General versus pain-specific cognitions: Pain catastrophizing but not optimism influences conditioned pain modulation

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Significance: Conditioned pain modulation is not the underlying mechanism of the pain-

alleviating effects of induced optimism. However, pain-specific cognitions including pain

catastrophizing and pain expectations affect endogenous pain modulation which should be

taken into account in treatment and CPM research.

Abstract

Background: Previous studies found evidence that dispositional optimism is related to lower pain sensitivity. Recent findings suggest that temporarily increasing optimism by means of imagining a positive future may also have pain-alleviating effects.

Objectives: The present experiment was designed to investigate conditioned pain modulation (CPM) as a potential underlying mechanism of this pain-alleviating effect of induced optimism.

Methods: For this purpose, 45 healthy participants were randomized into an optimistic or neutral imagery condition. Additionally, participants completed questionnaires on dispositional optimism, pain catastrophizing and pain expectations. CPM was assessed by delivering a series of five heat pain stimuli on the non-dominant hand before and during immersion of the dominant hand in water of 5C° for 70 seconds.

Results: A clear CPM effect was found, i.e. heat pain reports were lower during simultaneous cold water stimulation. Although the optimism manipulation successfully increased optimism, it did not affect pain ratings or CPM. Post-hoc analyses indicated that dispositional optimism was not associated with the magnitude of CPM, but pain catastrophizing and pain expectations did significantly correlate with the CPM effect.

Conclusion: Pain-specific but not general cognitions appear to influence endogenous pain modulation.

Keywords: conditioned pain modulation, optimism, pain catastrophizing, expectancies

Dispositional optimism, defined as global expectations that everything will turn out well, was found to be associated with lower pain sensitivity and better adaptation to acute and chronic pain (Geers, Wellman, Helfer, Fowler and France, 2008; Wright et al., 2011; Hanssen, Vancleef, Vlaeyen and Peters, 2014; Sobol- Kwapinska, Bąbel, Plotek and Stelcer, 2016). Even though optimism is considered a trait-like characteristic that is relatively stable over time (Scheier and Carver, 1985), optimism can be temporarily increased by means of positive imagery (Peters, Flink, Boersma and Linton, 2010). Previous studies demonstrated that inducing optimism through imagery led to lower pain intensity ratings during the cold pressor test (Hanssen, Peters, Vlaeyen, Meevissen and Vancleef, 2013) and counteracted the negative effects of pain on executive functioning (Boselie, Vancleef, Smeets and Peters, 2014; Boselie, Vancleef and Peters, 2017) and well-being (Boselie, Vancleef and Peters, 2018). These studies suggest that optimism may be causally related to lower pain sensitivity.

One mechanism by which optimism could affect pain sensitivity is through top-down modulation of subcortical and spinal nociceptive input, i.e. by activating descending pain inhibitory pathways. Conditioned pain modulation (CPM), or the "pain-inhibits-pain" phenomenon is frequently used as a measure of the inhibitory capacity of an individual's endogenous pain modulation system (Kennedy, Kemp, Ridout, Yarnitsky and Rice, 2016). Within the CPM paradigm, two nociceptive stimuli are applied simultaneously to different body parts. The more intense and/or longer lasting (conditioning) stimulus usually reduces the perceptual intensity of the other (test) stimulus. The magnitude of this reduction is assumed to reflect the efficacy of an individual's endogenous pain inhibiting system.

To our knowledge, only one study has examined the association between optimism and CPM, and found that higher optimism was related to enhanced CPM (Goodin et al., 2013). The role of specific, pain-related, expectations has been studied more often for their effect on CPM (Goffaux, Redmond, Rainville and Marchand, 2007; Bjørkedal and Flaten, 2012; Cormier, Piché and Rainville, 2013). Expecting pain relief during application of the conditioning stimulus increases CPM, whereas expecting hyperalgesia decreases CPM. It can be speculated that optimists hold more benign pain-specific expectations and expect lower levels of pain and/or more pain relief through the conditioning stimulus. Moreover, optimists show less pain catastrophizing (Sinclair, 2001; Bargiel-Matusiewicz and Krzyszkowska, 2009; Hanssen et al., 2013) and CPM seems to be lower in high pain catastrophizers (Rhudy, Maynard and Russell, 2007; Weissman-Fogel, Sprecher and Pud, 2008; Goodin et al., 2009). Thus, both pain expectations and pain catastrophizing could mediate the effects of optimism on CPM.

The present study aimed at examining whether enhanced CPM could explain the effect of optimism on pain. Following previous studies, we induced a temporary optimistic state by having participants imagine a positive future. CPM was compared between participants in the optimistic imagery condition and a neutral imagery condition. We hypothesized that participants in the optimism condition would show a more prominent CPM effect compared to participants in the control condition. We further hypothesized that the effect of optimism on CPM would be mediated by more benign pain expectations and/or by lower levels of pain catastrophizing.

Methods

Participants

A power calculation was performed based on the primary hypothesis of reduced pain ratings during CPM compared to baseline. Assuming a medium effect size (f = 0.25) and a correlation of .5 between the pre and post-assessment, to obtain a power of .90 with $\alpha = 0.05$ a total of 46 participants were needed. Participants were recruited through posters at Maastricht University, and through online participant platforms. Inclusion criteria were proficiency of the Dutch language and age between 18 and 35 years. People were not eligible if they had prior experience with the imagery exercises or the cold pressor test, or if they were suffering from any chronic or acute pain syndrome, cardiovascular disease or the Raynaud syndrome. Informed consent was obtained from each participant at the beginning of the experiment. Participation was rewarded with course credit or a gift voucher to the value of €7.50.

The final sample consisted of 45 students (40 females) from Maastricht University aged 18 to 26 years (M = 21.6, SD = 2.1).

Pain Stimulation

A Thermo-Sensory Analyzer (TSA; Medoc Advanced Medical Systems, Durham, NC) was used for applying contact heat. A 30 x 30 mm Peltier thermode was attached to the ventral forearm of participants' non-dominant hand. Heat pain thresholds were determined with the "Limits"-program of the TSA software in which the temperature of the thermode rises steadily from 36°C with the speed of 1°C per second. Participants were instructed to click on a mouse as soon as the stimulus was considered painful. This was repeated seven times. The temperature of the last five trials was averaged to calculate the pain threshold. For

the test stimulus, the individual pain threshold was increased by 3°C with a maximum temperature of 51°C. The "Ramp and Hold" program was used to apply the test stimuli. Starting at 36°C, temperature increased with 6°C/sec to reach the individual maximum temperature, which was presented for 1 sec, and then decreased again by 10°C/sec to 36°C. Five stimuli were given with a variable interstimulus interval of 5 − 7 sec. The Cold Pressor Test (CPT) served as the conditioning stimulus. Participants submerged their dominant hand in a water bath that was maintained at a constant temperature of 5°C. A Plexiglas tank of 36 x 30 x 15 cm (W x L x D) with an open heating bath circulator and an immersion cooler were used (Julabo ED-19A; Julabo Seelbach, Germany). A plastic tank containing water at 22°C was positioned next to the Plexiglas tank and served to standardize pre-stimulation temperature of participants' hands (immersion of 1 minute).

Optimism Manipulation

Participants were randomly assigned to the optimism or control condition following a computerized randomization procedure. Participants in the experimental condition were instructed to think and write about a future in which everything went well and all their dreams would be fulfilled. After writing for 15 minutes, they visualized this future as vividly as possible for another 5 min. This so called "best possible self" (BPS) exercise has repeatedly been shown to temporarily increase optimism (Peters et al., 2010; Hanssen et al., 2013; Boselie et al., 2014). In the control condition, participants wrote and visualized a typical day (TD) according to the same procedure.

Measures

Pain Catastrophizing Scale (PCS). The PCS is a 13-item questionnaire that measures catastrophic thoughts and feelings about pain (Sullivan, Bishop and Pivik, 1995). Participants indicate on a 5-point Likert scale ranging from 0 = not at all to 4 = always to what extent

statements, such as "I become afraid that the pain may get worse", apply to them. Higher scores reflect more catastrophic thinking. The psychometric properties of this instrument are good, with high internal consistency (α = .92) and moderate test-retest stability (.73) (Lamé, Peters, Kessels, Van Kleef and Patijn, 2008). Internal consistency in the present study was α = .89. In addition to the standard trait version of the PCS questionnaire, a situational version of the PCS (S-PCS) was used (Campbell et al., 2010). The instructions of the PCS were adjusted in such a way that all items referred to the experience of the experimental pain stimuli. In the present study, the internal consistency was high (α = .95).

Life-Orientation Test (LOT-R). Baseline levels of optimism were assessed by means of the LOT-R (Scheier, Carver and Bridges, 1994). The questionnaire contains three positive and three negative statements (e.g. "If something can go wrong for me, it will") and four filler items that are rated on a 5-point Likert scale with the anchors 1 (*strongly disagree*) to 5 (*strongly agree*). High scores indicate higher levels of optimism. The psychometric properties of the LOT-R have been found to be satisfactory and suitable for measuring dispositional optimism in healthy individuals (Glaesmer et al., 2012). In the present study, the Cronbach's alpha for the total scale was .74 indicating a satisfactory internal consistency.

Future Expectations (FEX). The FEX (Hanssen et al., 2013) assesses expectations for 10 positive and 10 negative future outcomes such as 'You will have health problems', 'People

will find you dull and boring' or 'You will get a lot of satisfaction out of life' tapping into five domains (general, health, personal, professional, social). This measure was used as a manipulation check of the optimism manipulation as previous studies found the optimism

induction to increase state optimism (Hanssen et al., 2013; Boselie et al., 2014; Boselie et al., 2017). Participants rated the likelihood of these outcomes on 7-point Likert scales ranging from 1 = not likely at all to occur to 7 = extremely likely to occur, resulting in two total scores, one for the positive and one for the negative statements. In the present study, Cronbach's α was .84 for the positive subscale and .83 for the negative subscale.

Positive and Negative Affect Schedule (PANAS). The PANAS is a self-report measure assessing positive and negative affect (Watson, Clark and Tellegen, 1988). Participants indicate on a 5-point Likert scale (1 = not at all, 5 = very much) to what extent the 20 words (e.g. inspired, restless, guilty) describe their current emotional state. It has good convergent and discriminant validity (Crawford and Henry, 2004) and both scales had a high internal consistency in the present study (positive affect: α = .84; negative affect: α = .85). Previous studies found the BPS manipulation to also increase positive affect (Sheldon and Lyubomirsky, 2006; Hanssen et al., 2013; Boselie et al., 2014; Boselie et al., 2017) and therefore the PANAS was used as a second manipulation check in this study.

Expected and experienced pain intensity ratings. Before each pain induction, participants completed a visual analogue scale (VAS) asking "*How painful do you expect the heat/cold stimulus to be?*" (0 = no pain at all to 100 = extreme pain). After each pain induction the actual experienced pain intensity was measured with the same VAS. In addition, before CPM expected pain change was assessed using the following question: "*Do you think that the perception of the heat stimulus changes when the other hand is immersed in the cold water? Please express your expectation as + x percent (for increased pain intensity) or – x percent (for decreased pain intensity) or 0 (for no change of pain intensity).*"

Quality of writing and imagery. In order to check for possible qualitative differences between the BPS and TD exercises, participants were asked to answer the following two questions on VAS scales ranging from 0 to 100: "How well could you imagine yourself in the situation you described in your writing?" (not at all–extremely well) and "How vivid were the pictures you imagined?" (not vivid at all–very vivid).

Procedure

An overview of the procedure is presented in Figure 1. Participants were told that they would participate in a study on the effects of visualization on their thoughts and feelings while experiencing hot and cold nociceptive stimuli. Upon arrival at the laboratory, participants signed an informed consent form. First, the heat pain threshold was determined. Next, five trials of the test stimulus (threshold + 3°C) were given. Participants rated expected painfulness once before the five trials and experienced pain after each trial on a VAS. Subsequently, participants filled out the LOT-R, PCS, FEX, and PANAS on a computer after which they completed either the BPS or TD writing and imagery assignment. The FEX and PANAS were filled out once more as manipulation check.

To examine whether the optimism manipulation affected heat and CPT pain ratings per se, another five trials of the test stimulus were given followed by a first administration of the CPT. Before the CPT, participants first immersed their dominant hand into water at room temperature for one minute. Then they immersed their hand into water of 5°C for 70 sec. Pain ratings were obtained at 20, 40, 60, and 70 sec. Participants who withdrew their hand from the water before 70 sec. had passed were asked for a pain rating at the moment of withdrawal. After a two-minute break, participants were instructed to re-visualize their BPS or TD for 3 min in order to ensure that the required state would still be present during the CPM

procedure. Subsequently, the CPM paradigm was introduced. First, expected pain intensity ratings were acquired for both the test stimulus and the conditioning stimulus, and expected pain change during CPM was assessed. Five trials of the test stimulus were then administered alone and pain ratings were obtained after each heat stimulus. Next, the combined test and conditioning stimulus phase started. Ten seconds after participants had inserted their hand in the cold water another five trials of the test stimulus were delivered, with pain ratings obtained after each trial. In addition, participants rated CPT pain at 70 sec. Finally, participants filled in the S-PCS, a demographics questionnaire, and again the FEX and PANAS to check whether the effects of the manipulation persisted. Participants were compensated and thanked for their participation.

Fig. 1.

Statistical Analysis

Prior to data analysis, data were checked for normality, outliers and missing values. The only missing data were pain ratings during cold water immersion that occurred due to premature withdrawal. Three participants did not complete the 70 sec immersion of the first CPT (range 40 – 43 s). Immediately upon hand withdrawal, these participants provided pain ratings that were imputed at every subsequent missing value of the immersion phase. Two CPT ratings of the CPM phase were missing, one due to premature withdrawal (53 s) and the other due to omission to record the score, and were replaced by the participants' final ratings of the previous CPT phase.[1] Four mean heat pain ratings were obtained (before manipulation, immediately after manipulation, before CPT and during CPT) by averaging the five ratings of

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[1] The participant withdrawing her hand prematurely received one out of five test stimuli without concurrent cold pressor pain. Omitting this participant from the analyses did not affect the results.

each individual trial within these series. Magnitude of the CPM effect was calculated as the difference in heat pain ratings during and before CPT.

Randomization checks with regard to age, FEX, LOT-R, PANAS, and PCS were performed by means of independent samples t-tests. Two ANCOVAs for FEX positive and negative, respectively, with time as within–subject factor (immediate post visualization, at the end on the experiment), group allocation (BPS, TD) as between-subject factor, and FEX baseline as covariate were used as manipulation checks. Similar analyses were performed for positive and negative affect (PANAS). Potential group differences in terms of quality of writing and visualization were tested by independent samples t-tests.

Differences in heat pain ratings (before CPM induction) between the conditions were assessed with a repeated measures ANOVA with mean heat pain score before versus immediately after the BPS/TD manipulation as within-subject factor and condition (BPS, TD) as between-subject factor. Differences in CPT pain ratings between the conditions were tested by means of a repeated measures ANOVA on the pain scores at 20, 40, 60 and 70 sec as the within subject variable and condition as between subject variable.

The hypothesis that induced optimism would lead to a more prominent CPM effect was tested with a repeated measures ANOVA with mean heat pain scores before and during the CPT as within-subject factor and condition as between-subject factor. In case of a significant effect of induced optimism, mediation analyses according to the method of Baron and Kenny (Baron and Kenny, 1986) were performed with CPM condition as predictor, the CPM effect as dependent variable and pain expectations or situational pain catastrophizing as the mediator in separate regression analyses.

Results

Twenty-three participants (4 men) were assigned to the BPS condition and 22 (1 man) to the TD condition. As the results did not change when controlling for sex, or when omitting male participants, analyses for the whole sample are reported. The randomization check revealed that the groups did not differ significantly on age or any of the baseline questionnaires, except for FEX negative which was lower in the BPS group ($t(43) = 2.077$; $p = .044$).

Manipulation check

The FEX and PANAS scores at the three time points in the two conditions are shown in Table 1. The ANCOVA for the positive FEX scores showed a significant condition effect ($F = 7.395$; $p = .009$) and no condition x time interaction ($F = .107$; $p = .745$), indicating that participants in the BPS condition had significantly higher positive FEX scores than participants in the TD condition at both post-manipulation time points. Similarly, for the negative FEX scores only the condition effect reached significance ($F = 9.299$; $p = .004$; condition x time interaction: $F = 1.315$; $p = .258$). To verify that the increase in optimism in the BPS condition lasted until the end of the experiment we additionally carried out a repeated measures ANOVA within the BPS condition with planned contrasts between the three time points. The positive FEX score was significantly larger at both post manipulation time points compared to the pre-manipulation time point (immediately post manipulation: $F = 22.931$, $p < .001$; end of experiment: $F = 5.768$, $p = .025$). Moreover, the final positive FEX score was not significantly different from the score immediately post manipulation ($F = 1.685$, $p = .208$). Similarly, for the negative FEX score, the repeated measures ANOVA within the BPS condition indicated lower scores at both post manipulation time points (resp. $F = 17.527$, $p < .001$ and $F = 7.330$, $p = .013$) and no difference between the post

manipulation time points ($F = 3.570$, $p = .072$). Thus, optimism effects were maintained throughout the experimental session.

For PA, the ANCOVA indicated a significant condition effect ($F = 8.342$, $p = .006$) and a trend towards a condition x time interaction ($F = 13.478$, $p = .068$). The ANOVA with planned contrasts within the BPS condition demonstrated that whereas positive affect increased immediately after the manipulation ($F = 6.424$, $p = .019$), this effect had disappeared at the end of the experimental session ($F = .214$, $p = .648$). Paralleling previous studies using the BPS (Hanssen et al., 2013; Boselie et al., 2014) there was no significant conditions effect on NA ($F = .342$; $p = .562$). The quality of imagination did not significantly differ between the BPS and the TD group (81.5 vs 84.2; $p = .476$). Similarly, there was no significant difference in the vividness of imagination (70.96 vs 72.45; $p = .802$).

Table 1.

Effects of the optimism manipulation on pain intensity

Heat pain ratings for the four assessment periods are displayed separately for the two conditions in Table 2. To assess the effects of the optimism manipulation on heat pain intensity the mean heat pain rating before (pre manipulation) and after (post manipulation) the BPS/TD manipulation were compared by means of a repeated measures ANOVA. The time effect was significant ($F(1,43) = 10.19$, $p = .003$), indicating an increase in pain ratings over time, but there was no time x condition interaction ($F(1,43) = .39$, $p = .538$).

Pain rating for the first CPT (i.e. when given alone) were examined by means of a repeated measures ANOVA with ratings at 20, 40, 60 and 70 sec as the dependent variable and condition as the independent variable. A significant time effect was found ($F(3,41) =$

20.53, $p < .001$), showing that pain increased with time in the water. There was no significant condition effect ($F(3,41) = 1.72$, $p = .179$) nor a time x condition interaction ($F(1,43) = 2.49$, $p = .620$). Mean CPT ratings at 20, 40, 60 and 70 sec were respectively 69.8, 79.1, 83.5, and 85.4 in the BPS condition and 68.9, 75.9, 81.4, and 81.6 in the TD condition. Thus, the optimism manipulation did not affect heat pain or CPT ratings.

Table 2.

Effects of the optimism manipulation on CPM

As can be seen from Table 2, heat pain ratings were lower during than before CPT in both conditions. The mean CPM effect was -11.58. A repeated-measures ANOVA revealed a significant effect of Time ($F(1,43) = 34.378$, $p < .001$), indicating that CPM was successfully induced, but a non-significant condition x time interaction ($F(1,43) = .007$, $p = .932$.). Thus, the manipulation did not affect CPM. Because of the absence of a condition effect on CPM, no mediator analysis was performed.

Post-hoc analyses: the role of dispositional optimism, trait pain catastrophizing, and pain expectations

In line with the results of previous studies, we explored whether dispositional optimism and/or trait pain catastrophizing were associated with the magnitude of CPM. In addition, because of the presumed role of pain expectations, we also explored the association of expected heat pain during CPM and expected pain relief and the magnitude of CPM. Pearson's correlations between scores on the LOT-R, the PCS, expected heat pain and expected pain relief and the CPM effect were calculated. Dispositional optimism ($r = -.177$, $p = .245$) and expected pain relief ($r = -.199$, $p = .189$) were not significantly correlated with the CPM effect. However, trait catastrophizing ($r = .413$, $p = .005$) and expected heat pain

(r=.375, $p = .011$) showed a significant positive correlation with the CPM effect. Thus, higher pain catastrophizing and higher expected heat pain during CPT were associated with less reduction in heat pain scores during the conditioning stimulus. Figure 2a and 2b show the scatterplots of these associations.

Fig. 2a.

Fig. 2b.

Discussion

The present study was set up to examine the effects of induced optimism on CPM as a potential underlying mechanism of the reduced pain sensitivity that was previously reported in optimistic individuals and after optimism induction. Although the manipulation of optimism was successful, no effect on sensitivity for heat or cold pain or on CPM was found. Post hoc analysis showed that there was neither an association of dispositional optimism with the CPM effect. Thus, no evidence was found that optimism could activate or enhance endogenous pain inhibitory mechanisms. However, we did find evidence that pain-specific cognitions may influence these endogenous pain inhibitory mechanisms. The post hoc analyses showed that both pain expectancies and trait pain catastrophizing were associated with the magnitude of the CPM effect.

One potential explanation for the absence of an (induced and dispositional) optimism effect on CPM could be that we used a very potent CPM paradigm. The paradigm with CPT pain as the conditioning stimulus and heat pain as the test stimulus generally has large effects possibly resulting from the activation of several underlying inhibitory circuits. Such a strong CPM paradigm might be especially sensitive for decreases of fully activated inhibition but insensitive for further increases because of ceiling effects. Thus, with this paradigm it might

be easier to uncover decreases in CPM effects due to catastrophizing than to find increases due to optimism. Another possibility is that optimism is generally ineffective in potentiating descending inhibition, and that its pain-reducing effects rely on other mechanisms. So far, only one study found an association between dispositional optimism and increased CPM (Goodin et al., 2013), and only after adjusting the analyses for sex, ethnicity, depressive symptoms and pain catastrophizing. Simple correlational analyses did not reveal a significant association between dispositional optimism and magnitude of CPM in that study either. Adjusting our analyses for sex and pain catastrophizing by including these variables in a multiple regression analysis together with dispositional optimism did not change the results and only yielded a significant effect for pain catastrophizing (data not shown). It may be speculated that global cognitions relating to all life domains as is the case in optimism, have less direct relevance for, and less effect on, nociceptive control circuits compared to more proximal pain-related cognitions.

The motivation for the present study was derived from the Hanssen et al. study that showed that inducing optimism by means of the BPS can lower cold pressor pain sensitivity (Hanssen et al., 2013). However, we could not replicate the pain-reducing effect of the BPS intervention in the present study. Neither heat pain ratings nor CPT pain ratings at baseline (i.e. when given alone, before the CPM induction) differed between the TD and BPS condition. One difference with the previous study was that in the present study, the experimental session lasted longer and several successive pain stimuli were applied. One could argue that this may have eliminated the effect of the BPS, reducing optimism to its baseline level in the course of the session. We tried to counter this by including a short re-visualization after the first cold pressor test, before the CPM procedure started. The manipulation check demonstrated that state optimism remained significantly elevated until

the end of the experimental session while mood effects declined, paralleling the findings of a previous study (Peters, Vieler and Lautenbacher, 2016). Hence, whether and under what circumstances induced optimism affects pain sensitivity requires further investigation.

The finding that higher levels of pain catastrophizing are associated with reduced CPM is in line with the results of two previous studies (Rhudy et al., 2007; Weissman-Fogel et al., 2008). If indeed people with high levels of pain catastrophizing have a less efficient pain inhibitory system, this may be one of the reasons why they are at increased risk for developing persistent pain. Pain catastrophizing is one of the main prognostic factors of pain persistence after an acute pain episode (e.g. Wertli et al., 2014) and after surgical procedures (Jackson, Tian, Wang, Iezzi and Xie, 2016; Sobol- Kwapinska et al., 2016). Less efficient enodogenous pain inhibition because of pain catastrophizing may lead to high pain intensity in the acute phase of injury, which can have a sensitizing influence on the nociceptive system (Chapman and Vierck, 2017). Indeed, less efficient CPM has previously been found related to higher levels of clinical pain (Yarnitsky, 2015; Vaegter and Graven-Nielsen, 2016) and increased risk of persistent pain after surgery (Yarnitsky et al., 2008; Ossipov, Morimura and Porreca, 2014; Petersen, Graven-Nielsen, Simonsen, Laursen and Arendt-Nielsen, 2016). Future studies should examine whether targeting pain catastrophizing by means of cognitive behavioral therapy could reinstal efficient descending pain inhibition (cf. (Seminowicz et al., 2013; Salomons, Moayedi, Erpelding and Davis, 2014; Shpaner et al., 2014), and thereby reduce the risk of persistent pain.

It should be noted that the association between pain catastrophizing and CPM has not consistently been reported (Cormier et al., 2013; King et al., 2013; Horn-Hofmann, Priebe, Schaller, Görlitz and Lautenbacher, 2016; Nahman- Averbuch, Sprecher, Jacob and

Yarnitsky, 2016) with one study even finding enhanced CPM with higher levels of pain catastrophizing (Granot et al., 2008). Whether or not pain catastrophizing affects endogenous pain inhibition may depend on the specific CPM protocol used (Granot et al., 2008; Nahman-Averbuch, Nir, Sprecher and Yarnitsky, 2016). As noted above, we have used a particularly strong CPM paradigm, which might facilitate finding an inhibitory effect.

Additionally, we found the expected painfulness of the heat stimuli during simultaneous cold pressor pain to be associated with the CPM effect. This concurs with other studies showing that pain expectations correlate with the magnitude of CPM (Keltner et al., 2006; Goffaux et al., 2007; Cormier et al., 2013). Robust associations between pain expectations and actual pain experiences have been reported in both clinical pain populations and pain free volunteers (Peerdeman, van Laarhoven, Peters and Evers, 2016) and it may be proposed that this is at least partly explained through endogenous pain modulation (Ploghaus, Becerra, Borras and Borsook, 2003). Expectancy manipulations, such as placebo and nocebo induction, could clarify whether the impact on pain is (partly) mediated through strengthening or weakening the efficiency of descending pain modulation as measured by CPM (Eippert, Finsterbusch, Bingel and Büchel, 2009).

This study has several limitations. First, pain catastrophizing and dispositional optimism were measured after the first series of heat pain stimuli had been applied. Despite that the PCS and LOT-R are considered trait measures and thus relatively stable, it cannot be ruled out that the recent pain experience might have affected their scores. Second, the homogeneity of the young and healthy sample may have led to ceiling effects in CPM as their pain inhibitory capacity was already high which might explain why we did not find any effects of optimism on CPM. Third, the sample mainly consisted of female participants and

results may not be generalizable to males. Sex differences in the magnitude of CPM have been reported, with women typically having less efficient CPM than men (Granot et al., 2008; Goodin et al., 2009). Future studies could examine whether sex effects are reduced when using a strong CPM paradigm such as in the present study. Moreover, the effect of expectations on CPM magnitude should be replicated in a mixed sex sample because at least one study found that induced expectations only affected the magnitude of CPM in women (Bjørkedal and Flaten, 2012).

To conclude, the results of the current study provide evidence that pain-specific cognitions but not generalized optimistic cognitions affect the CPM effect. Future studies should examine whether less efficient endogenous pain modulation could explain the prognostic role of pain catastrophizing and pain expectancies in the development of persistent pain and whether this can be curtailed by intervening on these psychological variables.

Author contributions:

All authors have contributed substantially to the content of the paper. MLP, MMH, FO and SL contributed to the design of the study. JT and FO acquired the data, results were analyzed and interpreted by JT and MLP. JT drafted the article, MLP critically revised it, and MMH, SL and FO reviewed and commented on it. All authors have given approval of the manuscript.

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Legends

Table 1

Means and standard deviations (SD) of FEX and PANAS scores throughout the experiment. BPS, best possible self; TD, typical day; FEX-Pos, Future Expectations positive scale; FEX-Neg, Future Expectations positive scale; PA, positive affect scale (PANAS); NA, negative affect scale (PANAS).

Table 2

Pain ratings for each assessment period per condition.

BPS, best possible self; TD, typical day.

Fig. 1. Experimental procedure.

Fig. 2a. The correlation between trait pain catastrophizing and the magnitude of the CPM effect ($r = .413$, $p = .005$).
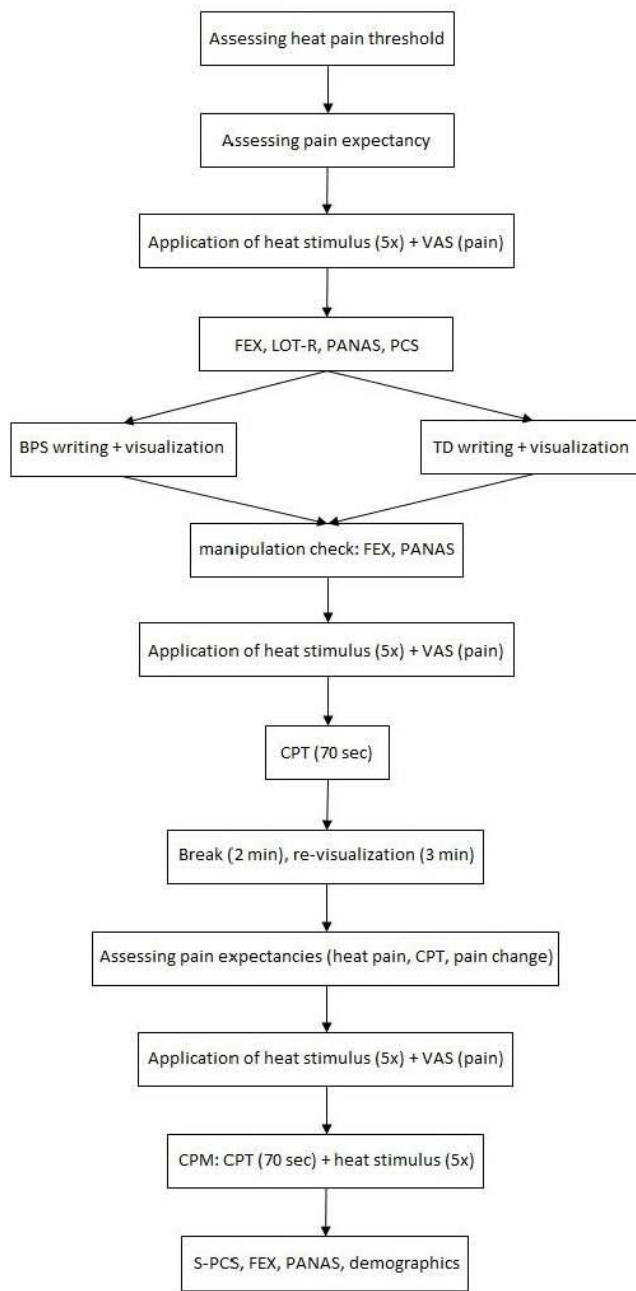
Fig. 2b. The correlation between expected heat pain during CPT and the magnitude of the CPM effect ($r = .375$, $p = .011$).
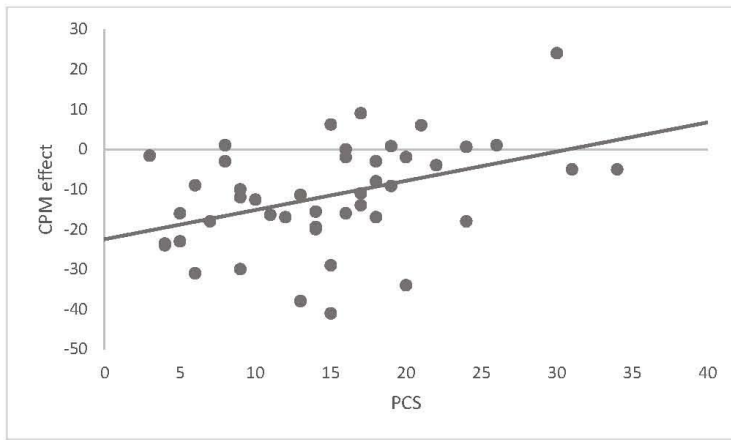
Table 1

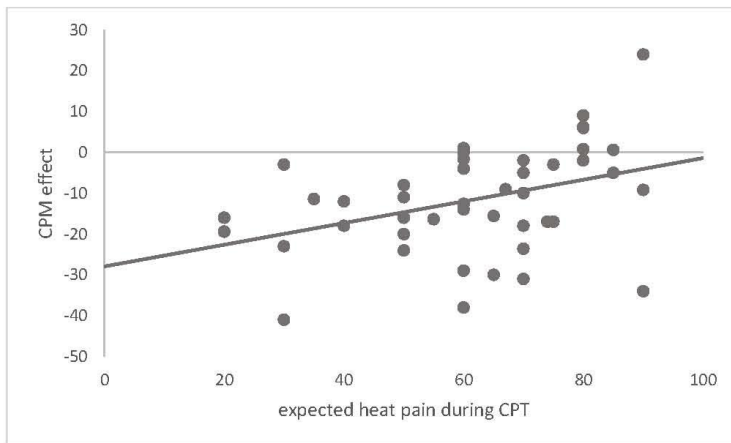| | Means (SD) | | | | | |
| | Pre manipulation | | Post manipulation | | Post revisualization | |
	BPS	TD	BPS	TD	BPS	TD
FEX-Pos	53.65 (5.81)	52.77 (7.41)	56.30 (5.90)	53.23 (7.94)	55.52 (6.71)	52.77 (7.10)
FEX-Neg	28.00 (7.37)	32.73 (7.89)	23.69 (6.19)	31.95 (8.91)	25.17 (6.71)	32.45 (8.91)
PA	30.87 (4.69)	28.5 (7.37)	33.65 (5.56)	26.91 (7.69)	31.39 (6.75)	27.00 (8.09)
NA	13.65 (4.55)	14.27 (4.49)	12.30 (2.87)	13.59 (4.25)	13.43 (3.91)	13.55 (3.90)

Table 2

	Pre manipulation	Post manipulation	Pre CPM	during CPM
BPS	59.82 (12.26)	63.17 (13.29)	60.73 (14.05)	48.98 (18.76)
TD	63.28 (19.80)	65.55 (20.56)	63.46 (20.73)	52.05 (27.54)

Fig. 1. Experimental procedure.

Fig. 2a. The correlation between trait pain catastrophizing and the magnitude of the CPM effect ($r = .413$, $p = .005$).

Fig. 2b. The correlation between expected heat pain during CPT and the magnitude of the CPM effect ($r = .375$, $p = .011$).