equivalent test for the novice and expert groups.

Subsequently, we examined the PCS × Rating Type × Trial Type (Figure 4b,c). A first post hoc test showed that, contrary to what was predicted, the Low compared to High PCS group reported a lower increase in pain unpleasantness between short and long painful stimuli only at a trend level (estimate = −0.27, SE = 0.15, $t(95) = -1.8$, $p = 0.075$). Also, the Low PCS group reported a higher increase in pain intensity (estimate = 0.45, SE = 0.17, $t(154) = 2{,}7$, $p < 0.01$) (Figure 4b). To help interpret this unexpected finding we conducted follow-up tests on short and long pain stimuli separately. Interestingly, we found that the High PCS group rated short painful stimuli as significantly more intense compared to the Low PCS group (estimate: 0.93, 95% CI = [0.20, 1.65], $t(60) = 2.6$, $p = 0.013$) (dashed lines Figure 4a), whereas intensity reports were not different between groups for long painful stimuli (estimate: 0.47, 95% CI = [−0.28, 1.23], $t(59) = 1.3$, $p = 0.22$) (the equivalent test for novice and expert groups did not show such an effect). The larger increase in pain intensity between short and long painful stimuli for the Low compared to High PCS group was not what we initially predicted. This effect could reflect either a ceiling effect for the high PCS group due to increased baseline pain sensitivity, or alternatively, an enhanced opening up to pain sensation during long painful stimuli for the Low PCS group.

Further continuing the interpretation of the PCS × Rating Type × Trial Type interaction, we finally conducted post hoc tests on differences between PCS groups in reported degree of sensory-affective uncoupling of pain (Figure 4c). As predicted, the Low compared to High PCS group reported more pronounced sensory-affective uncoupling of pain for long painful stimuli [(estimate = 1.21, SE = 0.34, $t(66) = 3.6$, $p < 0.001$; $d = 0.88$) (solid lines Figure 4c), whereas reported sensory-affective uncoupling of pain did not differ between PCS groups for short painful stimuli (estimate = 0.48, SE = 0.34, $t(66) = 1.44$, $p = 0.15$). The Low but not High PCS group additionally reported larger sensory-affective uncoupling of pain for long compared to short painful stimuli (Low PCS: estimate = 0.69, SE = 0.13, $t(2078) = 5.2$, $p < 0.0001$, $d = 0.45$; High PCS: estimate = 0.18, SE = 0.11, $t(2075) = 1.5$, $p = 0.12$) (see dashed lines Figure 4c).

These results suggest that the group differences in trait pain catastrophizing could indeed explain the observed group differences in sensory-affective uncoupling of pain for long painful stimuli, as predicted. In order to further assess the specificity of this finding, we tested whether pain catastrophizing could also predict sensory-affective uncoupling of pain for long painful stimuli, across participants, when controlling for the effect of meditation expertise. We found that this was indeed the case (see Results S3). This suggests that the above findings were not simply driven by group differences in meditation expertise unrelated to pain catastrophizing.

4 | DISCUSSION

This study aimed to better characterize the pain regulatory mechanism of OM mindfulness meditation; a meditation practice analogous to that employed in MBI for the treatment of chronic pain. To this end, we investigated the impact of an OM meditation state and expertise on sensory and affective pain experience during short (8 s) and long (16 s) painful stimuli.

4.1 | Effect of the state manipulation

We found that OM meditation compared to attentional distraction, reduced ratings of unpleasantness but not intensity for novice and expert practitioners. This finding replicates several studies that reported lower pain unpleasantness as a result of mindfulness training or expertise (Brown & Jones, 2010; Gard et al., 2012; Grant, Courtemanche, & Rainville, 2011; Grant & Rainville, 2009; Perlman et al., 2010; Zeidan et al., 2011, 2015, 2016), and extends this work in multiple ways.

The within-subject contrast of two opposing cognitive and attentional stances allowed us to better understand the relative regulatory efficacy of each. In the context of this study, mindfulness meditation emerged as the more adaptive strategy. This finding is in line with clinical and mindfulness theory which holds that cultivating an open and accepting attitude towards pain, especially when chronic and inescapable, is more adaptive than experiential avoidance (Bishop et al., 2004; Hayes et al., 2012; Kabat-Zinn, 2013). This notion has gathered empirical support from the clinical domain which has consistently linked excessive fear and avoidance behaviors to poorer clinical outcomes (Crombez, Eccleston, Damme, Vlaeyen, & Karoyl, 2013; Edwards et al., 2016). Our finding that both expert and novice practitioners reported lower pain unpleasantness during mindfulness-meditation, including for long tonic-like pain stimuli which have been suggested to better mimic chronic pain states (Racine et al., 2012), further supports this notion.

The finding on meditation-induced sensory-affective uncoupling of pain for experts, corroborates two other studies with long-term meditation practitioners, the first by Gard and colleagues on experienced Vipassana practitioners (Gard et al., 2012), and the second by Perlman and colleagues on Tibetan Buddhism practitioners (Perlman et al., 2010), that observed similar results.

Our finding of a reduction in pain unpleasantness during mindfulness-meditation for novices is also salient as other studies, with similar instructions, failed to observe effects for control participants (Gard et al., 2012; Grant & Rainville, 2009; Perlman et al., 2010). This difference is perhaps most readily attributed to the larger dose of meditation training for novices in our study, which included 2 days of formal training in OM and FA meditations with a teacher, and several weeks of home practice (2–18 weeks) (Abdoun et al., 2019). By contrast, other studies only provided written meditation instructions. Hence, it can be speculated that the capacity to nonjudgementally monitor (pain) experience is not trivial and requires at least some familiarity with and training in OM (and likely FA); a view also traditionally held (Lutz et al., 2006, 2008). However, practice metrics for novices could not predict the state effect (reduced unpleasantness with OM). Instead, time elapsed since the meditation weekend emerged as the sole significant predictor: novices who participated closer to the meditation weekend reported larger state effects. Although surprising at first, further inspection revealed a potential explanation. Specifically, we have reported before that novices who enrolled in the training protocol initially showed high motivation, but that the intensity of practice linearly decreased over weeks (Abdoun et al., 2019). This may well explain the observed decline in the state effect over weeks. If indeed true, this finding has several important implications. First, it suggests that, for beginner meditators, a continuous and disciplined effort may be required to achieve sustained effects on pain regulation. Second, the finding points to the importance of taking into account sustainability of effects as initial results might be overly optimistic. Lastly, the results beg the question how much effort is required to maintain effects and whether the capacity to nonjudgementally monitor pain can become learned and effortless (as the findings on experts suggest), and if so, at which stage. These are interesting avenues for future research.

Notably, the only other studies that also reported mindfulness-related reductions in pain ratings for novices provided formal training too. Specifically, in a series of experiments by Zeidan and colleagues, meditation-naive participants underwent 4 brief 20-min sessions of meditation training in a practice that involved sustained FA on the breath (Zeidan et al., 2011, 2015, 2016), a type of practice that qualifies as FA. When used in the context of pain, this might involve components more akin to distraction, which has been linked to attentional gating mechanisms and overall pain reductions (Miron & Duncan, 1989; Sprenger et al., 2012), as was observed in these studies. The present results suggest that novices can also be successfully trained in OM meditation and that this yields a different regulatory profile characterized by sensory-affective uncoupling, consistent with earlier work with expert practitioners (Perlman et al., 2010). However, this interpretation warrants caution as this study lacked a baseline control condition, and reported results were relative to a distraction condition that in itself may have reduced pain intensity. Furthermore, in the studies by Zeidan and colleagues, mindfulness meditation also impacted the affective dimension of pain more than the sensory dimension. Nonetheless, the observed reductions in pain intensity (up to 27%–40%) in those studies seem an order of magnitude larger than what has been reported in most studies on OM meditation, suggesting that different mechanisms are at play. Future research is needed to clearly delineate the respective beneficial effects of these different meditative practices, especially in a clinical context.

Finally, we hypothesized larger state effects for long compared to short painful stimuli and for experts compared to novices, which we did not observe. For experts, this may have had several possible reasons. First, across task conditions, experts showed a trait-like tendency towards larger sensory-affective uncoupling. Hence, for experts, sensory-affective uncoupling of pain may no longer have been state-dependent, a notion supported by the relation to trait pain catastrophizing (see below). Second, an exploratory analysis suggested that for experts larger sensory-affective uncoupling cultivated during OM spilled over to the control condition and thus attenuated overall state differences. As effortlessness is said to be key feature of nondual mindfulness (i.e. OP meditation), this spill-over of sensory decoupling following meditation in experts only could be a signature of this process. Further work is needed to explore this possibility.

4.2 | Effect of meditation expertise and relation to trait characteristics

The basic premise of mindfulness practice is that the repeated cultivation of a meditative state can eventually induce desirable changes in behavioral and psychological traits (Lutz et al., 2006). In accordance with this notion, several trait-like effects related to meditation expertise were observed across both task conditions. Specifically, experts reported lower overall pain unpleasantness but not pain intensity, reduced amplification of unpleasantness by long painful stimuli, and larger sensory-affective uncoupling particularly during long painful stimuli. Supporting the idea that these group differences reflected trait effects was that experts' lower trait pain catastrophizing, compared to novices, could explain several of the effects, although not all. Hence, pain catastrophizing may not fully exhaust all mechanisms underlying expertise; this possibility will be explored through a more refined, qualitative approach in a future publication. Regardless, experts showed increased resilience to pain amplifying processes, which was partly relatable to lower trait pain catastrophizing. Contrary to our expectation, lifetime meditation experience did not predict trait pain catastrophizing. Our findings corroborate other studies that reported reduced pain catastrophizing following MBI (Turner et al., 2016), and negative relations between measures of mindfulness and pain catastrophizing (Day, Smitherman, Ward, & Thorn, 2015; Dorado et al., 2018; Elvery, Jensen, Ehde, & Day, 2017; Jensen, Thorn, Carmody, Keefe, & Burns, 2018; Schutze, Rees, Preece, & Schutze, 2010). In addition, the observed pattern of pain reduction is remarkably in line with the specific cognitive attitude cultivated by mindfulness meditation that emphasizes openness to sensory experience and deliberate disengagement from cognitive-affective appraisals. The possibility that one can open up to the sensory aspects of pain experience while simultaneously reducing emotional distress is particularly relevant in the context of chronic pain conditions. Nevertheless, more research is clearly warranted to further substantiate these findings and to examine the extendibility of these findings to clinical pain contexts.

4.3 | Limitations

This study had several limitations. First, the study built on subjective pain reports. Although more readily accepted in pain research, they are also susceptible to demand characteristics (Orne, 1962; Weber & Cook, 1972). However, we consider it unlikely that these were primarily driving results as we reported complex relations between various experimental factors and trait variables. Second, the study design did not allow to conclusively disentangle state and trait effects. An inclusion of a baseline control condition would have made it clearer whether effects observed across task conditions were state-induced or trait-like. Third, we selected participants with low pain sensitivity, which decreases the generalizability of the findings. Finally, the cross-sectional design rendered it unclear whether meditation expertise was the causal factor of lower trait pain catastrophizing in expert practitioners.

5 | CONCLUSION

This study associated mindfulness meditation with sensory-affective uncoupling of pain in trained novice and expert meditators and identified trait pain catastrophizing as a predictor of sensory-affective uncoupling. These findings help to illuminate the cognitive mechanisms of mindfulness-based pain-regulation and provide a better understanding of its relation to other pain-regulation strategies.

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CONFLICT OF INTEREST

All authors of the present paper declare no conflicting interests.

AUTHOR CONTRIBUTIONS

AL conceived the study. JZ, OA and AL were responsible for the study design. JZ executed the study and was responsible for data analysis. AL, OA and RB contributed to the data analysis and data interpretation. JZ drafted the manuscript in close collaboration with OA and AL. RB provided feedback on the manuscript. All authors have read and approved the manuscript and contributed substantially to the manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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