The role of cognitive and affective flexibility in individual differences in the experience of experimentally induced heat pain

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Abstract
Adaptation to the context in which we experience pain requires cognitive flexibility (CF) and affective flexibility (AF). Deficits in both flexibility types may be precursors of more intense and prolonged pain. This study aimed to examine the relation between CF and AF, and the experience of experimentally induced pain. Furthermore, correlations between behavioral and self-report measures of flexibility were explored. CF and AF were assessed with task-switching paradigms, using neutral (numbers ranging from 1 to 9, excluding 5) or affective stimuli (positive and negative pictures), respectively. Pain sensitivity measures, such as pain threshold (°C), pain tolerance (°C), and retrospective pain experience ratings (Visual Analog Scale) were assessed for an experimentally induced heat pain stimulus. Self-reported CF was measured with a questionnaire. Results demonstrated no associations between the flexibility constructs and any of the pain outcome measures. Correlations between the behavioral and self-report measures of CF were absent or weak at best. Current results are discussed against the background of methodological considerations and prior empirical research findings, suggesting the contribution of AF in especially the recovery from pain.

Keywords
Affective flexibility, cognitive flexibility, heat pain, pain threshold/tolerance, task switching

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People are typically confronted with constantly changing environments to which they must adapt in order to best navigate life. In the same way, the circumstances in which we experience pain are subject to change. Optimal adaptation to these contextual changes requires the use of cognitive and affective

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resources, and thus flexibility at both the cognitive and affective level (Attal et al., 2014). Cognitive flexibility (CF) is conceptualized as the ability to adjust goals and to shift between different thoughts or behaviors in order to best match fluctuating environmental demands (Lezak, 1995). It involves two components of executive functioning, namely shifting and inhibition (Miyake et al., 2000). Consequently, insufficient CF is provoked by problems in inhibiting inappropriate thoughts and goals and by difficulties in shifting between goals and mental sets (Genet et al., 2013). CF can be considered an adaptive quality, as deficits in CF have been related to a variety of mental disorders such as depression (Lee et al., 2012), obsessive-compulsive disorder (Sadock & Sadock, 2007; Sternheim et al., 2014), borderline personality disorder (Ruocco, 2005), and anorexia nervosa (Abbate-Daga et al., 2011).

In the context of pain, a fair amount of research has demonstrated the negative impact of experimentally induced (e.g., Attidge et al., 2016; Boselie et al., 2014; Moore et al., 2012; Van Ryckeghem et al., 2012) and naturally occurring acute (e.g., Attidge et al., 2016, 2017) and chronic pain (e.g., Eccleston, 1995; Karp et al., 2006; Verdejo-Garcia et al., 2009) on various measures of CF. For instance, acute experimental pain has been shown to diminish shifting performance (Boselie et al., 2014; Van Ryckeghem et al., 2012). By contrast, CF has also been suggested to impact pain perception (Bjekić et al., 2018; Karsdorp et al., 2014; Oosterman et al., 2010). Moreover, deficits in CF have been suggested to be a precursor of more intense and prolonged pain experience and as such contribute to pain chronicity (as reviewed in Moriarty et al., 2011). A prospective study on postsurgical pain showed that the presence of chronic pain and high pain intensity 6 and 12 months after surgery were both independently predicted by impairments in CF (Attal et al., 2014).

A construct related to CF and suggested to be particularly interesting to examine in relation to pain is affective flexibility (AF; Malooly et al., 2013). AF is conceptualized as a domain-specific instantiation of CF, encompassing the ability to flexibly control the processing of emotional material, thereby switching between emotional and neutral information (Genet & Siemer, 2011; Genet et al., 2013; Malooly et al., 2013). AF has been suggested to underlie resilience (i.e., the ability to bounce back from adversity; Campbell-Sills & Stein, 2007) and has been found to be associated with less rumination (Genet et al., 2013). However, whether AF is adaptive may depend on the affective context in which it occurs; especially switches away from negative information and toward positive information have been shown to be adaptive (Genet et al., 2013; Malooly et al., 2013; Meesters et al., 2019).

Given the emotional characteristics of pain, AF has been suggested to be of relevance for the experience of pain. In a recent experimental study conducted in healthy college students, Meesters et al. (2019) reported an inverse relationship between AF and recovery from experimental pain. In this previous study, AF was measured with an affective task-switching paradigm (Malooly et al., 2013)—identical to the task used in the present study—that required participants to switch between processing the affective and neutral aspects of affective pictures. A Tourniquet pain procedure was used to induce ischemic pain by restricting the blood supply to the nondominant arm. Recovery in terms of pain intensity was assessed as the time from the moment of Tourniquet task termination until a pain intensity rating of 0 was given by the participant. The results showed that faster switches from neutral toward emotional characteristics of positive stimuli (i.e., AF) were predictive of faster recovery from ischemic pain in terms of pain intensity. These findings offered tentative support for the suggestion that AF, conceptualized as CF toward emotional material, might act as an explanatory mechanism in the experience and management of pain. However, the aforementioned study did not find an association between AF and pain tolerance. Whether the link between AF and pain is specific to recovery from pain remains elusive, as the pain tolerance measurement was hindered by a ceiling effect in that specific study (Meesters et al., 2019).

The current study was specifically set up to examine the relation between flexibility (i.e., CF and AF) and pain sensitivity using a heat pain induction task. CF and AF were assessed by a task-switching paradigm employing neutral (CF; numbers ranging from 1 to 9, excluding 5) or affective stimuli (AF; positive and negative pictures), respectively. We hypothesized that better performance on both flexibility measures, and thus increased flexibility, would be associated with increased pain threshold and tolerance for pain, as well as lower retrospective pain experience ratings. For exploratory purposes, a self-report measure of CF was administered to explore its association to the pain outcomes and the behavioral measures of flexibility. Moreover, the incorporation of both CF and AF in the
same study allows the examination of the relation between both constructs and their respective contribution to pain outcomes.

Method
Participants
Eighty-five healthy participants were recruited by means of advertisements at Maastricht University, on an electronic research participation system (SONA) and social media (i.e., Facebook). The following exclusion criteria were formulated: pregnancy, acute/chronic pain, injury or pain to the nondominant arm, (a history of) cardiovascular problems, severe medical diseases (e.g., diabetes, asthma), diagnosis of a psychiatric (e.g., depression, anxiety disorder) or neurological (e.g., epilepsy) disorder, the use of anxiolytics or antidepressants, and/or poor vision that was not corrected. Additionally, at the start of the lab session, we asked participants whether they had taken any analgesic medication earlier that day and if so, they were also excluded from participation. Self-report at the start of the experiment was used to check these criteria, resulting in the exclusion of two participants. The final sample consisted of 83 participants (mean age 21.3 years; SD = 2.76; 18 male).

Measures and materials
Pain induction apparatus and pain outcome measures
Pain induction: Thermal stimulation. A 30 × 30 mm² thermod as part of the Medoc Pathway Advanced Thermal Stimulator (Medoc-ATS Ltd, Advanced Medical System, Ramat Yishai, Israel) was attached to the volar surface of the nondominant forearm at approximately 5 cm from the wrist. Two series of four thermal stimuli were delivered; each stimulus started at a preset baseline temperature (32°C) and gradually increased in temperature by 1°C. The stimulus promptly returned to baseline temperature at a rate of 8°C s⁻¹ when the participant terminated the stimulus by a left or right mouse click or when the preset maximum temperature (51°C) was reached.

Pain threshold and pain tolerance. Pain threshold was determined for the first series of four thermal stimuli by instructing the participants to terminate the stimulus at the moment that they first started to experience pain. The average temperature (°C) of this series excluding the first trial was calculated to obtain a measure of pain threshold. Pain tolerance was assessed for the second series of four stimuli using the instruction to stop the stimulus at the moment that participants could no longer tolerate the pain. Again, the average temperature (°C) of this series excluding the first trial was computed to obtain a measure of pain tolerance.

Self-report anticipation and experience of pain intensity, pain unpleasantness, and fear of pain. Visual Analog Scales (VASs) of 100 mm were used to measure anticipated and retrospective pain experience (i.e., pain intensity, pain unpleasantness, and fear of pain). The anchors of the VAS ratings ranged from 0 = “not painful/unpleasant/fearful at all” to 100 = “unbearably painful/extremely unpleasant/fearful.” VAS ratings pertaining to anticipated pain experience were administered twice; once prior to the first threshold measurement and once again prior to the first tolerance measurement. Ratings for anticipated pain experience were included for exploratory purposes and are not further reported in this article. For retrospective pain experience, each VAS was administered after each heat stimulus and mean VAS scores across the last three trials of the threshold and tolerance series separately were computed.

Flexibility measures
Cognitive switching task setup. A task-switching paradigm identical to the one used by Boselie et al. (2017) was administered in order to assess CF. This task employs two different sorting rules for categorizing stimuli in order to measure switching and inhibiting abilities. Stimuli are numbers ranging from 1 to 9, excluding 5, and presented in succession on a monitor. Participants have to categorize these stimuli according to whether the number is odd or even (odd/even rule), or whether the number is higher or lower than 5 (higher/lower rule). Stimuli are preceded by a 500 ms prime (i.e., odd/even or higher/lower) indicating the next sorting rule. In order to remind the participants of the answer options, information about what answer option matches with which response key is simultaneously presented with the stimulus. There is no time limit for giving a response and the next prime and stimulus are presented upon pushing a
key on a response box. The participants have their left-hand index finger on the left button and their right-hand index finger on the right button of this response box. There are four versions of this task based on the mapping of the active categorization rule (odd/even or higher/lower) to the response keys (left or right), which were counterbalanced across participants.

The task entails a 12-trial practice block and a 192-trial test block. In the practice block, the first six stimuli have to be sorted according to the higher/lower rule, and the second series of six stimuli have to be sorted following the odd/even rule. The test block has two different trial types, namely trials on which the sorting rule changes from one trial to the next (switch trials) and trials on which the sorting rule is repeated (repeat trials). The test block consists of 96 trials of each type with switch and repeat trials in semi-randomized fixed order. Reaction times (RT; ms) and accuracy are registered.

**Affective switching task setup.** An affective task-switching paradigm was employed to assess AF (Genet et al., 2013). The design of this computer task is similar to the cognitive switching task, but in this case participants sort affective pictures according to either an affective rule (determining whether the picture is positive or negative) or a neutral rule (determining whether the picture contains one or no humans, or two or more humans). The stimuli are 160 pictures from the International Affective Picture System (Lang et al., 1997) that can be classified into four categories based on the two sorting rules. There are no primes in this task, but the pictures are shown with the active categorization rule (the cue) depicted on the left and right side of the picture: “+” and “−” indicate positive and negative, “≤1” and “≥2” indicate one or no people and two or more people. The picture is displayed against either a white or a gray background with the color of the background corresponding to the cue. The picture category and cue are combined according to a pseudorandom order. There are eight task versions based on the mapping of the frame color (white or gray) to the active categorization rule (valence or number of people), and mapping of the response keys (left or right) to the categorization rule (“+/−” or “≤1”/“≥2”).

The task consists of two 10-trial practice blocks in which one of two rules is practiced per block and two 160-trial test blocks in which both rules are presented intermixed. For each trial, RT (ms) and accuracy are recorded. Trials are defined as either a switch or a repeat trial. A switch trial is a trial on which the categorization rule changes from the prior to the current trial, whereas a repeat trial is a trial on which the same categorization rule is repeated for the current trial. The first trial of each block is disregarded in data analyses, as it cannot be categorized as either a switch or a repeat trial. It is important to note that the valence of the pictures never changes in the switch trials; it is only the categorization rule that alternates.

Mean RTs were calculated for eight different trial types, as defined on the basis of both the active categorization rule and picture valence of the previous and current trials. There were four switch trial types (i.e., positive to neutral rule, negative to neutral rule, neutral to positive rule, and neutral to negative rule) and four repeat trial types (positive to positive rule, negative to negative rule, neutral to neutral rule for positive pictures, and neutral to neutral rule for negative pictures).

Reduced pain sensitivity is expected to be associated with greater flexibility (i.e., lower switch costs) in (1) switching toward processing affective features in a positive context, and (2) switching away from processing the affective features in a negative context, as well as with reduced flexibility (i.e., larger switch costs) in (3) switching away from processing affective characteristics of a positive context, and (4) switching toward processing affective features of a negative context.

**Preprocessing and scoring of task-switching data.** Analyses for both switching tasks were performed on mean RTs, excluding incorrect responses (cognitive switching task: 6.4% of the trials; affective switching task: 7.3% of the trials). Following previous studies using the same switching tasks (Boselie et al., 2017, 2018; Genet et al., 2013; Grol & De Raedt, 2018; Malooly et al., 2013), the effect of outlying RTs was limited by replacing (1) RTs ≤ 250 ms with the value of 250 ms (cognitive switching task: 0% of the trials; affective switching task: 0.014% of the trials), and (2) RTs larger than 2.5 SD above the individual mean RT with the individual mean plus 2.5 SD (cognitive switching task: 3.06% of the trials; affective switching task: 2.37% of the trials).

For the cognitive switching task, switch costs (ms) were calculated by subtracting RTs on repeat trials from RTs on switch trials (Boselie et al., 2017). Higher switch costs are indicative of slower responses to switch than repeat trials and reflect less CF. For the
affective switching task, four types of switch costs were computed. In particular, affective-to-neutral (AtoN) switch costs were calculated by subtracting RTs on affective repeat trials from RTs on affective-to-neutral trials: switch cost AtoN = switch (affective to neutral) – repeat (affective to affective). This type of switch cost was separately computed for positive (SC posAtoN) and negative (SC negAtoN) pictures. Similarly, switch costs for neutral-to-affective (NtoA) task sets were computed for positive (SC posNtoA) and negative (SC negNtoA) pictures separately, using the formula: SC NtoA = switch (neutral to affective) – repeat (neutral to neutral). Higher switch costs are indicative of reduced flexibility in making the specific shift of interest (i.e., away from or toward the affective rule in a positive or negative context).

**Self-report questionnaires.** Basic sociodemographic information (age, gender, mother tongue, nationality, type and year of study) was obtained at the start of the survey. Some exit questions concerning the goal of the study and the two switching tasks (attention and motivation to perform the tasks, pleasantness, interest in the task, task duration and difficulty) were also inquired. Psychological questionnaires were administered in order to test the relationship between psychological constructs and switching abilities.

The Cognitive Flexibility Inventory (CFI; Dennis & Vander Wal, 2010) consists of 20 items measuring self-reported CF (e.g., “I consider multiple options before making a decision”; “I often look at a situation from different viewpoints”). Items are scored on a 7-point Likert-type scale with anchors at 1 (“strongly disagree”) to 7 (“strongly agree”). Higher sum scores (range 20–140) reflect more CF. The CFI has good psychometric properties (Dennis & Vander Wal, 2010; Johnco et al., 2014). An internal consistency of $\alpha = .85$ was obtained for the current sample.

The Acceptance and Action Questionnaire-II (Bond et al., 2011; Fledderus et al., 2012), the “difficulties engaging in goal-directed behaviors when experiencing negative emotions” subscale of the Difficulties in Emotion Regulation Scale (Gratz & Roemer, 2004), the Life Orientation Test–Revised (Scheier et al., 1994), the Highly Sensitive Person Scale (Ruocco, 2005), the Cognitive Emotion Regulation Questionnaire short form (CERQ–short; Garnefski & Kraaij, 2006), the Pain Catastrophizing Scale (Sullivan et al., 1995), the Fear of Pain Questionnaire–Short Form (Lee et al., 2012), the State-Trait Anxiety Inventory Y2 form (Spielberger et al., 1983), the Positive and Negative Affect Schedule 10-item version (PANAS–short; Mackinnon et al., 1999), and four questions concerning stress levels were assessed for exploratory purposes beyond the scope of this article and are therefore not further considered in this article.

**Procedure**

Upon arrival, study eligibility was verified and participants were informed about the test procedure. Written informed consent was obtained from each participant. Because wounds could potentially affect the experience of the thermal stimuli, the volar surface of the nondominant arm was checked for (healing) wounds, defined as a disruption of the skin for which the skin integrity is/was broken and there is/ was a hemorrhage. None of the participants had any wounds. The lab session took approximately 1 hr and could be completed in either English or Dutch (65.1% of the participants chose English).

First, participants completed the two switching tasks. The order in which participants had to complete these tasks was counterbalanced. Task instructions were explained verbally and shown once again in text on the monitor at the start of each task. After both switching tasks were completed, the experimenter explained the pain induction procedure. The participants were told that the sensations caused by the stimulus could become unpleasant or painful. Before the start of the first stimulus, participants filled out the VAS ratings for anticipated pain experience. The difference between pain intensity and pain unpleasantness was clarified using a standardized written explanation employing a sound analogy reported in details elsewhere (Price & Harkins, 1987). The thermode was then attached to the volar surface of the nondominant forearm. During the pain procedure, participants had their nondominant arm resting in front of them on the table and their dominant hand on the stop mouse. The experimenter indicated verbally when a stimulus would be delivered. Pain threshold was measured first with an interstimulus interval of 30 s during which participants filled out the VAS ratings for retrospective pain experience. Before starting the pain tolerance measurements, participants were asked to fill in the anticipated VAS ratings. The interstimulus interval now was 90 s, and again participants filled out the retrospective VAS ratings during this period.
Following the removal of the thermode, the sociodemographic, psychological, and exit questionnaires were administered using an online survey application (Qualtrics, Provo, Utah, USA). Lastly, participants received either a 7.50-euro gift voucher or course credits as a reward for their participation and were debriefed.

Statistical analyses

The current study’s sample size was determined a priori using G*Power (version 3.1.9.2) with hierarchical multiple regression analyses as the main analyses. A minimal sample size of 78 participants was set for a medium effect size ($f^2 = .18$; Meesters et al., 2019), with one cognitive and four affective switch costs as predictors and one covariate (sex), a power of .80, and $\alpha$ of .05. SPSS version 24 software (SPSS, Inc., Chicago, Illinois, USA) was employed for statistical analyses. Descriptive statistics were retrieved, and normality and homogeneity of variance were checked showing that assumptions for subsequent statistical analyses were met. For pain-related data, the impact of outliers was reduced by substituting scores deviating more than 3 $SD$ in positive or negative direction from the group mean by the group mean $\pm 3$ $SD$. Participants who did not reach the pain threshold within the preset temperature limits (maximum $51^\circ C$) were omitted from all analyses incorporating pain outcome variables, as painful sensations were not successfully induced in these participants. For pain tolerance, analyses were performed both including and excluding participants who reached the preset maximum temperature of $51^\circ C$. In case these analyses yield similar results, the results of analyses including the participants who reached the preset tolerance maximum are reported in this article.

Pain threshold ($^\circ C$), pain tolerance ($^\circ C$), and retrospective pain experience ratings (i.e., pain intensity, pain unpleasantness, and fear of pain ratings for both threshold and tolerance) were the outcome variables of interest. The relationship between the different types of cognitive and affective switch costs and pain threshold, pain tolerance, and retrospective pain experience ratings was examined using Pearson’s correlation coefficients, thereby correcting for multiple testing ($\alpha < .01$). Hierarchical multiple regression analyses were used as the general analytical approach. Results from these analyses were considered significant when an $\alpha$ of $.05$ was obtained. Two sets of hierarchical multiple regression analyses were conducted to test the predictive value of the cognitive and affective switch costs for all pain outcome variables. For the first set of analyses, age and sex were entered in the first step and the switch costs in the second step of the regression models. In case age and/or sex were not significantly related to the outcome variables, these predictors were removed from the regression model, but all other predictors were retained. For the second set of analyses, a backward deletion procedure was used for switch cost predictors after the deletion of age and sex in case of insignificance. Furthermore, the relation between various self-report measures of flexibility and the behavioral flexibility measures (i.e., both switching paradigms) was explored with Pearson’s correlation coefficients, thereby correcting for multiple testing ($\alpha < .01$).

Results

Descriptive statistics

One participant (1.20%) did not reach the pain threshold within the preset temperature limits of the thermal stimulus (maximum $51^\circ C$) in any of the three threshold trials and was therefore excluded from all analyses involving pain outcome variables. Likewise, tolerance was not reached for six (7.2%) participants for whom a pain tolerance value of $51^\circ C$ was registered. The mean and $SD$ of pain threshold, pain tolerance, retrospective pain experience ratings, and self-report questionnaire scores and their correlations are depicted in Table 1.

Cognitive and affective switching tasks

For the cognitive switching task, results of the paired samples $t$-test showed that RTs on switch trials ($M = 1,446.2$ ms, $SD = 541.7$ ms) were significantly greater than RTs on repeat trials ($M = 1,283.6$ ms, $SD = 410.5$ ms), $t(82) = 6.58, p < .001, d = 1.45$. Similarly, using paired samples $t$-tests, greater RTs on switch trials ($M = 1,494.6$ ms, $SD = 324.2$ ms) than on repeat trials ($M = 1,354.9$ ms, $SD = 292.3$ ms), $t(81) = 12.1, p < .001, d = 2.62$, were found for the affective switching task.

The mean and $SD$ of the different types of cognitive and affective switch costs as well as their correlations are presented in Table 1. A repeated measures analysis of variance with a Greenhouse–Geisser correction revealed a significant difference between the four types of affective switch costs, $F(2.59, 212.2) = 31.8, p < .001$. Post hoc analyses using the Bonferroni
Table 1. Mean, SD, and Pearson’s correlations for pain threshold, pain tolerance, subjective pain experience ratings, self-reported cognitive flexibility, and the different types of cognitive and affective switch costs.

| Measure                                      | M (SD) | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|----------------------------------------------|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Pain threshold                               | 46.00 (2.17) | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| Pain tolerance                               | 48.20 (1.35) | .83*** | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| Subjective pain experience ratings—threshold |        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 3. Pain intensity                            | 54.52 (20.10) | .18 | .09 | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| 4. Pain unpleasantness                       | 52.17 (22.27) | .22 | .10 | .89** | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| 5. Fear of pain                              | 25.41 (18.76) | .20 | .13 | .52** | .51** | —   | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| Subjective pain experience ratings—tolerance |        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 6. Pain intensity                            | 56.45 (15.85) | .02 | .10 | .69** | .60** | .53** | —   | —   | —   | —   | —   | —   | —   | —   | —   |
| 7. Pain unpleasantness                       | 57.44 (19.04) | .03 | .07 | .67** | .69** | .50** | .89** | —   | —   | —   | —   | —   | —   | —   | —   |
| 8. Fear of pain                              | 47.81 (20.09) | .06 | .09 | .50** | .53** | .71** | .77** | .83** | —   | —   | —   | —   | —   | —   | —   |
| 9. CFI                                       | 101.3 (13.05) | −.06 | −.02 | .02 | .11 | −.07 | −.02 | .08 | .04 | —   | —   | —   | —   | —   | —   |
| Switch costs                                 |        |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 10. CF, general SC                           | 159.3 (212.7) | .07 | .13 | .01 | −.08 | −.03 | .06 | .03 | .02 | .19 | —   | —   | —   | —   | —   |
| 11. AF, general SC                           | 141.3 (104.8) | .09 | .13 | .03 | .02 | .08 | .11 | .02 | .02 | .08 | .36*** | —   | —   | —   | —   |
| 12. AF, SC posAtoN                           | 181.9 (221.7) | −.03 | .06 | .02 | −.08 | .06 | .10 | −.06 | .06 | .01 | .07 | .30** | —   | —   | —   |
| 13. AF, SC negAtoN                           | 299.2 (260.8) | −.15 | −.01 | −.02 | −.01 | .10 | −.09 | −.12 | .08 | .08 | .19 | .41*** | .36 | —   | —   |
| 14. AF, SC posNtoA                           | 79.4 (238.8) | −.04 | −.03 | .10 | .11 | .06 | .05 | .04 | .08 | .17 | .48*** | −.19 | .10 | —   | —   |
| 15. AF, SC negNtoA                           | −42.4 (236.5) | .15 | .17 | .03 | .11 | .04 | .05 | .02 | −.07 | .03 | .13 | .33*** | −.003 | −.21 | .14 |

Note. N = 83 (18 men) for self-report measures and switch costs; N = 82 (18 men) for pain threshold and related subjective pain experience; N = 77 (15 men) for pain tolerance and related subjective pain experience. Pain threshold = the average temperature (°C) across the last three threshold measurements; pain tolerance = the average temperature (°C) across the last three tolerance measurements; CFI = Cognitive Flexibility Inventory; CF = cognitive flexibility; SC = switch cost; AF = affective flexibility; SC posAtoN = switch cost for positive picture and affective-to-neutral trial; SC negAtoN = switch cost for negative picture and affective-to-neutral trial; SC posNtoA = switch cost for positive picture and neutral-to-affective trial; SC negNtoA = switch cost for negative picture and neutral-to-affective trial; M = mean; SD = standard deviation.

**p < .01. ***p ≤ .001.
correlation showed that mean SC negAtoN was significantly larger than mean SC posAtoN (p = .01), mean SC negNtoA (p < .01), and mean SC posNtoA (p < .01). In addition, mean SC negNtoA was significantly smaller than mean SC posAtoN (p < .01), mean SC negAtoN (p < .01), and mean SC posNtoA (p < .1). No significant difference was found between mean SC posAtoN and mean SC posNtoA (p = .06).

In line with previous studies using similar task-switching paradigms to assess CF and AF (Genet et al., 2013; Malooly et al., 2013; Meesters et al., 2019), weak to moderate correlations were found between the different switch costs, suggesting that these switch costs express distinct components of CF and AF. Table 1 also displays the correlations between the different types of switch costs and the self-report measures. All switch costs were unrelated to the self-report measure of CF.

**CF and AF as predictors for pain threshold and pain tolerance**

The relationship between the different types of cognitive and affective switch costs and all outcome variables was examined using Pearson’s correlations (Table 1). Very weak to weak correlations were found between the different cognitive or affective switch costs at one hand and pain threshold or pain tolerance at the other hand.

Variance inflation factors (VIFs; range 1.00–1.27) were checked for each hierarchical multiple regression model and suggested no collinearity problems between predictors. A nonsignificant regression model was identified for pain threshold, $R^2 = .05, F(5, 76) = .74, p = .60$. On the contrary, a significant regression model for pain tolerance was found, $R^2 = .17, F(6, 75) = 2.46, p < .05$. Sex showed to be a significant predictor of pain tolerance, but not of pain threshold, indicating that men exhibited a higher pain tolerance than women. Similar results were obtained when the regression analyses were performed with the backward deletion procedure for both pain threshold, $R^2 = .03, F(1, 80) = 2.54, p = .12$, and pain tolerance, $R^2 = .11, F(1, 80) = 10.0, p < .01$.

**CF and AF as predictors for retrospective pain experience ratings**

Pearson’s correlations did not reveal any significant associations between the cognitive or affective switch costs and the retrospective pain experience ratings neither for the threshold series (all ps ≥ .31, Table 1) nor for the tolerance series (all ps ≥ .32, Table 1). For each multiple regression model, VIFs (range 1.00–1.26) were checked and indicated no problems with collinearity between predictors. For the threshold series, nonsignificant regression models were identified for retrospective pain intensity, $R^2 = .11, F(6, 75) = 1.59, p = .16$, and fear of pain, $R^2 = .10, F(6, 75) = 1.45, p = .21$. Sex showed to be a significant predictor of both retrospective pain intensity ($β = .33, p < .01$) and fear of pain ($β = .30, p = .01$). The regression model for retrospective pain unpleasantness was significant, $R^2 = .17, F(6, 75) = 2.60, p < .05$, with sex as significant predictor ($β = .38, p = .001$), suggesting that men gave lower pain unpleasantness ratings than women. When applying backward deletion, significant regression models were identified for retrospective pain intensity, $R^2 = .11, F(1, 80) = 9.88, p < .05$, pain unpleasantness, $R^2 = .13, F(1, 80) = 12, p = .001$, and fear of pain, $R^2 = .09, F(1, 80) = 7.48, p < .01$, with sex as significant predictor in all models (pain intensity: $β = .33, p < .01$; pain unpleasantness: $β = .36, p = .001$; fear of pain: $β = .92, p < .01$).

For the tolerance series, analyses revealed no significant regression model for retrospective pain intensity, $R^2 = .08, F(6, 70) = 1.03, p = .41$, pain unpleasantness, $R^2 = .05, F(6, 70) = .55, p = .77$, and fear of pain, $R^2 = .07, F(6, 70) = .92, p = .49$. Sex was a significant predictor of retrospective fear of pain ($β = .27, p < .05$). Backward deletion yielded similar results for pain unpleasantness, $R^2 = .03, F(1, 75) = 2.35, p = .29$, but significant regression models for pain intensity, $R^2 = .06, F(1, 75) = 4.32, p < .05$, and fear of pain, $R^2 = .07, F(1, 75) = 5.83, p < .05$, with sex as significant predictor (pain intensity: $β = .23, p < .05$; fear of pain: $β = .27, p < .05$).

**Discussion**

The purpose of the present study was to investigate the link between two specific types of flexibility (i.e., CF and AF) and pain sensitivity outcomes (i.e., pain threshold, pain tolerance, and retrospective pain experience ratings). Results showed no evidence for the hypothesis that increased levels of CF and AF would be related to lower pain experience.

Current results are in disagreement with previous findings suggesting a relationship between CF and pain experience (Attal et al., 2014; Bjekić et al.,
2018; Moriarty et al., 2011; Oosterman et al., 2010). However, note that studies on the relation between CF and the experience of pain have predominantly focused on the effect of pain on cognitive switching performance, thereby demonstrating reduced switching performance when in pain (Boselie et al., 2014; Karp et al., 2006; Van Ryckeghem et al., 2012; Verdejo-Garcia et al., 2009). Although CF has been proposed as a precursor of prolonged pain responses as well (for a review, see Moriarty et al., 2011), empirical evidence on the direct relation between CF and pain is sparse. Using a prospective study design, Attal et al. (2014) demonstrated low levels of CF to be predictive of the development of postsurgical chronic pain. The present, short-term thermal stimulation as pain induction method might not be sensitive enough to capture the influence of a similar effect of flexibility on heat pain tolerance. Furthermore, we included a college student sample with relatively low variability in CF.

In the current study, we adopted a task-switching paradigm to assess CF (Boselie et al., 2017). Note that the definition of CF includes the ability of switching between tasks in accordance with changing environmental demands, and thereby implies that CF requires not only task-switching ability but possibly also the ability to inhibit prepotent, automatic responses, that is, cognitive inhibition. Indeed, cognitive inhibition is closely associated with cognitive task-switching ability (Miyake et al., 2000). Contrasting the available evidence on the link between task-switching performance and pain, several studies have reported better cognitive inhibition to be associated with reduced sensitivity for experimental pain (Bjekic et al., 2018; Karsdorp et al., 2014; Oosterman et al., 2010). It may be speculated that inhibition may be the component of CF that plays the most important role in pain perception (Miyake et al., 2000). Future research should therefore consider the use of different tasks specifically tapping into the inhibition and switching components of CF.

In line with earlier work (Meesters et al., 2019), we found no associations between AF and pain tolerance. The current study was designed to include a pain procedure that was better adapted to measure pain tolerance, because it has a smaller ceiling effect than the ischemic pain procedure in the previous study by Meesters et al. (2019). In addition, the use of thermal stimuli to induce pain also allowed a pain threshold measurement. However, we found no evidence for an association between AF and pain threshold, nor for retrospective pain experience ratings. So far, evidence only exists for an association between AF and recovery from ischemic pain with faster switches from neutral to positive contexts being beneficial for recovery (Meesters et al., 2019). We may therefore suggest that the link between AF and pain specifically applies to recovery from pain. Given the affective dimension of pain experience (e.g., Craig, 2003), recovery from pain entails recovery from an affective challenge. In other words, recovery involves a switch in affective contexts and hence may benefit from flexibility in attending to and disengaging from a painful stimulus. Also, flexibility involves faster and stronger responding to changing stimuli with a quicker return to baseline when the stimulus is not there anymore (e.g., Papousek et al., 2012), which seems to correspond to the warning function of pain to inform us about potential physical harm or illness as well as adaptive recovery when the painful stimulus has been removed. As AF is a relatively new concept, future studies seem necessary to aid understanding of AF and its relation to the experience of pain.

For the affective switching task, different switch costs could be calculated on the basis of the direction of the switch, that is, whether a switch was being made from the affective toward the neutral rule or vice versa. The current findings showed that individuals find it harder to switch away from processing negative information than from positive or neutral information. On the contrary, the fastest switches are made from processing neutral toward negative information. These results imply that the processing of negative information takes precedence over positive or neutral information.

Last, it should be noted that explorative correlational analyses showed zero to weak associations between the behavioral measure of CF and AF, and self-reported CF. This lack of an association is remarkable and hard to explain, especially given the conceptual overlap between the self-report and behavioral constructs of interest. One speculative explanation for the lack of correlations between the behavioral and self-report measure of flexibility might be sought in conceptual distinctiveness between the aspects of flexibility that are assessed by the instruments. Alternatively, resulting correlations might evidence a discrepancy between self-reported (explicit) and behavioral (implicit) flexibility measures (Fazio & Olson, 2003; Wilson et al., 2000). However, note that the aforementioned explanations are speculative at best, and in need of further scrutiny.
Some potential study limitations should be discussed. First, the study sample consisted of healthy pain-free students who were mainly highly educated women generally scoring high on self-reported CF, resulting in decreased generalizability of our findings. Second, a significant proportion of participants reached the predetermined maximum tolerance level. Nevertheless, sensitivity analyses did not show any effects of tolerance maximum on hypothesized associations. Furthermore, sample size is relatively low for the multiple correlations. Given the assumption that flexibility may be a predictor of maladaptive pain behavior and cognitions, study designs with long-term follow-up assessments and/or designs measuring flexibility in naturalistic settings to increase ecological validity may be more desirable. In addition, switch costs are widely distributed (Boselie et al., 2017, 2018; Meesters et al., 2019) and as a result may be less suitable for studying individual differences. We did not control for differences in general working memory ability which could have been important for switching task performance (Genet et al., 2013). Future studies should therefore control for general working memory ability.

We used heat stimulation to induce pain in the current study to more reliably assess pain threshold and tolerance. However, this prevented replication of the previously found association between AF and recovery from pain (Meesters et al., 2019). It remains elusive what the exact influence of the employment of different pain procedures in the current (i.e., heat stimulation) compared to the previous study (i.e., ischemic pain procedure; Meesters et al., 2019) may have been on study outcomes. Pain induced by heat stimulation is qualitatively different from pain induced by ischemic procedures. For instance, heat stimulation induces phasic pain, a short-lived type of pain with almost immediate recovery after stimulus removal. In contrast, ischemic procedures induce tonic pain—a relatively long-lasting type of pain—for which recovery typically takes longer as compared to phasic pain. Furthermore, the duration of the pain task in both studies (short vs. long) may be related to a difference in the need for coping, that is, pain of long duration may require more coping than phasic pain. Finally, the pain procedure allowed participants to terminate pain stimulation themselves, which might have induced a feeling of perceived control that affected pain sensitivity measures.

In conclusion, the present study did not find any evidence for the predictive value of CF and AF for heat pain threshold and tolerance. Furthermore, performance on both flexibility measures was not related to the subjective pain experience ratings (i.e., pain intensity, pain unpleasantness, and fear of pain for both pain threshold and tolerance series). Future research is necessary to further elucidate the role of flexibility as a steering mechanism in pain. Unraveling what psychological factors play a role in the perception of pain is worthwhile, as both prevention and therapy of chronic pain would benefit of such knowledge.

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**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Ethical approval**

All procedures performed in this study were in accordance with the standards of the Ethical Review Committee of the Faculty of Psychology and Neuroscience (ERCPN), Maastricht University. Informed consent was obtained from all individual participants included in the study.

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