Cognitive defusion is a core cognitive mechanism for the sensory-affective uncoupling of pain during mindfulness meditation

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Abstract

Objective: Mindfulness meditation can downregulate the experience of pain. However, its specific underlying regulatory mechanisms are still largely unknown. Here, we aimed to investigate the role of cognitive defusion in mindfulness-based pain regulation.

Methods: We implemented a thermal heat paradigm that was designed to amplify the cognitive-affective aspects of pain experience in novice (2-day formal training; average ~20h home practice) and expert meditators (>10.000h practice). We collected pain intensity and unpleasantness reports, and trait measures of pain catastrophizing assessed by the Pain Catastrophizing Scale (PCS), cognitive defusion assessed by the Drexel Defusion Scale (DDS), and cognitive fusion assessed by the Cognitive Fusion Questionnaire (CFQ), as well as of several other constructs commonly reported in the literature.

Results: Experts reported significantly lower PCS but higher DDS than novices. Furthermore, across participants, the PCS and DDS were negatively correlated and shared unique variance that survived controlling for other mindfulness-related and other cognitive-emotional constructs. Conversely, the relationships between PCS and other constructs commonly reported in the literature did not appear specific as none of the relationships survived controlling for DDS. In further support of the relevance of DDS to pain, both the DDS and PCS specifically predicted pain unpleasantness as opposed to pain intensity. However, DDS appeared a more specific predictor of pain unpleasantness than PCS, as the relationship between DDS and unpleasantness survived controlling for PCS, but not vice versa. At a reviewer's request we further included the CFQ. While this measure behaved very similarly to DDS in relationship to

PCS and pain self-reports, it showed a less specific relationship with questionnaire measures compared to DDS.

Conclusions: Collectively, these findings highlight the central role of cognitive defusion in mindfulness-based pain regulation.

Keywords: Mindfulness meditation, cognitive defusion, pain catastrophizing, pain affect, dereification, cognitive distancing, emotion regulation, meta-awareness.

Introduction

An early Buddhist account describes pain as being composed of two distinct "arrows": an immediate physical sensation and a secondary response linked to negative mentation. It is claimed that although negative mentation often habitually follows awareness of unpleasant physical stimuli, this need not be necessarily so, as for individuals trained in mindfulness meditation it is possible to uncouple the immediate pain sensation from the affective reactivity to it, allowing the physical component to be fully experienced without concomitant emotional distress (Bodhi, 2005).

In line with early contemplative notions, pain is now generally considered a multidimensional experience comprising, sensory-discriminative, affective-motivational and cognitive-evaluative dimensions (Melzack and Casey, 1968; Tracey and Mantyh, 2007). Furthermore, the efficacy of mindfulness-based interventions (MBIs) for chronic pain management is increasingly supported by the clinical literature (Hilton et al., 2017), whereas experimental studies indicate that mindfulness meditation is indeed primarily associated with reductions in pain unpleasantness as opposed to intensity in healthy participants, as reviewed by Zeidan et al., 2019. However, the specific cognitive mechanisms underlying mindfulness-based pain regulation still remain largely debated (e.g. Zeidan et al., 2019).

It has been proposed that mindfulness meditation may reduce pain by counteracting the detrimental effects of pain catastrophizing, which refers to “an exaggerated negative 'mental set' brought to bear during actual or anticipated pain experience” (Sullivan et al., 2001), and is a key predictor of increased pain in healthy and clinical samples (Quartana et al., 2009; Sullivan et al., 2001), as well as of the maintenance and exacerbation of chronic pain (Edwards et al., 2016; Gatchel et al., 2007); making it an important clinical treatment target. Pain catastrophizing, refers to a type of conceptual processing that is reactive, judgmental and, often, implicit. This can be contrasted with the specific cognitive attitude cultivated during mindfulness meditation, which consists of a “nonelaborative, nonjudgmental, present-centered awareness” (Bishop et al., 2004). Thus, mindfulness and pain catastrophizing can be construed as antithetical constructs.

Several studies have examined statistical relations between pain catastrophizing as measured by the Pain Catastrophizing Scale (PCS) (Sullivan et al., 1995), a reference standard psychometric tool for pain catastrophizing; and mindfulness (most frequently) as measured by the Five Facet Mindfulness Questionnaire (FFMQ) (Baer et al., 2006), a popular mindfulness questionnaire that purports to measure five mindfulness dimensions: Non-Judging, Non-Reacting, Act Aware, Observing and Describing. Supporting the idea that mindfulness and pain catastrophizing are antithetical constructs, these studies have typically observed inverse correlations between the PCS and Non-Judging, Non-Reacting and Act Aware (but not Observing and Describing) FFMQ facets (Day et al., 2015, Turner et al., 2016; Schutze et al., 2010; Elvery et al., 2017). However, the specificity of these findings is questioned by one of the studies, which found that none of the significant relationships between PCS and FFMQ facets survived controlling for worry -an anxiety-related construct- thus underlining the need to control for other more general cognitive-emotional constructs when examining relations between PCS and mindfulness-related constructs (Day et al., 2015). Importantly, the non-specificity of the relationship between PCS and FFMQ facets raises the question whether there are other mindfulness-related constructs that show a more specific relationship to PCS.

The question of specificity is not only relevant to elucidating the mechanisms of mindfulness-based pain regulation, but could also inform a larger debate. Specifically, a question at the forefront of the field is whether different psychosocial treatments act by specific or common mechanisms of action (Jensen, 2011; Thorn et al., 2011). As pointed out by Day et al., 2015, addressing this question first requires a clear understanding of how the different statistical instruments used to measure relevant psychological constructs overlap before any treatment intervention. Given the centrality of pain catastrophizing to chronic pain, it would be particularly useful to identify psychological constructs that show a specific inverse relationship to –i.e. share unique variance with- pain catastrophizing, so that it can be studied how such constructs are similarly of differently affected by different treatment interventions.

Another candidate cognitive mechanism underlying mindfulness-based pain regulation -with potential cross intervention and transdiagnostic relevance- is cognitive defusion, which refers to “the ability to gain psychological distance from internal experiences such as thoughts and feelings, seeing them as mere events in the mind rather than as accurate, truth-based reflections of reality” (Forman et al. 2012). Cognitive fusion (the antithesis of defusion) refers to a mental state where one is entangled in thoughts to the extent that they are taken literal and dominate feelings and behavior (Hayes et al., 1999; 2006). With mindfulness meditation, the capacity for cognitive defusion is presumably developed through the non-reactive monitoring of experience (Lutz et al., 2015). Specifically, the sustained cultivation of a mental state that notices but does not engage in conceptual elaboration –facilitated by paying attention to present moment sensory experience- is thought to foster a change in perspective from being entangled into the contents of experience onto that experience. This allegedly enables one to become aware of the usually implicit features of one's mental life, including the thinking process itself -a process known as meta-awareness. This, in turn, allows for the recognition that thoughts are simply mental events and not the things that they seem to represent -a capacity labeled dereification or metacognitive insight. Notably, while some mindfulness accounts (e.g. Lutz et al. 2015), clearly distinguish meta-awareness and dereification as core cognitive mechanisms of mindfulness meditation, these constructs are commonly treated as identical in the psychological literature of "cognitive defusion" (Hayes, 2004) and "decentering" (e.g., Fresco et al., 2007a). Given that we aimed to test the importance of meta-awareness and dereification to (mindfulness-based) pain regulation (and well-validated measures for these constructs are lacking), we chose to focus on cognitive defusion rather than on decentering, as, to our knowledge, the former is largely limited to these dimensions, whereas the latter also includes acceptance/compassion dimensions (see Hadash et al., 2017); which, although both relevant to mindfulness meditation, are beyond the scope of the present work. Of note, cognitive defusion is not only a hypothesized action mechanism of mindfulness meditation, but also of acceptance-based therapies -from where the construct derives (Hayes et al., 1999), and of cognitive behavioral therapy (CBT), for which incidental increases in defusion-related constructs have been observed (Teasdale et al., 2001). Furthermore, changes in defusion-related constructs have already been shown to underlie therapeutic change in depression (Bieling et al., 2012), and social anxiety disorder (Hayes-Skelton and Lee, 2018). Nevertheless, the construct has received little attention in pain research, although some studies have reported positive associations between defusion-related constructs and improved pain outcomes in chronic pain patients (McCracken et al., 2013a/b, 2014).

From the perspective of cognitive defusion, pain catastrophizing is an example of a state of high cognitive fusion, where pain-related thoughts such as “It’s killing me” or “this lasts forever” appear realistic and thus provoke fear and emotional distress (McCracken et al., 2014; Hayes et al., 1999), and, consequently, pain amplification (Leeuw et al., 2007). Conversely, in a meditation-related cognitively defused state, the same thoughts or feelings may still occur, but can be perceived from a distanced perspective as mere mental events that are not necessarily accurate, making them lose their representational integrity, diffusing emotional responding and secondary elaborative processing as a result (Kabat-Zinn, 1982, Chambers et al., 2009). It has been suggested that this process might produce an uncoupling of the sensory component of pain from its affective and cognitive dimensions (Kabat-Zinn, 1982). Thus, cognitive defusion and pain catastrophizing are possibly antithetical constructs with an inverse relationship to pain experience. The present work aimed to test this hypothesis.

Previously, we reported evidence that low pain catastrophizing is a marker of mindfulness-related sensory-affective uncoupling of pain (Zorn et al. 2020). Specifically, when comparing novice (2-day formal training; average ~20h home practice) to expert meditators (>10.000h meditation training) during an acute pain task that was designed to amplify the cognitive-affective aspects of pain experience –through the implementation of (16s) long pain stimuli and the manipulation of pain anticipation, we found that experts reported significantly lower pain catastrophizing (PCS) and PCS negatively predicted sensory-affective uncoupling of pain (defined as the difference between intensity and unpleasantness ratings). Thus, participants from this experiment, and from a larger sample that did not participate in the specific pain experiment, provided an interesting sample to test our hypotheses. We collected two self-report measures of cognitive (de)fusion: the Drexel Defusion Scale (DDS; Forman et al., 2012) and the Cognitive Fusion Questionnaire (CFQ; Gillanders et al., 2014). Whereas the DDS is designed to measure defusion, the CFQ has been designed to measure cognitive fusion (Gillanders et al., 2014). As we were primarily interested in the regulatory mechanisms underlying mindfulness meditation (i.e. cognitive defusion), we chose to focus on the DDS in this work. At the request of a reviewer, we also reported CFQ in an exploratory manner.

The purpose of the current study was twofold. A first aim was to examine the relationships between pain catastrophizing as assessed by the PCS, and several mindfulness-related constructs, including: 1) the FFMQ scales, 2) the DDS, and 3) interoceptive awareness as assessed by the MAIA scale (Mehling et al., 2012). Based on previous research, we hypothesized that all included mindfulness constructs (except the Observing and Describing FFMQ scales) would be negatively correlated with the PCS. However, based on the theoretical notion that cognitive fusion (the antithesis of cognitive defusion) is at the root of what causes one to catastrophize about pain (i.e. entanglement/believing in thoughts), we expected the strongest negative overlap between PCS and DDS. For this reason, we also expected that the DDS would share unique variance with the PCS that would survive controlling for variance shared with other cognitive-emotional constructs such as anxiety, worry and depression, as well as for interoceptive awareness. A second aim was to investigate the relation of DDS and PCS to pain-related outcomes. To this end, we first examined their association with pain intensity and unpleasantness reports of novice and expert meditators collected during the acute pain task. In line with our previous report, we expected that PCS and DDS would both primarily predict pain unpleasantness as opposed to intensity, but in the opposite direction: positively and negatively respectively. We also examined the specific relationship of both constructs to pain self-reports, i.e. the unique predictive value of PCS and DDS to pain ratings, controlling for shared variance. This exploration was open-ended.

Material and Methods

Participants

Participants were recruited for the *Brain and Mindfulness* ERC-funded project, which includes a cross-sectional observational study on mindfulness meditation conducted at the Lyon Neuroscience Research Center from 2015 to 2018. Participants included novice and long-term meditation practitioners (hereafter referred to as experts), who were recruited through multiple screening stages which have been reported into detail elsewhere (see the Brain & Mindfulness Project Manual, Abdoun et al., 2018). Meditation-naive participants were recruited locally through flyers and posters in public spaces, mailing lists, Facebook, and notifications to research participants databases. Experts were recruited through networking by a long-term meditation practitioner with extensive contacts with communities in multiple Buddhist meditation centers, predominantly in France but also internationally. Inclusion criteria included: age 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 and affiliation to the social security system (mandatory for research participation in France). Pregnant and breastfeeding women were excluded. Novices were additionally required not to have significant experience with meditation or other other mind-body training techniques. Experts were required to have: a minimum of 10.000 hours of formal practice in the Kagyu or Nyingma schools of Tibetan Buddhism, ii) followed at least one traditional 3-year meditation retreat, iii) a regular daily practice in the year preceding inclusion. For experts, inclusion criteria were checked during a phone-interview by the long-term meditation practitioner in charge of expert recruitment who was extensively familiar with the meditation traditions at hand. A total of 43 novices (53.2 ± 7.0 years old, 22 females) and 27 experts (51.9 ± 8.4 years old, 12 females) were included in the present study. All participants underwent a medical check and 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).

Power analysis

We conducted a power analysis to determine the effect sizes we had the power to detect with N = 70 (the number of subjects available). This revealed that we had 80% power to detect correlation coefficients with medium effect sizes (r = .33) at α=0.05 (two-tailed). We reckoned that this was at the low end for these types of studies: correlations between PCS and relevant FFMQ-scales (Non-Reacting/Non-Judging) are usually between r = -.20 to -.35 (Day et al., 2015; Schutze et al., 2010; Elvery et al., 2017; Turner et al., 2016). However, our study differed from these other studies in that our sample of novices and experts was expected to cover an extended range of trait values compared to other more conventional samples. Such increased sample variance is associated with an increase in correlation coefficients and hence power (see methods). For this reason, and because assumptions were met (we observed an extended range of trait values by the inclusion of experts and higher correlation coefficients compared to the literature), we considered statistical power to be within acceptable levels.

Meditation practices and novice training protocol

Two broad styles of mindfulness meditation are Open Monitoring (OM) and Focused Attention (FA) meditation. Both styles are complementary and central to MBIs. Traditionally, initial FA practice is considered a prerequisite for OM (Lutz et al., 2008). FA involves the sustained focusing of attention of a selected object (e.g. the breath), non-judgmentally noticing when the mind has wandered, and redirecting attention back to the intended object. This is said to increase the capacity to detect distractions and to calm the mind. The resulting improved monitoring capacity (i.e. meta-awareness), forms the transition point to OM, which involves the non-selective and non-reactive monitoring of all present moment experience (Chambers et al., 2009; Lutz et al., 2008). The purpose of OM practices is to gain insight into cognitive-emotional patterns, including the realization that thoughts are not necessarily real, but mere mental events (i.e. dereification). It is in this sense that OM practice may promote cognitive defusion - i.e. psychological distance from thoughts and feelings, seeing them as mere mental events rather than as intrinsically real (Forman et al., 2012). Importantly, repeated meditation practice is thought to foster trait change, including in the capacity for cognitive defusion (Lutz et al., 2015). Novices were initially meditation-naïve -including when trait measures were obtained, but extensively familiarized with both practices during a meditation weekend led by an experienced meditation teacher (see Abdoun et al., 2019 for an extensive description of the training protocol). Subsequently, novices participated in the pain paradigm having, on average, ~20h of home (FA and OM) practice experience (see Zorn et al., 2020). Experts were extensively familiar with both practices, including with an advanced style of OM labeled Open Presence (OP) (Rangdrol, 2011). In this state, control-oriented elaborative processes are reduced to a minimum and a suspension of subject-object duality (non-duality) is also reportedly involved. These features are thought to further strengthen the practitioner's capacity for cognitive defusion. To summarize, the total sample could be expected to range from low to moderate (novices) to high (experts) cognitive defusion, which we considered a strength of the present work as it provided an extended range to study relationships between constructs.

Questionnaires

All participants filled a battery of self-administered questionnaires (for a complete overview, see the Brain & Mindfulness Project Manual, Abdoun et al., 2018). Novices filled the questionnaires prior to participation in the meditation weekend. Experts filled their questionnaires either during their visit or from home afterwards. Questionnaires included in the present work are listed below.

Drexel Defusion Scale (DDS)

The DDS is a 10-item questionnaire that measures one's ability to distance themselves from a variety of psychological experiences. The questionnaire starts with an extensive introduction on the concept of defusion that is intended to help respondent's understand the construct. Participants are asked to indicate the degree to which they would be able to defuse from hypothetical situations with negative thoughts or feelings on a 6-point Likert scale ranging from ‘‘not at all’’ (0) to ‘‘very much’’ (5). Higher scores indicate higher cognitive defusion. The DDS has shown good preliminary internal consistency (a = 0.83), and high convergent and divergent validity (Forman et al., 2012).

Cognitive Fusion Questionnaire (CFQ)

The CFQ is a 7-item questionnaire that measures cognitive fusion (Gillanders et al., 2014). Participants are asked to indicate to what degree statements about cognitive fusion apply to them in general on a 7-point Likert (1= Never true; 7 = Always true). Items are combined to yield a total score. The CFQ showed good internal consistency (α = .88 to .93 for different samples) and convergent and divergent validity in its initial validation (Gillanders et al., 2014).

Pain Catastrophizing Scale (PCS)

The PCS is a 13-item questionnaire that asks respondents to reflect on past painful feelings and to indicate to what degree they experienced different pain-related thoughts or feelings on a 5-point Likert-scale from 0 (not at all) to 4 (all the time). The PCS comprises three subscales of rumination, magnification and helplessness which are combined to yield a total score. Higher scores reflect higher pain catastrophizing (Sullivan et al., 1995). The PCS has been found to show excellent internal consistency (a = 0.93), concurrent and discriminant validity (Osman et al., 1997), and good test-retest reliability over a 6-week period (r = 0.75) (Sullivan et al., 1995).

Five Facet Mindfulness Questionnaire (FFMQ)

The FFMQ is a 39-item questionnaire that measures five purported mindfulness dimensions including: Observing (noticing or attending to internal/external experiences), Describing (labeling internal experiences with words), Acting with awareness (attending to present moment experience), Non-Judging (adopting a non-evaluative stance towards thoughts and feelings) and Non-Reacting (allowing thoughts and feelings to pass). Participants indicate to what degree they experience these dimensions in their daily life on a 5-point Likert-type scale ranging from 1 (never or very rarely true) to 5 (very often or always true). Scores are calculated separately for subscales, with higher scores reflecting higher mindfulness. The FFMQ facets have been found to demonstrate adequate to good internal consistency, with alpha coefficients ranging from .75 to .91 (Baer et al., 2006).

Multidimensional Assessment of Interoceptive Awareness (MAIA)

The MAIA is a 32-item questionnaire that measures different aspects of interoceptive body awareness including: Noticing, Not Distracting, Not Worrying, Attention Regulation, Emotional Awareness, Self-Regulation, Body Listening, Trusting. Responses are provided on 6-point Likert-scales that range from 0 (Never) to 5 (Always). The different subscales have adequate to excellent internal consistency (α = .66 to .87). Scales can be combined to yield a total score. Higher scores indicate higher positive interoceptive awareness (Mehling et al., 2012).

Penn-State Worry Questionnaire (PSWQ)

The PSWQ is a 16-item questionnaire that measures the propensity to worry, using Likert rating from 1 (not at all typical of me) to 5 (very typical of me). A total score can be calculated, and higher scores indicate higher trait worry (Meyer et al., 1990). The PSWQ has shown good internal consistency with alpha coefficients ranging from .88 to .95 (Startup and Erickson, 2006), and good test-retest reliability over 8-10 weeks (r= 0.92) (Meyer et al., 1990).

State-Trait Anxiety Inventory (STAI)

The STAI is a 40-item questionnaire that measures state and trait anxiety. For the purpose of the current study we only used the STAI trait scale (20-items) which asks respondents to describe how they generally feel. All items are rated on a 4-point scale, from 1 (almost never) to 4 (almost always). Higher scores indicate greater anxiety. The STAI has shown good internal consistency with alpha coefficients ranging from .86 to .95, and test-retest reliability coefficients ranged from .65 to .75 over a 2-months period (Spielberger., 1983).

Beck Depression Inventory (BDI)

The BDI is a 21-item questionnaire that measures characteristic attitudes and symptoms of depression. Each question has four scores ranging from 0 (symptom not present) to 3 (symptom very intense). A total sum score is calculated to reflect depression severity (Beck, et al., 1961). The BDI-I has shown good internal consistency with alpha coefficients of .86 and .81 for psychiatric and non-psychiatric populations respectively, and good concurrent and discriminant validity (Beck et al . 1988).

Acute pain paradigm

Inclusion

A subsample of included participants participated in an acute pain paradigm that was conducted in an fMRI-scanner (neuroimaging results will be published in a separate publication). To be eligible for this experiment, participants had to be MRI-compatible (absence of claustrophobia/internal magnetic objects). Novices were additionally required to have a pain sensitivity equal to or higher than 47 C˚: comparable to the higher pain thresholds that have been observed for experienced practitioners in previous studies (Lutz et al., 2013; Grant et al., 2011). This served to avoid the introduction of artificial group differences in neuroimaging analyses. A subset of 29 novices (13 females) and 25 experts (12 females) met the additional inclusion criteria and participated in the acute pain paradigm.

Pain calibration

The pain calibration procedure has been described in detail elsewhere (Zorn et al., 2020). Briefly, painful stimuli were provided by a TSA 2001-II thermal stimulator (Medoc Advanced Medical Systems, Haifa, Israel) with a 30 mm × 30 mm flat thermode applied to the palmar side of the left wrist. Using the method of limits (Fruhstorfer et al., 1976), all participants underwent an initial calibration procedure to determine their pain sensitivity corresponding to a subjective pain level of 7 on a scale of 0 (“no pain”) – 10 (“the worst pain imaginable’’). A second finer calibration procedure was performed to determine the optimal temperature for a 16s long heat stimulation that would be used during the experiment itself.

Experimental design

The experimental setup and behavioral results of the acute pain paradigm have been reported into detail elsewhere (Zorn et al., 2020). Briefly, the task was designed to amplify the cognitive-affective aspects of pain experience: through the implementation of long tonic-like pain stimuli, which have been suggested to better mimic chronic pain states (Racine et al., 2012), and the manipulation of pain anticipation, which may induce anxious pain anticipation (e.g. Ploghaus et al, 2001). Participants received short (8s) and long (16s) noxious thermal heat stimuli (pain level of 7) intermixed with 16s nonpainful warm control stimuli (6 degrees cooler). All stimuli were applied to the palmar side of the left wrist. During anticipation and reception of thermal stimuli, participants performed one of two task conditions: Open Monitoring meditation (OM) or a Distraction control condition (DIS) that was intended to prevent participants from cultivating a meditative stance towards pain. See Figure 1 for more details on the experimental paradigm. See Supplementary Information 1 for full task instructions.

Pain ratings

After each thermal stimulation, participants provided two self-reports using 1-9 Item Likert scales. Questions were presented randomly and included questions on pain intensity, unpleasantness (and relief, not reported here). Participants were informed that pain intensity referred to the sensory aspect of stimuli; whereas pain unpleasantness related to their affective reaction to it (i.e. how much it bothered them). Additionally, task performance was probed (OM: quality of meditation; DIS: final sum addition task) and analyzed as part of our previous report (Zorn et al., 2020), leading to the exclusion of 1 expert due to poor counting task performance. This expert was also excluded from the analyses of the associations between pain ratings and trait scores in the present work. See Supplementary Information 2 for an overview of rating scale questions and frequency of presentation.

Analysis

All statistical analyses were performed using R version 3.4.4 (R Core Team, 2017).

Correlations. We used zero-order correlations and partial correlations to explore the relationships between traits, and between traits and pain ratings. One benefit of our sample combining novices and experts is that it offers extended ranges of values on all measures, and therefore provides higher sensitivity for correlational analyses (Bland and Altman 2011). However, a limitation of such a sample is that it cannot be directly compared to the existing literature, as the extended range is expected to produce higher correlation coefficients compared to typical samples composed of either healthy or clinical participants, with more restricted ranges. In order to allow for a quantitative comparison of our results with those previously reported in the literature (notably between PCS and other trait questionnaires), we re-estimated the correlation coefficients after restricting the range of our data to typical ranges by mean-centering each group of participants. As most of the measures could be affected by age (Cassidy et al., 2012) or sex (Keogh, 2006), covariates (e.g. sex, age) were regressed out by adding them as controlling variables. Group differences on these scores were tested using Wilcoxon-Mann-Whitney tests which are more robust to violations of assumptions required by equivalent parametric tests.

Pain ratings. Pain self-reports have been analyzed in depth in a separate publication (Zorn et al., 2020), in which we showed that, across task conditions and groups, PCS negatively predicted sensory-affective uncoupling of pain specifically for long but not short trial types -in line with the idea that tonic-like pain stimuli better mimic chronic pain states (Racine et al., 2012). Given that the present work aimed to study the respective relationship of PCS and DDS to sensory and affective pain dimensions, we here chose to limit our analyses to long pain stimuli, which provided the most sensitive test. Furthermore, given that we were interested in studying the relationship between trait measures and pain experience, pain ratings were averaged across states to obtain trait-like scores for each subject, for each pain dimension (intensity and unpleasantness). Finally, to allow us to test specifically whether trait measures predicted pain intensity, unpleasantness or both - usually complicated by the high correlation between these measures, pain intensity was partialled out from the correlations between trait scores and pain unpleasantness (and vice versa).

Results

Concurrent validity of DDS and PCS

As Table 1 shows, all scales and subscales had good to excellent internal consistency as indexed by their Cronbach's alpha coefficients. In addition, Table 1 shows, for each scale and subscale, means, standard deviations and sample size for the total sample (first row), and Novice (second row) and Expert (third row) group, including a test for group differences as assessed by Wilcoxon-Mann-Whitney tests and Cohen's d standardized measure of effect size (fourth row). All group differences reached statistical significance, with experts scoring higher on mindfulness-related measures including DDS, CFQ, MAIA and FFMQ scales, but lower on measures of general negative cognitive-emotional constructs including, PCS, PSWQ, STAI and BDI compared to novices.

					FFMQ									
		PCS	DDS	CFQ	OBS	DESC	ACT	nJDG	nRCT	total	MAIA	PSWQ	STAI	BDI
All (n=70)	α	.93	.88	.92	.80	.92	.90	.86	.89	.95	.96	.92	.93	.80
	M	13.2	33.0	20.5	30.6	27.5	28.6	30.9	24.0	141.6	102.4	44.8	36.8	4.0
	SD	8.9	8.3	7.5	4.9	6.4	6.2	5.5	5.7	24.0	27.9	11.4	8.8	3.9
Novices (n=43)	M	17.2	28.9	24.0	28.7	25.4	26.4	28.8	21.2	130.4	89.0	49.6	39.5	5.1
	SD	8.5	6.6	6.7	4.6	5.6	5.8	5.4	4.5	20.3	25.6	11.4	9.0	4.3
Experts (n=27)	M	6.9	39.4	14.9	33.8	31.0	32.1	34.1	28.4	159.4	123.7	37.3	32.5	2.3
	SD	5.2	6.4	4.8	3.6	6.3	5.0	4.0	4.3	18.0	15.2	6.4	6.8	2.4
Group difference	d	1.40	1.61	1.50	1.19	0.95	1.05	1.10	1.63	1.50	1.56	1.26	0.85	0.75
	p	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.001	.003

For further analyses, data from Novice and Expert groups were combined (see methods). Pooled data showed a smooth bivariate distribution (see Supplementary Figure 1), legitimating the use of correlation coefficient as a measure of association between trait variables across the entire pool of participants. Table 2 shows correlations between PCS and other commonly associated psychological constructs after regressing out gender and age from all variables. First, we assessed correlations between PCS and other constructs (top two rows), with and without controlling for groups (see methods). As predicted, the mindfulness-related construct that showed the highest correlation with PCS was the DDS (R=-.64), which was higher than the correlation of the MAIA (R=-.55) and the different FFMQ scales (Non-Judging: R=-.45; Non-Reacting: R=-.55; the FFMQ scales typically showing the highest correlations with PCS as here). Of note, the PCS also showed moderate to strong positive correlations with other general negative cognitive-emotional constructs including PSWQ (R=.58), STAI (R=.52) and BDI (R=.47). Controlling for groups (allowing correlation coefficients to be compared with existing literature; see methods), did not fundamentally change these results, except that PCS was no longer correlated with the FFMQ facets of Observing (R=-.20) and Describing (R=-.16) (as predicted) and Acting with Awareness (R=-.13) (contrary to prediction). These findings provided initial support for our hypothesis that DDS is a core antithetical construct to PCS. As a next step, we explored the concurrent validity between DDS and PCS. Partial correlations (third row) showed that correlations between PCS and other scales were no longer significant when controlling for DDS, with the notable exception of PSWQ (worry) (.25), suggesting that relationships between PCS and other commonly associated constructs are not specific but underlain by a single construct captured by DDS. In contrast, the relationship between PCS and DDS was found to be highly specific as it survived controlling for each of the other scales (fourth row). In accord with these findings, DDS demonstrated (moderate to) high correlation (i.e. shared variance) with all other constructs (see fifth row), that was maintained when controlling for groups (bottom row). Collectively, these findings offer compelling support for the concurrent validity of DDS in relation to PCS, in line with our central hypothesis.

			FFMQ									
	DDS	CFQ	OBS	DESC	ACT	nJDG	nRCT	total	MAIA	PSWQ	STAI	BDI
$R_{PCS,\cdot}$	**-.64*****	**.59*****	**-.43*****	**-.35****	**-.35****	**-.45*****	**-.55*****	**-.51*****	**-.55*****	**.58*****	**.52*****	**.47*****
95% CI	[-.76,-.47]	[.41,.73]	[-.60,-.21]	[-.55,-.12]	[-.54,-.12]	[-.62,-.24]	[-.70,-.36]	[-.67,-.31]	[-.70,-.35]	[.39,.72]	[.31,.67]	[.26,.64]
$R_{PCS,\cdot\|group}$	**-.45*****	**.37****	-.20	-.16	-.13	**-.25***	**-.31***	**-.27***	**-.32****	**.40*****	**.39****	**.36****
95% CI	[-.62,-.23]	[.15,.57]	[-.42,.04]	[-.38,.09]	[-.36,.12]	[-.46,-.01]	[-.52,-.08]	[-.48,-.03]	[-.52,-.08]	[.17,.58]	[.17,.58]	[.13,.56]
$R_{PCS,\cdot\|DDS}$		.19	-.06	.09	.00	-.10	-.16	-.06	-.17	**.25***	.10	.19
95% CI		[-.06,.41]	[-.30,.18]	[-.16,.32]	[-.24,.24]	[-.33,.15]	[-.39,.08]	[-.29,.19]	[-.40,.07]	[.01,.46]	[-.14,.33]	[-.05,.41]
$R_{PCS,DDS\|\cdot}$		**-.35****	**-.53*****	**-.57*****	**-.57*****	**-.51*****	**-.41*****	**-.45*****	**-.42*****	**-.41*****	**-.45*****	**-.52*****
95% CI		[-.54,-.12]	[-.68,-.33]	[-.72,-.39]	[-.71,-.38]	[-.67,-.31]	[-.60,-.19]	[-.62,-.23]	[-.60,-.20]	[-.59,-.18]	[-.62,-.23]	[-.67,-.31]
$R_{DDS,\cdot}$		**-.79*****	**.60*****	**.64*****	**.54*****	**.61*****	**.73*****	**.76*****	**.71*****	**-.69*****	**-.72*****	**-.54*****
95% CI		[-.86,-.67]	[.43,.74]	[.47,.76]	[.35,.69]	[.44,.75]	[.59,.82]	[.63,.84]	[.57,.81]	[-.79,-.53]	[-.82,-.58]	[-.69,-.35]
$R_{DDS,\cdot\|group}$		**-.65*****	**.44*****	**.53*****	**.38****	**.46*****	**.56*****	**.62*****	**.54*****	**-.54*****	**-.67*****	**-.46*****
95% CI		[-.77,-.49]	[.22,.61]	[.33,.68]	[.15,.57]	[.24,.63]	[.37,.71]	[.44,.75]	[.34,.69]	[-.69,-.34]	[-.78,-.51]	[-.63,-.24]

Table 2

At a reviewers' request, analyses were repeated in an exploratory manner, exchanging DDS for CFQ -another measure of cognitive (de)-fusion; see Table 3. In doing so, we found that CFQ demonstrated a very similar pattern of correlations with other constructs compared to DDS (first two rows). This is consistent with CFQ being highly correlated with DDS in our sample (R=-.79; R=-.65 controlling for groups). Further in line with these findings, CFQ also behaved very similarly to the DDS with respect to PCS. Specifically, after controlling for CFQ, the relationships between PCS and all other constructs were strongly attenuated and only the associations with MAIA, PSWQ and the Non-Reacting facet of FFMQ remained significant (third row). In further similarity to DDS, the relationship between PCS and CFQ was robust to controlling for variance shared with each other construct (last row). However, what set the DDS and CFQ apart was that the DDS explained most of the shared variance between PCS and CFQ, while the reverse was not true (see third and fourth row of first column respectively).

	DDS	FFMQ OBS	FFMQ DESC	FFMQ ACT	FFMQ nJDG	FFMQ nRCT	FFMQ total	MAIA	PSWQ	STAI	BDI
$R_{CFQ,\cdot}$	$\mathbf{-.79}^{***}$	$\mathbf{-.66}^{***}$	$\mathbf{-.59}^{***}$	$\mathbf{-.68}^{***}$	$\mathbf{-.72}^{***}$	$\mathbf{-.66}^{***}$	$\mathbf{-.80}^{***}$	$\mathbf{-.66}^{***}$	$\mathbf{.71}^{***}$	$\mathbf{.77}^{***}$	$\mathbf{.59}^{***}$
95% CI	[-.86,-.67]	[-.78,-.50]	[-.72,-.40]	[-.79,-.52]	[-.82,-.58]	[-.77,-.49]	[-.87,-.69]	[-.78,-.50]	[.56,.81]	[.65,.85]	[.41,.73]
$R_{CFQ,\cdot\|group}$	$\mathbf{-.65}^{***}$	$\mathbf{-.52}^{***}$	$\mathbf{-.46}^{***}$	$\mathbf{-.57}^{***}$	$\mathbf{-.61}^{***}$	$\mathbf{-.44}^{***}$	$\mathbf{-.68}^{***}$	$\mathbf{-.46}^{***}$	$\mathbf{.57}^{***}$	$\mathbf{.74}^{***}$	$\mathbf{.53}^{***}$
95% CI	[-.77,-.49]	[-.68,-.32]	[-.63,-.24]	[-.71,-.38]	[-.74,-.43]	[-.62,-.22]	[-.79,-.52]	[-.63,-.24]	[.38,.71]	[.61,.83]	[.33,.68]
$R_{PCS,\cdot\|CFQ}$	$\mathbf{-.35}^{**}$	-.05	-.01	.09	-.04	$\mathbf{-.27}^{*}$	-.08	$\mathbf{-.26}^{*}$	$\mathbf{.28}^{*}$	.11	.18
95% CI	[-.54,-.12]	[-.29,.19]	[-.25,.23]	[-.16,.32]	[-.28,.20]	[-.48,-.03]	[-.32,.16]	[-.47,-.02]	[.04,.49]	[-.13,.35]	[-.06,.41]
$R_{PCS,CFQ\|\cdot}$	.19	$\mathbf{.46}^{***}$	$\mathbf{.51}^{***}$	$\mathbf{.51}^{***}$	$\mathbf{.43}^{***}$	$\mathbf{.36}^{**}$	$\mathbf{.35}^{**}$	$\mathbf{.37}^{**}$	$\mathbf{.32}^{**}$	$\mathbf{.35}^{**}$	$\mathbf{.44}^{***}$
95% CI	[-.06,.41]	[.24,.63]	[.30,.67]	[.31,.67]	[.21,.61]	[.13,.56]	[.12,.55]	[.14,.56]	[.08,.52]	[.12,.55]	[.22,.61]

Table 3

Relationship between traits (PCS, DDS) and sensory and affective pain self-reports

Next, we investigated the unique and respective roles of DDS and PCS in predicting pain-related outcomes. To this end, we assessed their respective correlation with intensity and unpleasantness ratings of novice and expert meditators collected during an acute pain task. We first re-analyzed pain self-reports for long pain stimuli only (see methods). A simple ANOVA model of subjects' average long pain ratings yielded a significant Group (Novices/Experts) x Rating Type (Intensity/Unpleasantness) interaction ($\chi 2$ (1) = 13.16, p <.001). In line with our previous report (Zorn et al., 2020), this interaction was driven by experts reporting significantly lower pain unpleasantness than novices (estimate = -1.81, 95% ci = [-2.52,-1.05], t(59) = -5.1, p < .0001), whereas pain intensity reports did not differ between groups (estimate = -0.70, 95% ci = [-1.42,0.02], t(59) = -1.9, p = .057). We then tested our hypothesis that PCS and DDS would both primarily predict pain unpleasantness as opposed to pain intensity but in opposite direction. Pooled data again followed a smooth bivariate distribution (see Supplementary Figure 2). Results for the respective relationship of DDS and PCS to pain outcomes are displayed in

Figure 1. As predicted, pain intensity was not significantly correlated with neither DDS (R=.21, 95% CI [-.06 .45], p>.13) nor PCS (R=-.18, 95% CI [-.43 .09], p>.19) (upper left plot, controlled for pain unpleasantness). By contrast, pain unpleasantness was significantly negatively correlated with DDS (R=.-55, 95% CI [-.71 -.32], p<.0001), and positively with PCS (R=.49, 95% CI [.25 .67], p<.001) (upper right plot; values outside brackets, controlled for pain intensity). Further assessing the specificity of these relationships, we found that the relationship between DDS and unpleasantness survived controlling for PCS (R=.-33, 95% CI [-.55 -.06], p=.016), whereas the relationship between PCS and unpleasantness, was not significant when controlling for DDS (R=.20, 95% CI [-.08 .45], p>.16) (upper right plot; values between brackets). Taken together, these findings suggest that PCS and DDS indeed both specifically predict pain unpleasantness as opposed to pain intensity, but in the opposite direction, positively and negatively respectively, and that DDS is a more specific predictor of pain unpleasantness than PCS.

At a reviewers' request, analyses were again repeated in an exploratory manner, exchanging DDS for CFQ (see Figure 1). Like DDS, CFQ was not significantly correlated with pain intensity (R=-.09, 95% CI [-.35 .18], p>.51) (lower left plot, controlling for pain unpleasantness). In further similarity to DDS, CFQ was significantly correlated with pain unpleasantness (R=.46, 95% CI [.22 .65], p<.001) (lower right plot; values outside brackets, controlling for pain intensity). However, the CFQ differed from the DDS in that its relationship with the unpleasantness did not appear specific as it did not survive controlling for PCS (R=.-24, 95% CI [-.04 .48], p>.09), while, conversely, the relationship between PCS and unpleasantness did survive controlling for CFQ (R=.30, 95% CI [.03 .53], p=.033) (lower right plot; values between brackets).

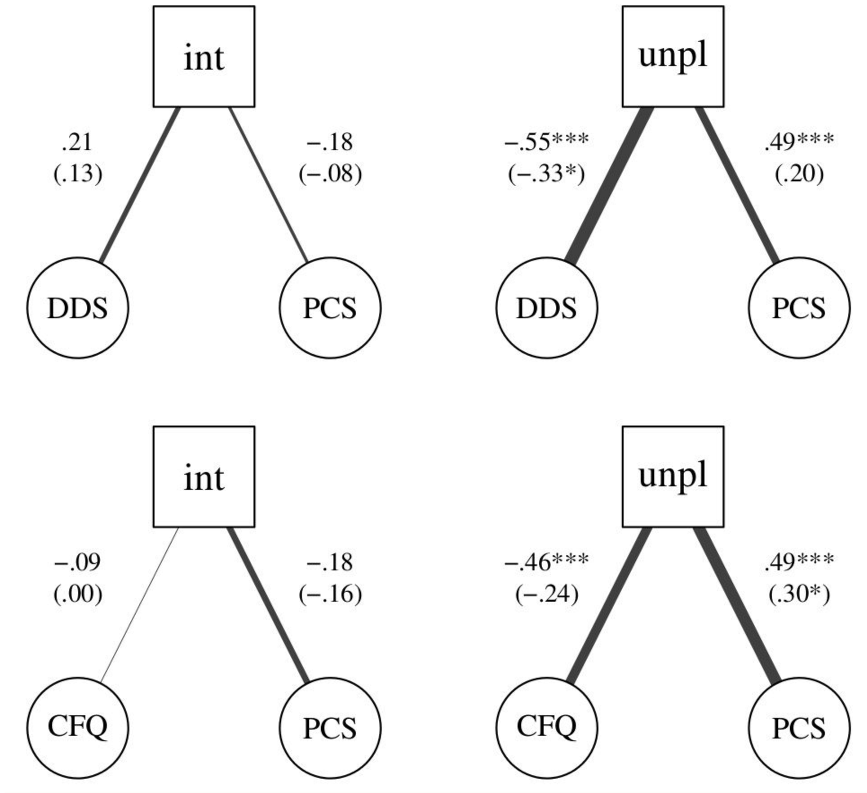

Figure 1

Discussion

This study built on previous work in which we presented preliminary evidence that lower trait pain catastrophizing (PCS) is an important marker of mindfulness-based sensory-affective uncoupling of pain experience. Using the same sample of novice (~20h of practice) and expert meditators (>10.000h of experience), we here aimed to explore the regulatory cognitive mechanisms of mindfulness meditation underlying such effects: testing the hypothesis that cognitive defusion, as measured by the DDS, is a core cognitive mechanism underlying mindfulness-based pain regulation with a unique and specific inverse relationship to PCS and an opposite relation to (affective) pain experience. At reviewer's request, analyses were repeated, substituting DDS for CFQ, another measure of cognitive (de-)fusion.

As predicted, the DDS emerged as a core antithetical construct to PCS. Specifically, we found that DDS and PCS were negatively correlated and shared unique variance that survived controlling for other mindfulness-related constructs, including FFMQ facets and interoceptive awareness (MAIA), and common negative-affective cognitive-emotional constructs, including anxiety (STAI), depression (BDI), and worry (PSWQ). Conversely, the relationships between PCS and other constructs, with the exception of the PSWQ (but including Non-Judging/Non-Reacting FFMQ facets), were no longer significant when controlling for DDS: questioning the specificity of these relationships to PCS. The CFQ, designed to measure cognitive fusion, behaved very similarly to DDS: also strongly attenuating the relationship between PCS and other constructs and showing a specific relationship to PCS that survived controlling for the other constructs. However, the relationship between DDS and PCS survived controlling for CFQ, but not vice versa, suggesting that DDS in particular captured variance unique to PCS. The significance of DDS to pain was further supported by the finding that DDS was a more specific predictor of pain unpleasantness than PCS. This was not the case for CFQ, again suggesting that DDS was the more relevant construct in relation to pain. The significance of these findings will be discussed further below.

Firstly, the results supported the hypothesis that cognitive defusion is a core cognitive mechanism of mindfulness-based pain regulation. Experts reported markedly higher DDS than novices, the DDS showed a specific negative association with PCS across participants, and, like the PCS, the DDS specifically predicted pain unpleasantness as opposed to pain intensity, but positively and negatively respectively. Hence, the results offer compelling preliminary evidence that cognitive defusion (DDS) is an important psychological process underlying the positive pain regulatory effects of mindfulness meditation (i.e., sensory-affective uncoupling of pain). It is noteworthy that DDS appeared as a more specific predictor of pain unpleasantness than PCS (which was reduced to non-significance after controlling for DDS). This is remarkable, given that the PCS is widely regarded as one of the most potent predictors of increased pain (e.g. Keefe et al., 2004; Gatchel et al., 2007). Nevertheless, replication in longitudinal studies and other samples, including clinical populations, is warranted before any conclusive results can be drawn.

Secondly, we included both the DDS (Forman et al., 2012), designed to measure cognitive defusion, and the CFQ (Gillanders et al., 2014), designed to measure cognitive fusion, which allowed a respective comparison of these constructs. Both measures are fairly recent and lack extensive validation. However, two recent reports performing factor analyses on decentering/defusion-related constructs (Naragon et al., 2017; Hadash et al., 2017), are reassuring concerning their construct validity. Briefly, both studies found very similar two-factor solutions, where the DDS largely mapped onto the first factor and the CFQ largely onto the second. Both studies interpreted the first factor as reflecting disidentification from internal experience and the second factor as reflecting (reduced) automatic reactivity to thought content. Both studies also observed similar expected divergent associations with criterion variables. Specifically, the first factor (intentional disidentification from internal experience) was primarily associated with FFMQ Non-Reactivity, whereas the second factor (reduced) (automatic reactivity to thought content) was primarily associated with measures of negative thinking, including worry, rumination, anxiety and depression symptoms. Collectively, these studies suggest that DDS reflects disidentification with experience and the CFQ automatic reactivity

(Hadash et al., 2017). In further support of this interpretation, the first factor (DDS) but not second factor (CFQ) predicted self-reported disidentification during a meta-awareness with disidentification manipulation in one of the studies (Hadash et al., 2017). In line with this earlier work, we found largely similar association patterns, with DDS showing strongest associations with FFMQ Non-Reactivity, and the CFQ (mildly) stronger associations with indices of emotional reactivity (anxiety and depression). Interestingly, our results, additionally, suggest that the DDS (but not CFQ) has incremental predictive power in predicting PCS over FFMQ Non-Reactivity, as the relationship between DDS and PCS survived controlling for the latter but not vice versa. The FFMQ Non-Reactivity scale specifically measures non-reactive observation of inner experience (Baer et al., 2006). Therefore, one interesting possibility is that the incremental validity of DDS (to FFMQ-Non-Reactivity) reflects disidentification with experience (rather than mere non-reactivity). This would be in line with some mindfulness accounts (Lutz et al., 2015) hypothesizing that dereification (i.e. not taking thoughts to be real) together with meta-awareness are critical aspects underlying the beneficial effects of mindfulness-meditation, such as non-reactivity or equanimity, on emotion regulation. Future research, ideally aided by the development of psychometric scales measuring dereification/disidentification with experience, is required to further investigate this interesting possibility. This research should also include an effort to develop a measure of cognitive defusion in expert meditators in non-dual mindfulness as the ones studied in the present study. According to them, cognitive defusion is a capacity which can apply not only to the contents of experience (thoughts, emotions, bodily sensations), as measured by the DDS, but also to subjective features such as the sense of being a permanent self, or the duality subject and object (Dunne et al. 2011). One noteworthy observation is that the CFQ and DDS were highly correlated in the present work (-.65; controlling for groups), but not in previous work (0.07 to 0.28) (Naragon et al., 2017;

Hadash et al., 2017). The reason for this difference is unclear. However, we included a sample that was highly familiar with the concept of cognitive defusion (experts) and a sample interested in the subject of meditation (novices), as opposed to more regular healthy or clinical samples in other studies, which might have influenced these results. More research in diverse samples could potentially clarify this issue.

Thirdly, our findings inform a larger literature interested in identifying antithetical constructs to PCS. Most such studies to date have explored relationships between PCS and FFMQ facets in clinical (Day et al., 2015, Turner et al., 2016; Schutze et al., 2010), and healthy samples (Elvery et al., 2017). Although these studies all found that PCS correlated negatively with Non-Judging/Non-Reacting FFMQ facets in particular, one of the studies also found that these were no longer significantly related to PCS when controlling for worry as assessed by the PSWQ (Day et al., 2015). According to the authors of that study this finding might be explained by the fact that many of the FFMQ facets have content that appear related to anxiety, worry, or negative affectivity. Such lack of sufficient divergent validity is congruent with a high degree of correspondence reported between mindfulness scores, on the one hand, and stress (Goldberg et al., 2014; Stanley et al., 2011), and personality factors (Siegling and Petrides, 2014), on the other. And could as well explain other counterintuitive results in the literature, for instance, Non-Reactivity being associated with a stronger association between pain intensity and pain catastrophizing (Jensen et al., 2018), and Non-Judging and Acting with Awareness with amplified negative effects of catastrophizing (Dorado et al., 2018). Our finding suggests that the relationship between DDS and PCS is a more specific one, as was expected based on our, and others (Kabat-Zinn, 1982; McCracken et al., 2013a), theorizing that cognitive defusion, or rather the lack thereof, is a construct at the root of what causes one to catastrophize about pain: namely being entangled in thoughts and consequently taking thoughts to be phenomenologically real instead of mere mental events that do not necessarily need to be reacted upon.

Fourthly, our findings contribute to a larger discussion on whether different effective psychosocial treatment interventions act by distinct or common cognitive mechanisms of action. Illuminating this question first entails achieving a better insight into the specific mechanisms underlying different treatment effects (Jensen, 2011; Thorn et al., 2011). Our finding that the DDS is a specific antithetical construct to PCS that might underlie mindfulness-based pain regulation is particularly interesting in this light, because defusion/decentering-related constructs have been hypothesized to be transdiagnostic therapeutic mechanisms of change that are shared across different psychosocial treatment interventions (e.g. Mennin et al., 2013; Bernstein et al., 2015). In line with this idea, Baquedano et al. found that, compared to self-immersion, a cognitive defusion stance reduces food-related salivation and automatic food bias (Papies et al., 2012; Baquedano et al, 2017). Segal and colleagues showed that the posttreatment growth of mindfulness-related regulatory capacity decreases depression relapse, and that this growth was mediated specifically by the capacity to develop the skill to decenter thoughts, a construct overlapping with cognitive defusion (Farb et al., 2018). In this special issue, Barnhofer et al, further reported that a MBI compared to psycho-education and rest specifically increased decentering, decreased brooding and decreased symptoms in depressed patients and that these changes were correlated to a reduced dorsolateral prefrontal cortex activation during an implicit emotion regulation (Barnhofer et al. in press). Similar, results have been observed with other treatment interventions including CBT (Teasdale, 2001; Fresco et al., 2007b). Our results suggest that these effects extend to the context of pain regulation, which is congruent with the fact that cognitive defusion, by its very definition, is a construct relevant to emotion regulation in general. That is, the construct of defusion focuses on a cognitive process rather than on cognitive content, and thus all emotional disorders where maladaptive cognitive schema are central (irrespective of their content) should be amenable to positive change by the promotion of cognitive defusion.

Limitations

This study had several limitations. First, the very specific sample under study, including healthy novice and expert meditators, warrants more research into the transferability of findings to the clinical domain. Second, the cross-sectional nature of the study did not allow for causality attributions, which requires future longitudinal work. Third, the study built on self-reports, which although readily accepted in pain research, are also susceptible to demand characteristics (Orne, 1962; Weber and Cook, 1972). However, we consider it unlikely that these were primarily driving the results, given that the main interest of this work was the specificity of effects which is less likely to be influenced by this type of effect. Fourth, novices engaged in a meditation intervention in between the collection of trait self reports and pain self-reports, which posed a potential confound. However, given the brevity of the intervention (~20h), we consider it unlikely that this unduly influenced results (see also previous point). A last limitation arose from the DDS, which includes an extensive introduction on the concept of cognitive defusion, which might induce desirable responding and asks respondents to indicate to what degree they would be able to defuse from hypothetical vignettes, which might cause overlap with (estimated) self-efficacy (e.g. Gillanders et al., 2014). Future work should assess whether these concerns are justified.

Conclusion

This study shows that cognitive defusion specifically and negatively correlated with pain catastrophizing and has an inverse and positive relationship to sensory-affective uncoupling of pain. Overall, these findings highlight the central role of cognitive defusion as a positive regulatory mechanism of mindfulness-related pain regulation. These findings are promising to the clinical domain and warrant more research on this interesting construct.

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Table and Figure captions

Table 1. Summary data for psychometric scales.

The first line displays Cronbach's alpha coefficients (α) for each scale and subscale. Further displayed for each scale and subscale are means, standard deviations and sample sizes for all participants (first row), Novices (second row) and Experts (third row), including a test for group differences as assessed by Wilcoxon-Mann-Whitney tests and Cohen's d standardized measure of effect size (fourth row). *Pain Catastrophizing Scale, DDS: Drexel Defusion Scale, CFQ: Cognitive Fusion Questionnaire, FFMQ: Five Facet Mindfulness Questionnaire (subscales: OBS: Observing, DESC: Describing, ACT: Acting with Awareness, nJDG: Non-Judging, nRCT: Non-Reacting), MAIA: Multidimensional Assessment Interoceptive Awareness, PSWQ:*

Penn-State Worry Questionnaire, STAI: State-Trait Anxiety Inventory, BDI: Beck Depression Inventory.

Table 2. Correlations between pain catastrophizing and commonly associated psychological constructs and zero-order and partial correlations DDS.

The top two rows display zero-order correlations between PCS and other scales (controlling and not controlling for groups). Subsequently displayed are partial correlations between PCS and each other scale, controlling for DDS (third row), and between PCS and DDS controlling for each other scale (fourth row). The bottom two rows display zero-order correlations between DDS and other scales (controlling and not controlling for groups). Gender and age were regressed out from all variables. *PCS: Pain Catastrophizing Scale, DDS: Drexel Defusion Scale, CFQ: Cognitive Fusion Questionnaire, FFMQ: Five Facet Mindfulness Questionnaire (subscales: OBS: observe, DESC: describe, ACT: act with awareness, nJDG: non-judgment, nRCT: non-reactivity), MAIA: Multidimensional Assessment of Interoceptive Awareness, PSWQ: Penn-State Worry Questionnaire, STAI: State-Trait Anxiety Inventory, BDI: Beck Depression Inventory. Significance values: *: p<.05, **: p<.01, ***: p<.001.*

Table 3. Zero-order and partial correlations CFQ.

The top two rows display zero-order correlations between DDS and other scales (controlling and not controlling for groups). Subsequently displayed are partial correlations between PCS and each other scale, controlling for CFQ (third row), and between PCS and CFQ controlling for other scales (fourth row). Gender and age were regressed out from all variables. *PCS: Pain Catastrophizing Scale, DDS: Drexel Defusion Scale, CFQ: Cognitive Fusion Questionnaire, FFMQ: Five Facet Mindfulness Questionnaire (subscales: OBS: observe, DESC: describe, ACT:*

*act with awareness, nJDG: non-judgment, nRCT: non-reactivity), MAIA: Multidimensional Assessment of Interoceptive Awareness, PSWQ: Penn-State Worry Questionnaire, STAI: State-Trait Anxiety Inventory, BDI: Beck Depression Inventory. Significance values: *: p<.05, **: p<.01, ***: p<.001.*

Figure 1. Schematic illustration of the experimental paradigm.

Each trial started with a 5-8 sec introductory period. A 2s veridical visual cue then appeared that indicated whether the temperature of the upcoming stimulation would be nonpainful warm (image of radiating heat) or painful hot (image of burning flames), followed by a 5-8 s anticipation period before stimulus onset. A thermal stimulation (to the palmar side of the left wrist) was then delivered. A second visual cue (3-6 s after stimulus onset) informed participants about whether the unfolding stimulation would be short (8 s) or long (16 s) (and served a psychological relief manipulation not reported here). Nonpainful warm stimuli were always long and provided a baseline control condition for the MRI. Following stimulus offset, a 5-8 s rest period preceded the presentation of two rating scales (5 s each) (see main text for rating types). During each trial, a simple single-digit number (1-3) was presented every 2 s from the start of the trial until rating scales were displayed (see black horizontal bars). Subjects randomly alternated between two task conditions: Distraction, involving the mental addition of the numbers and a blocking of all pain experience or OM involving the cultivation of an open attitude to pain (and no mental addition). Participants received a total of 10 thermal stimuli for each combination of trial type (Short Hot; Long Hot; Long Warm) by task condition (OM; Distraction); 60 thermal stimuli in total. ITI: intertrial interval (adapted from Zorn et al. 2020).

Figure 2. Relationships between trait and pain self-reports.

The top two plots display the relationships of DDS and PCS (circles) to pain ratings (squares) of pain intensity (controlled for pain unpleasantness) (left) and pain unpleasantness (controlled for pain intensity) (right). Values outside brackets zero-order correlation coefficients and values inside brackets are partial correlation coefficients (controlled for the respective other trait construct). Line widths are proportional to the corresponding partial correlation coefficients. The bottom two plots display the equivalent results for CFQ. *int: pain intensity, unpl: pain unpleasantness, PCS: Pain Catastrophizing Scale, DDS: Drexel Defusion Scale. Significance values: *: p<.05, **: p<.01, ***: p<.001.*

Supplementary Figure 1. Distribution of trait self-reports in relation to PCS.

Pooled data showed a smooth bivariate distribution across Novices and Experts. *PCS: Pain Catastrophizing Scale, DDS: Drexel Defusion Scale, Cognitive Fusion Questionnaire, FFMQ: Five Facet Mindfulness Questionnaire (subscales: OBS: observe, DESC: describe, ACT: act with awareness, nJDG: non-judgment, nRCT: non-reactivity), MAIA: Multidimensional Assessment of Interoceptive Awareness, PSWQ: Penn-State Worry Questionnaire, STAI: State-Trait Anxiety Inventory, BDI: Beck Depression Inventory.*

Supplementary Figure 2. Distribution of trait-self reports in relation to pain ratings.

Pooled data showed a smooth bivariate distribution across Novices and Experts. *PCS: Pain Catastrophizing Scale, DDS: Drexel Defusion Scale, CFQ: Cognitive Fusion Questionnaire.*

Supplementary material

Supplementary Information 1

Written instructions

Distraction condition: Concentrate your mind on the numbers and visual cues on the screen. Whenever a new number appears, mentally add it to the total sum of the previous number(s). You should focus your attention only on the numbers and the cues. Block all other emotions, sensations, or thoughts that may arise during the calculation task. Be very focused so that you don't miss any number or cue.

OM condition: Start to anchor your attention in your body. Simply rest your body. Relax your muscles. Rest your mind without blocking anything. Allow everything to arise in the field of awareness as it is in the present moment. The body and the mind rest in unity. Gently watch the numbers and the cues appear on the screen. Pay attention to cues, while not doing anything in particular with the numbers. When the thermal stimulus arises, gently let it be a support for your attention. You know that you are feeling the sensation; you recognize it, while resting the mind on this support. While resting your attention on the thermal sensation, thoughts, or emotions may arise. Just let them be in the vast field of your awareness while remaining at ease in the present moment.

Auditory instructions

Distraction condition: Concentrate your mind on the number and the visual cues on the screen. You should focus your attention completely on the screen and the counting task. Block all the emotions, sensations and thought that arise during this task. Be very concentrated so that you don’t miss any number or visual cue.

OM condition: Relax your body and your mind, there is no need to block anything. When the heat stimulation starts, gently be aware of it. Be aware of your experience of this sensation and let your mind relax with it. When any thoughts or emotions arise, let them be there in the vast space of your awareness.

Supplementary Information 2

Different self-report questions:

'Intensity: How hot was the stimulation?'

Labels: 1 = Not at all, 9: Extremely hot

'Unpleasantness: How much did the stimulation bother you?'

Labels: 1 = Not at all, 9: Extremely

'Relief': How relieved where you by the end of the stimulation?'

Labels: 1 = Not at all, 9: Extremely

'Meditation Instruction': To what degree where you able to follow the instruction?'

Labels: 1 = Not at all, 9: Completely

'Addition': What is the total sum of the numbers that were presented?'

5 different two digit-numbers were presented, one of which was the correct answer.

Presentation frequency:

OM condition:		
10 x Warm Long	**10 x Hot Long**	**10 x Short Long**
6 x Unpleasantness	6 x Unpleasantness	6 x Unpleasantness
6 x Relief	6 x Relief	6 x Relief
4 x Intensity	4 x Intensity	4 x Intensity
4 x Meditation	4 x Meditation	4 x Meditation

Distraction condition:		
10 x Warm Long	**10 x Hot Long**	**10 x Short Long**
6 x Unpleasantness	6 x Unpleasantness	6 x Unpleasantness
6 x Relief	6 x Relief	6 x Relief
4 x Intensity	4 x Intensity	4 x Intensity
4 x Addition	4 x Addition	4 x Addition

Supplementary Figure 1

Supplementary Figure 2

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