Increasing Optimism Protects Against Pain-Induced Impairment in Task-Shifting Performance

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Disclosures

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Abstract

Persistent pain can lead to difficulties in executive task performance. Three core executive functions that are often postulated are inhibition, updating and shifting. Optimism, the tendency to expect that good things happen in the future, has been shown to protect against pain-induced performance deterioration in the executive function updating. This study tested whether this protective effect of a temporary optimistic state by means of a writing and visualization exercise extended to the executive function shifting. A 2 (optimism: optimism vs. no-optimism) x 2 (pain: pain vs. no-pain) mixed factorial design was conducted. Participants (N=61) completed a shifting task once with and once without concurrent painful heat stimulation following an optimism or neutral manipulation. Results demonstrated that shifting performance was impaired when experimentally heat pain was applied during task execution, and that optimism counteracted pain-induced deterioration in task shifting performance.

Perspective:

Experimentally induced heat pain impairs shifting task performance and manipulated optimism counteracted this pain-induced performance deterioration. Identifying psychological factors that may diminish the negative impact of persistent pain on the ability to function in daily life is imperative.

Key words: optimism; pain; shifting ability; executive functioning; deterioration.

Highlights

- Writing and visualizing about your best possible future self can increase optimism.
- Experimentally induced heat pain impairs shifting task performance.
- Manipulated optimism counteracts these pain-induced shifting impairments.

Introduction

Persistent pain can lead to difficulties in executive task performance. Prior studies on the interruptive effect of pain have routinely adopted dual-task paradigms that present painful stimuli during executive tasks performance [10, 48-50] to examine the ability of pain to capture attention at the expense of other ongoing activities [15-17, 20, 41, 42, 60, 77]. Attention is a cognitive process that enhances some information and inhibits other information from receiving further processing [55]. Attention relies on executive functioning, which is described as the ability to actively monitor behaviour, inhibit or facilitate certain responses, and optimise one's approach to unfamiliar circumstances [30, 45, 67]. There are three core executive functions that are often postulated, namely inhibition of prepotent responses (inhibition), updating and monitoring of working memory representations (updating) and shifting between mental sets or tasks (shifting) [45]. Studies have demonstrated that experimental [8, 10, 15-17, 48] and persistent pain [5, 6, 51] impairs the performance on tasks that reflect these executive functions.

The ability to shift requires individuals to allocate their attentional resources flexibly and fluently between multiple demands, by inhibiting irrelevant responses and facilitating relevant responses [30, 46, 67]. For instance, shifting ability enables a person to continuously switch between different languages in a conversation. Research has shown that shifting between tasks comes with a certain cost. Responses after a task switch are typically slower and less accurate compared to responses when repeating a task, which is called switch costs [2, 58, 78]. Experimentally induced pain in healthy participants has been found to increase these switch costs, leading to task shifting performance deterioration [48, 49, 76]. Moreover, persistent pain impairs task shifting performance in chronic pain patients [6, 50].

A possible factor that may counteract these pain-induced shifting impairments is optimism, the tendency to expect that good things will happen in the future [13]. Optimism, has been associated with beneficial coping strategies [57, 71], applying different coping strategies more flexibly [57, 71], reduced pain intensity [32, 43] and more goal attainment despite pain [1, 18]. We recently demonstrated that increasing optimism can diminish the deteriorating effect of experimentally induced pain on the executive function updating [8]. Drawn from the broaden-and-build theory [24-26], optimism may act as a protective factor, by (re)directing an individual's attention (i.e., the broaden hypothesis) towards accurate task performance and/or increasing cognitive or self-regulation resources (i.e., the build hypothesis). In the competing limited resources theory, both cognitive and self-regulation (i.e., the ability to control or alter thoughts, emotion and behaviour [11, 12]) resources are considered to be limited. Experiencing pain may fatigue these resources causing executive task performance to

decline [20, 68, 70]. Optimism may diminish self-regulatory fatigue by increasing cognitive or self-regulation resources, counteracting pain-induced task performance deterioration [35, 69, 70]. In the integrative neurocognitive model, bottom-up and top-down variables can modulate the ability of pain to capture an individual's attention at the expense of accurate task performance [42]. Optimism may increase top-down variables such as goal perseverance and effort leading to higher goal attainment [1, 13, 18, 62, 83].

This study examined whether the protective effect of manipulated optimism can be extended to the executive function shifting. Participants completed a shifting task once with and once without concurrent painful heat stimulation. Moreover, half of the participants received an optimism manipulation prior to the completion of the shifting tasks. It was hypothesized that (i) pain will decrease task shifting performance and (ii) increasing optimism counteracts the deteriorating effect of pain on task shifting performance.

Methods

Participants

A total of 65 healthy undergraduates from Maastricht University were recruited for this study. A minimal sample size of 40 participants (20 per group) was required and determined with G*Power [21] with the following parameters: $\alpha = .05$, power = .95, correlation among two repeated measures = 0.5 and an effect size of $\eta p^2 = .08$ (derived from our previous study [8]). Exclusion criteria were suffering from a chronic pain disorder or currently experiencing pain, being pregnant, suffering from heart or vascular diseases, wearing an electronic implant, being diagnosed with a psychopathological disorder in the past three months, taking anxiolytics or antidepressants or having participated in comparable prior experiments. As all the instructions and stimulus materials were in Dutch, good comprehension of the language was required. Participants could enrol themselves for a specific timeslot via an online system. A random allocation sequence was generated before the start of the study by the first author, which was used by the research assistants (i.e., experimenter) to assign the participants to a specific condition. Participants were not aware of the allocation.

Due to technical difficulties during testing, 2 participants had to be excluded from data analysis. Furthermore, although participants were informed that currently experiencing pain was an exclusion criterion;

two participants did report to experience pain on baseline and were therefore excluded from further data analysis. The remaining 61 participants (6 male) had a mean age of 21.48 (*SD* =2.47).

A 2 (optimism: optimism vs. no-optimism) x 2 (pain: pain vs. no-pain) mixed factorial design was employed, with optimism as between subjects factor and pain as within subjects factor. Participants were randomly assigned to one of the two conditions: (i) optimism (*n* = 31; 1 male, mean age = 21.65, *SD* = 2.97), (ii) no-optimism (*n* = 30; 5 male, mean age = 21.30, *SD* = 1.86). During recruitment, participants were informed that they would experience heat stimulation, which could be unpleasant. Participation was rewarded with a gift voucher of 15 Euro or course credit. The standing human subjects' ethics committee of the Faculty of Psychology and Neuroscience, Maastricht University approved the study protocol.

Manipulations

Optimism manipulation

Optimism was induced by the Best Possible Self (BPS) manipulation, a positive future thinking technique based on work by King [38]. Previous research has proven the effectiveness of the BPS in increasing positive affect, positive future expectancies and decreasing negative future expectancies [8, 32, 54]. Participants either received the BPS manipulation or the neutral manipulation (Typical Day: TD). In the BPS condition participants wrote about a life in the future where everything turned out for the best. In the TD condition participants wrote about a typical day. The instructions in the BPS and TD condition were identical to previous studies [7, 8, 54]. Both manipulations followed the same procedural format: 1 minute to think about what to write followed by uninterrupted writing for 15 minutes and ending with 5 minutes of imaging the story they just wrote. Instructions were given both verbally and in writing.

Pain manipulation

The Medoc Pathway Advanced Thermal Stimulator (ATS; Medoc Advanced Medical Systems, Ramat Yishai, Israel) was used to induce painful heat stimulation via a metal plate (3*3 cm) that was attached on the inner side of the wrist of the non-dominant hand. During a calibration phase, individual pain thresholds of participants were identified through the Medoc search protocol [49]. In this search protocol, heat stimulation starts at baseline temperature of 32°C and participants could increase or decrease the temperature by pressing

one of two buttons. Each button press would respectively increase or decrease temperature with 1.6˚C. The heat stimulation during the pain manipulation was based on the stimulus temperature that was selected as pain threshold in the calibration phase (up to a maximum of 48°C; all participants with thresholds higher than this were tested at a temperature of 48°C, thereby complying with safety protocol for heat pain stimulation). The heat stimulus started at the baseline temperature (32°C) to increase at a rate of 8°C/s to 1°C above the participant's pain threshold, where it oscillated for 10 oscillations 1°C above and 1°C below the threshold, before returning to baseline [49]. This cycle was repeated continuously until the shifting task was completed (duration between 4-8 minutes).

Measures

Executive functioning: task shifting

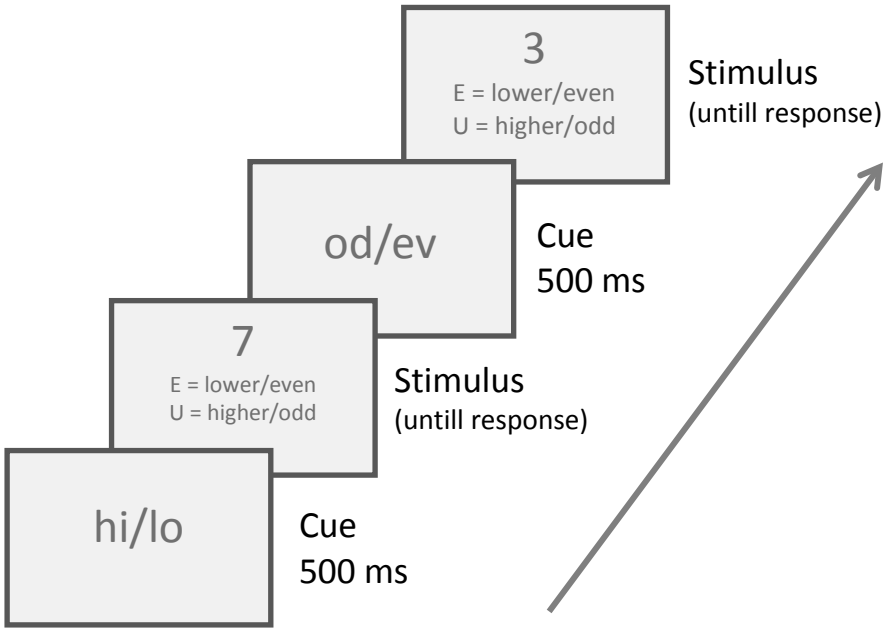
The task shifting paradigm is widely used as an approach to study mental set shifting [47, 66, 78], reflecting executive functioning [46], with reliability (e.g., calculated by adjusting split-half (odd–even) correlations with the Spearman-Brown prophecy formula) scores ranging from .46 to .91 [3, 33, 45, 66]. In the shifting task, 8 single-digit numbers (1, 2, 3, 4, 6, 7, 8, and 9) were presented one-by-one on a computer screen. Participants need to follow a discrete task rule on each trial, that can either change (i.e., switch trial) or remain the same (i.e., repetition trials) from one trial to the next. Participants had to follow 2 task rules, namely indicating whether the target number was higher or lower than 5 and indicating whether the target number was even or odd. The task rule (i.e., higher/lower or odd/even) that needed to be applied to each trial was briefly primed (500 ms) before the presentation of the target number [37, 44]. To keep the length of the priming cue similar, only the first two letters were given of each word (i.e. hi/lo or od/ev). The response time was not restricted; the target number was shown until a response was given by the participant on the two button response box. The mapping of response keys were randomized across participants. For example, the mapping could be that the participant had to press button E when the target number was lower than 5 or an even number. In contrast, the participant had to press button U when the target number was higher than 5 or an odd number. Which button corresponded to which option (e.g. E = lower/even and U = higher/odd) was simultaneously presented with the target number in order to ensure that participants were aware of the required sorting options.

Responses on a switch trial are typically slower and less accurate compared to responses on a repetition trial (i.e., switch costs). Additionally, the task distinguishes between congruent and incongruent trials. Congruent trials are trials for which the correct response is mapped to the same response button under both task rules, while for incongruent trials the correct response differs depending on the task rule. Responses on congruent trials are faster and more accurate compared to responses on incongruent trials (i.e., congruency effect) [2]. Sensitive switch costs are switch costs (i.e., switch minus repeat trials) on incongruent trials.

The shifting task consisted of a practice phase and testing phase. The practice phase included 12 trials, with six trials cueing the participant to classify the target number as higher as or lower than 5 and six trials where they had to classify the target number as odd or even. In the testing phase 192 trials were presented, with 96 switch trials of which 48 were congruent. The presentation of target numbers was fixed semi-randomized to ensure the previously mentioned distribution of switch and congruent trials. Additionally, the same priming cue was not allowed to be presented for more than 4 consecutive trials. Figure 1 depicts an example of two consecutive trials.

The total duration of the shifting task ranged from 4 to 8 minutes. Reaction times and accuracy were registered. The main outcome variables of the task are (sensitive) switch costs. The (sensitive) reaction time switch cost score is computed by subtracting (incongruent) repeat trials from (incongruent) switch trials, such that higher positive (sensitive) values are indicative that participants were slower to respond to switch trials than to repetition trials (i.e., larger switching cost). The (sensitive) accuracy switch cost score is computed by subtracting the proportion of correct responses on (incongruent) switch trials from the proportion of correct responses on the (incongruent) repeat trials, such that higher positive (sensitive) values are indicative that participants were less accurate on switch trials compared to repetition trials (i.e., larger switching cost).

Figure 1. Timeline of events in the task shifting paradigm, showing two consecutive runs of trials.



Baseline questionnaires

The Life Orientation Test-Revised (LOT-R) [61] measures dispositional optimism and consists of 10 items: 3 positively phrased items (e.g. 'I'm always optimistic about my future'), 3 negatively phrased items (e.g. 'I rarely count on good things happening to me') and 4 filler items (e.g., 'It's important for me to keep busy'). The items are rated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The total LOT-R score is obtained by summation of the scores on the positively phrased items and the reversed scores on the negatively phrased items and ranges from 10 to 30. Higher scores reflect higher levels of dispositional optimism. The LOT-R has been demonstrated to be a reliable and valid measurement instrument [61].

Pain Catastrophizing was measured by the Pain Catastrophizing Scale (PCS) [73].Participants indicate to what degree they experienced each of 13 stated thoughts and feelings while experiencing pain on a 5- point Likert scale, ranging from 0 (not at all) to 4 (all the time). An example of an item is 'I keep thinking about how much it hurts'. The total PCS score is obtained by summing the responses of all the 13 items (scores range from 0 to 52). Higher scores on the PCS indicate greater pain catastrophizing [53]. The PCS has been found to be a reliable and valid measurement instrument [53].

Manipulation checks

Effectiveness of the optimism induction was assessed by means of the Future Expectancies Scale (FEX) [19] and the Positive and Negative Affect Schedule (PANAS) [79]. The FEX measures positive and negative future expectancies. It consists of 20 items that make statements about positive (*n* = 10; e.g., 'people will admire you') and negative (*n* = 10; e.g., 'things will not turn out as you had hoped'') future events. The 20 statements cover 5 different domains (work, health, personal, social and general). Participants rate the likelihood that they will experience the specific events on a 7-point Likert scale, ranging from 1 (not at all likely to occur) to 7 (extremely likely to occur). Higher scores reflect a higher estimated likelihood of positive (FEX-Pos) or negative (FEX-Neg) future events, with scores ranging from 10 to 70. The internal consistency of the FEX subscales have been demonstrated to be satisfactory [32].

The PANAS consists of 20 items that measure positive (PA, 10 items) and negative (NA, 10 items) affect. Participants indicate the degree to which a certain feeling is present at that moment on a 5-point Likert scale ranging from 1 (not at all) to 5 (extremely). Examples of PA items are 'excited' and 'inspired'. Examples of NA items are 'nervous' and 'afraid'. Subscale scores can range from 10 to 50, with higher scores on NA items reflecting higher levels of emotional distress. In contrast, high PA scores correspond to experiencing more pleasurable feelings. The PANAS subscales have been demonstrated to be valid and reliable [14].

To assess whether the pain manipulation was successful, two Visual Analogue Scales (VASs) were administered to measure experienced pain intensity and fear of pain. Each VAS was anchored 0 (no pain/ fear of pain al all) to 100 (extreme pain / fear of pain).

Procedure

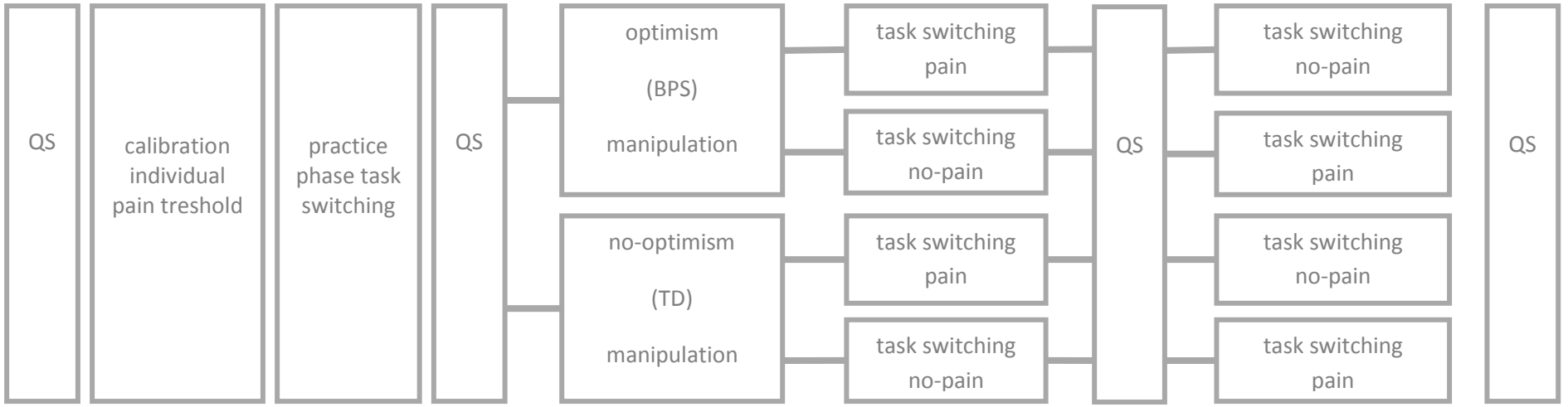
Before participants signed an informed consent, they were explicitly informed verbally about the procedure. Then participants completed the FEX, PANAS, LOT-R and the PCS questionnaires via computer. Next, participants completed the calibration phase to determine the participant's individual pain threshold level with the following instructions: 'When the procedure starts, the starting temperature will not be perceived as painful. The aim is to find the moment that you perceive the temperature as just painful. In order to detect this moment, you will be able to increase and decrease the temperature in little steps by clicking on the right or left mouse button. Please let me know when you feel you have found that moment.' When participants indicated that the temperature was 'just painful', they had to indicate next how painful the heat stimulation was verbally

on a scale of 0 (not at all painful) to 10 (extremely painful). Next, the selected heat stimulus was presented for 10 sec, after which participants rated the selected stimulus again. If participants rated the selected heat stimulus after 10 seconds below a 4, participants were asked again if they considered this temperature as 'just painful'. If this was not the case, participants were asked again to adjust the temperature until they identified their subjective pain threshold. The final rating was noted down by the experimenter. Individual pain threshold temperatures generated from the calibration phase were then used during the pain manipulation.

After the calibration phase, participants performed the practice phase of the shifting task. Subsequently, PANAS and FEX were administered via computer again as baseline measurement for the optimism manipulation check. Next, participant either received the BPS manipulation (optimism) or the TD manipulation (no-optimism). FEX and PANAS were administered again to check whether the manipulation was successful in increasing optimism and positive affect.

Next, the shifting task was completed once with and once without concurrent painful heat stimulation. The order was counterbalanced. The heat stimulation started immediately when the participant pressed on the 'yes' button after reading the task instructions of the shifting task and stopped when the task was completed. Only after task completion with painful heat stimulation, participants completed the VAS pain ratings on paper. See Figure 2 for an overview of the experimental procedure. Participants were then thanked for their participation and received their compensation. Participants were debriefed via e-mail after study completion. In total, the duration of the experimental lab session was approximately 1.5 hours.

Figure 2. Visual presentation of the experimental procedure.



Note: QS=questionnaires.

Data analyses

Data were checked for a normal distribution and reliability analyses were performed on the FEX, LOT-R, PCS and the PANAS questionnaires. One-way analyses of variances (ANOVAs) were used to check for baseline differences between the conditions (BPS vs. TD) on self-reported pain catastrophizing (PCS), optimism (LOT-R, FEX) and positive and negative affect (PANAS). Individual responses below 250 ms, or responses that deviated more than 3 x SD above group mean reaction time were omitted from further analysis (2, 36 %). Furthermore, reaction time analyses were conducted on correct responses only (5, 79% trials were omitted).

The effectiveness of the optimism manipulation on positive and negative affect and positive and negative future expectancies was tested with ANCOVAs with optimism condition (BPS vs TD) as between subjects factor and baseline scores of positive and negative affect (centered) and positive and negative future expectancies (centered) as covariates. The manipulation is successful when results show a significant main effect of optimism. This method of analysing is more powerful and precise than using repeated measures ANOVA in a randomized pre-post design [75].

Mixed ANOVAs, with optimism condition as between subjects variable, pain as within subjects variable and task shifting performance variables as dependent variables, were conducted to test the hypothesized interaction effect of pain and optimism on executive task performance. The dependent task shifting performance variables were switch cost reaction time (i.e., reaction time on a switch trial minus a repeat trial) and switch cost accuracy (i.e., accuracy percentage on a repeat trial minus a switch trial). Sensitive switch costs were calculated in the same way, but only incongruent trials were used. Planned follow-up analyses were conducted to test the hypothesis that pain has a deteriorating effect on executive task performance in the TD condition, but not in the BPS condition.

Results

Baseline descriptives

The internal consistency (Cronbach's alpha) was satisfactory for all the questionnaires (range .77-.90). Results of several ANOVAs with optimism as between subject's factor revealed no significant differences between the BPS and TD condition at baseline *(all p-values >.05).*

Optimism (BPS) manipulation check

The ANCOVAs revealed a significant main effect of optimism condition, controlling for the effect of scores obtained before the manipulation, for positive future expectancies (F (1, 58) = 9.01, p < 0.01, ηp^2 = .13), positive affect (F (1, 58 = 13.65, p < 0.001, ηp^2 = .19) and negative future expectancies (F (1, 58) = 6.49, p = 0.01, ηp^2 = .10). The optimism condition main effect was not significant for negative affect (F (1, 58) = 0.21, p = 0.65, ηp^2 = .00). Participants in the BPS condition scored higher on positive future expectancies (M =55.25, SD=3.41 vs. M =53.38, SD=3.46) and positive affect (M =31.24, SD=5.34 vs. M =27.62, SD=5.43), and scored lower on negative future expectancies (M =28.17, SD=4.91 vs. M =30.46, SD=5.00) than participants in the TD condition. Participants did not differ on negative affect (M =12.48, SD=3.45 vs. M =12.77, SD=3.50).

Pain manipulation

Individual pain threshold was identified during the calibration phase. The minimal obtained threshold temperature was 36.6 ˚C and the maximal threshold temperature was 46.5 ˚C, with a mean of 43.07 ˚C (SD = 2.28). The mean intensity score of the individual pain threshold during calibration was 5.11 (SD = 1.33). Following the task shifting completion with concurrent heat stimulation, participants reported on VAS scales a mean pain intensity of 44.28 (SD = 21.76) and a mean fear of pain of 24.21 (SD = 22.39).

Task shifting performance

Overall mean reaction times ((i) pain (mean = 1355.86 ms, SD = 519.09) and (ii) no-pain (mean = 1253.15 ms, SD = 508.70)) and accuracy scores (i) pain (mean = 94.26 %, SD = 6.43) and (ii) no-pain (mean = 95.06 %, SD = 6.27) were inspected to identify outliers (mean scores > 3 x SDs above/below the group mean). Six participants

(reaction time n=1, accuracy n=5) were removed from analyses that included the task shifting variables. Mean and standard deviation scores on the dependent task shifting variables are displayed in Table 1.

Results indicated a trend towards significance for the optimism condition x pain interaction effect on switch cost reaction time (F (1, 53) = 3.75, p = 0.06, ηp^2 = .07) and a significant optimism condition x pain interaction effect on sensitive switch cost reaction time (F (1, 53) = 6.67, p = 0.01, ηp^2 = .11). Sensitive switch costs per condition are displayed in Figure 3. Interaction effects on accuracy variables were not significant (all p values >.34). Planned follow-up paired t-tests indicated that participants in the TD condition were slower to respond when in pain (switch cost reaction time: t (25) = 3.25, p < .01, d = 1.30, 95% CI of d [0.69 to 1.91]; sensitive switch cost reaction time: t (25) = 3.85, p < .01, d = 1.54, 95% CI of d [0.91 to 2.17]). Of crucial importance, the deteriorating effect of pain on task shifting performance was not present in the BPS condition (switch cost reaction time: t (28) = 0.03, p = .97, d = 0.01, 95% CI of d [-0.51 to 0.54]; sensitive switch cost reaction time: t (28) = 0.28, p = .78, d = 0.11, 95% CI of d [-0.42 to 0.63]). Main effects of optimism condition and pain condition respectively on accuracy switch cost variables were not-significant (all p values >.42; all p values >.58).

Following visual inspection of Figure 3, t-tests within the pain condition and the no pain condition respectively were conducted. No significant differences between BPS and TD were observed on any of the outcome variables (pain: switch cost reaction time: t (53) = 1.10, p = .28, d = 0.30, 95% CI of d [-0.24 to 0.84]; sensitive switch cost reaction time: t (53) = 1.60, p = .12, d = 0.44, 95% CI of d [-0.10 to 0.99]; no-pain: switch cost reaction time: t (53) = 0.99, p = .33, d = 0.27, 95% CI of d [-0.27 to 0.81]; sensitive switch cost reaction time: t (53) = 1.77, p = .08, d = 0.49, 95% CI of d [-0.06 to 1.03]).

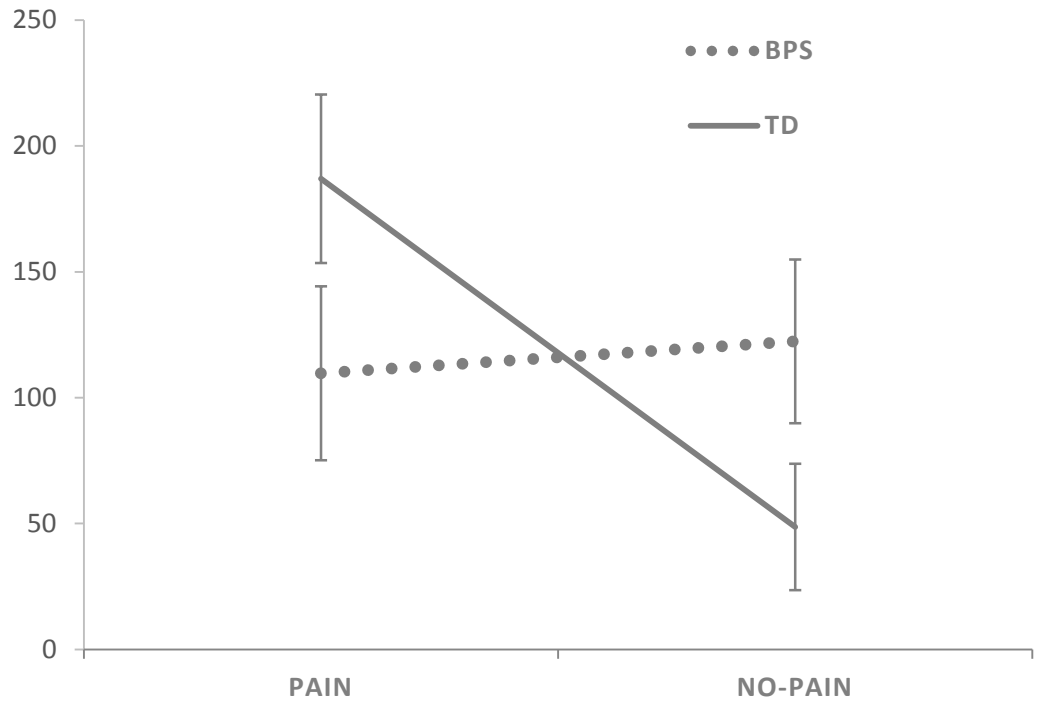
We repeated the analysis excluding the 6 male participants and results yielded comparable results, with the optimism x pain interaction effect on switch cost reaction time not reaching significance (F (1, 48) = 2.86, p = 0.10, ηp^2 = .06), but the optimism x pain interaction effect on sensitive switch cost reaction time remaining significant (F (1, 48) = 5.14, p = 0.03, ηp^2 = .10). More importantly, the pattern remained the same in that only participants in the TD condition showed pain-induced task deterioration.

Table 1. Means (M) and Standard Deviations (SD) for task shifting dependent variables, displayed per condition.

	Best Possible Self (optimism) (*n*=29)		Typical day (no-optimism) (*n*=26)		Total (*N*=55)	
	Pain *M (SD)*	No-pain *M (SD)*	Pain *M (SD)*	No-pain *M (SD)*	Pain *M (SD)*	No-pain *M (SD)*
Switch cost						
Reaction time (ms)	142.02 (133.50)	140.96 (143.61)	183.55 (147.79)	105.54 (117.47)	161.65 (140.68)	124.22 (131.91)
Accuracy (%)	1.62 (3.92)	.86 (2.72)	1.44 (2.45)	1.64 (2.89)	1.53 (3.28)	1.23 (2.80)
Sensitive switch cost						
Reaction time (ms)	109.67 (186.29)	122.38 (174.89)	186.96 (170.85)	48.61 (128.06)	146.20 (181.73)	87.51 (157.59)
Accuracy (%)	-.29 (2.28)	-.14 (3.20)	.32 (3.16)	.08 (2.32)	.00 (2.72)	-.04 (2.79)

Switch cost reaction time = reaction time switch trial minus reaction time repeat trial (ms); Sensitive switch cost reaction time = reaction time incongruent switch trial minus reaction time incongruent repeat trial (ms); Switch cost accuracy = mean accuracy percentage repeat trial minus mean accuracy percentage switch trial; Sensitive switch cost accuracy = mean accuracy percentage incongruent repeat trial minus mean accuracy percentage incongruent switch trial.

Figure 3. Results of the task shifting dependent variable sensitive switch cost (ms), displayed per condition. *Error bars represent standard errors.*



Discussion

The aim of the study was to examine whether experimental pain negatively affects concurrent executive task performance as measured by the shifting task, and whether optimism can protect against this deteriorating effect. Results demonstrate that shifting performance was impaired when experimental heat pain was applied during task execution, and that inducing a temporary optimistic state can counteract pain-induced deteriorating in task shifting performance. To be more precise, results indicated that decrements on (sensitive) switch cost reaction times were only apparent in the TD condition. Irrespective of pain, participants in the BPS condition showed comparable response times.

Prior research [10, 15-17, 20, 36, 41, 42, 48-50, 60, 77] has shown that pain attracts our attention which leads to pain-induced interference effects on concurrent task performance. The ability to shift requires individuals to switch their attention flexibly between multiple demands, by inhibiting irrelevant responses and facilitating relevant responses. In the context of pain, an individual not only needs to inhibit responding to the irrelevant task but also needs to inhibit responding to the pain stimulus. The ability to shift becomes compromised if attention towards the pain stimuli is prioritized over giving attention towards the shifting task or when pain decreases the existing resources that are necessary for fast and accurate task performance. The present results showed that pain indeed interferes with this shifting ability as responses after a task switch were slower. However, in contrast to prior studies [36, 49, 50], the presence of pain did not deteriorate task shifting accuracy. Thus, participants needed more time to arrive at the same accurate response when they experienced concurrent pain.

The primary purpose of this study was to examine whether optimism can protect against these pain-induced shifting impairments. Results showed that inducing a temporary optimistic state, by means of the Best Possible Self writing and visualization exercise was able to counteract the pain-induced interference effect on concurrent task shifting performance. There are several possibilities why optimism may act as a protective factor in this context. Within the context of the competing limited resources theory [19, 20] two potential mechanisms are proposed. First, optimism may increase cognitive or self-regulation resources, leading to an adaptation of the challenges of coping with pain while simultaneously performing a task [68-70]. Second, optimism may increase an individual's ability to prioritize attention towards accurate shifting performance and by preventing a predominant response to be interrupted by the pain. This protective effect of optimism may also

be explained within the context of the integrative neurocognitive model, that proposes that top-down variables can modulate the ability of pain to capture an individual's attention at the expense of accurate task performance [42]. Optimism may increase top-down modulation by increasing for instance goal perseverance and effort leading to higher goal attainment despite experiencing pain [1, 13, 18, 62, 83]. Both increasing resources and attention (i.e., by either prioritizing of attention or modulating top-down variables) are viable explanations of the protective ability of optimism from the perspective of the broaden-and-build theory [24]. This theory states that positive emotions are able to broaden an individual's attention and thinking pattern and build personal resources, causing an upward spiral to ensue in which building durable resources results in further positive emotions, in turn enhancing an individual's subsequent emotional well-being [24, 25, 27-29].

There are three core executive functions that are often postulated: inhibition, updating and shifting [45]. The current finding that optimism protects against the negative effects of pain on shifting ability is in line with our prior study that found a similar effect on the executive function updating [8]. However, it should be noted that this latter finding was not consistent. This protective effect of optimism was shown when updating was measured with the operation-span task [8] but not when using the 2-back task [7]. It is possible that optimism can only act as a protective factor when the task demand is high, increasing the attentional load, requiring more executive resources to be allocated to performing the task [40, 42, 59]. It might be suggested that the task load is higher in the shifting and operation-span task compared to the 2-back task. Taken together, these findings indicate that future research should examine whether task load is an important factor to consider when investigating pain and optimism effects on executive task performance.

The current findings might have clinical implications. Most of the prior discussed studies used experimental pain to examine its influence on time-limited and brief tasks in healthy participants, but persistent pain has also been shown to impair executive functioning in chronic pain patients [6, 51]. The current finding suggests that these pain-induced impairments may be an obstacle to accurately perform everyday tasks. As such, these impairments may have a marked impact on work performance. Indeed, one in four chronic pain patients report that their pain impacted their employment status [9] and pain is associated with marked loss in productive time due to reduced work performance [72]. Prior research has found that optimism is associated with experiencing less goal barriers and more goal attainment despite experiencing chronic pain [1, 13, 18].

Taken together with the current finding that optimism counteracts executive task deterioration, it is imperative to examine whether chronic pain patients can benefit from interventions aimed to increase optimism and positive emotions, such as acceptance and commitment therapy [74, 80], mindfulness-based cognitive therapy [31, 81], positive psychotherapy [63] or implementing positive psychology exercises [56, 64, 65, 82] in current treatment approaches such as cognitive-behavioural therapy [52]. Results of a recent published pilot study confirmed the feasibility and acceptability of an intervention based on positive psychology techniques such as the Best Possible Self exercise in chronic pain patients [23]. Similarly, a recently completed randomized controlled trial showed that this intervention can be delivered online. More importantly the intervention significantly increased happiness and optimism, and decreased pain catastrophizing and anxiety in chronic pain patients (Peters, unpublished data 2017). Next to these improvements on positive and negative trait and state variables, it should be further explored whether this positive psychology internet intervention can also counteract pain-induced cognitive impairments.

It should be noted that the current study had some limitations. The generalization of these results towards a chronic pain population is limited as the study sample consisted of healthy students that experienced experimentally induced pain. However, the pain stimulus was designed in a way to mimic the experience of persistent pain by using a continuous stimulation that fluctuates over time compared to a phasic stimulation. Furthermore, although the task switching paradigm is widely used as an approach to study mental set shifting and switch cost are a robust finding [47, 66, 78], reliability scores vary greatly ranging from .46 to .91 [3, 33, 45, 66], with many scores not meeting the recommended reliability criterion of. 70 [34]. Future research should attempt to gain more insight how reliability can be improved so it is possible to compare outcomes. Additionally, pain was not measured during task performance, as the very act of rating pain intensity would have disrupted task performance [39]. As a consequence, it is not possible to disentangle the effects of pain on task performance in function of the experienced pain intensity. Moreover, both positive affect and optimism were changed by the manipulation, reflecting the intertwined nature of affect and optimism. However, as we cannot separate these constructs, it remains unclear whether the protective effect demonstrated in this study is not merely the result of an overall positive emotional state. Furthermore, as the written narratives of the optimism manipulation are not analysed, we cannot check whether participants adhered to the instructions. Lastly, it is noteworthy to mention that predominantly female students participated in the study. Although females may exhibit greater pain sensitivity (e.g., lower pain threshold, tolerance and higher pain intensity)

than males [4, 22], a potential bias effect of gender is weakened in this study by using a calibration procedure to identify individual pain threshold levels.

In conclusion, the present study shows that experimentally induced pain impairs shifting task performance. Additionally, a brief optimism manipulation counteracted this pain-induced deterioration of shifting task performance. We aim to extend these findings to chronic pain patients and examine whether increasing optimism can also protect against executive functioning impairments due to chronic pain.

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