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Short title: Pain, Incentive, and Effort

Pain and Gain: Monetary Incentive Moderates Pain's Impact on Effort-Related Cardiac Response

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Abstract

Ample evidence suggests that pain leads to additional demand in cognitive functioning, presumably due to its negative affective component and its propensity to capture attention. To highlight the role of motivational incentive, two experiments tested the combined effect of pain and monetary incentive on effort-related cardiovascular response during cognitive performance. In both studies, healthy volunteers received individually adjusted painful or nonpainful thermal stimulations during a difficult cognitive task (4-back task in Experiment 1; short-term memory task in Experiment 2) and expected high (12 Swiss Francs in both experiments) or low monetary incentive (1 Swiss Franc in Experiment 1; 0.10 Swiss Francs in Experiment 2) for successful performance. Effort was primarily assessed as changes in cardiac pre-ejection period (PEP). We predicted pain to increase subjective task difficulty during cognitive performance. Moreover, according to motivational intensity theory, we expected this to increase effort only when high effort was justified by high monetary incentive. Correspondingly, pain should lead to low effort (disengagement) when monetary incentive was low. Effort in the nonpainful conditions was expected to fall in between these conditions. The results of both studies support our predictions. Our findings provide the first evidence for the moderating effect of monetary incentive on physical pain's impact on effort-related cardiovascular response. Accordingly, motivational incentives can counteract effort deficits associated with pain.

Keywords: Pain; Effort; Cardiovascular Reactivity; Monetary Incentive, Pre-ejection period

1. Introduction

Pain is defined as "an unpleasant sensory and emotional experience associated with (…) actual or potential tissue damage" (Raja et al., 2020). The present research tested whether experimentally manipulated pain influences effort-related cardiovascular responses during cognitive performance and highlighted the role of monetary incentive—a prominent motivational variable—in this process. There is ample evidence that pain interacts with cognitive, affective, and social factors (Gatchel et al., 2007). Chronic pain—i.e., pain that lasts for more than 3 to 6 months—is associated with negative psychological states such as depression (Miller & Cano, 2009) and fatigue (Van Damme et al., 2018) and strongly impairs well-being, social life, work, and daily life activities (Breivik et al., 2006). Moreover, individuals with pain often show motivational deficits (Becker et al., 2018) and disengagement from personal or professional goals (Affleck et al., 2001; Becker et al., 2018; Crombez et al., 2016). These findings suggest that pain should influence effort—the mobilization of resources for action execution (Gendolla & Wright, 2009). However, to date very little research directly investigated the pain – effort link. To advance our understanding of this issue, we thus tested in healthy volunteers whether monetary incentive moderates pain's impact on effort-related cardiovascular response during the execution of difficult cognitive tasks. In the tradition of research on motivational intensity theory (Brehm & Self, 1989), we objectively assessed effort intensity in terms of sympathetically mediated responses in the cardiovascular system (see Gendolla et al., 2012, 2019; Richter et al., 2016; Wright & Kirby, 2001, for reviews).

1.1 Pain's Impact on Cognitive Functioning

Pain is fundamental for survival—its primary function is to signal potential threat to the organism and to urge adaptive action (Eccleston & Crombez, 1999; Kumazawa, 1996; Melzack & Casey, 1968). Theories thus suggest that pain captures attention, presumably due to its aversive affective component, and interrupts ongoing behavior to cope with the threatening situation (e.g., Eccleston & Crombez, 1999; Legrain et al., 2009). Accordingly, numerous studies found that both acute and chronic

pain impair cognitive performance (Bell et al., 2018; Berryman et al., 2013, 2014; Kuhajda et al., 2002; Moriarty et al., 2011)—but these effects seem to be restricted to demanding, complex tasks involving executive or attentional functions (Buhle & Wager, 2010; Moore et al., 2012, 2019; Oosterman et al., 2012). Moreover, coping with pain requires cognitive control (Bushnell et al., 2013; Lorenz et al., 2003). Overall, these findings suggest that pain and cognitive control share common and limited resources such as attention and/or working memory. This indicates that pain taxes resources for cognitive performance and should therefore have effects on cognitive effort. However, theories with specific predictions about pain's impact on effort are lacking. Consequently, we build our analysis on motivational intensity theory (Brehm & Self, 1989), a well-established general effort theory, and integrate the above-discussed pain effects into this framework.

1.2 Motivational Intensity Theory

Motivational intensity theory (Brehm & Self, 1989) postulates that effort is determined by subjective task difficulty and success importance. Subjective difficulty refers to the evaluation of required effort to succeed on a task, whereas success importance determines how much effort is justified for success (i.e., potential motivation). The theory builds on the idea that effort is grounded in a resource conservation principle. Consequently, people avoid the waste of effort (rather than effort itself) and should thus not engage more effort than is required and justified for attaining a goal. Therefore, when task difficulty is fixed and known, motivational intensity theory predicts that effort increases proportionally with subjective task difficulty as long as success is possible and the required effort is justified by success importance. When a task is too difficult or when the required effort is not justified, individuals should disengage to avoid wasting resources, resulting in low effort.

Success importance determines the magnitude of maximally justified effort (i.e., potential motivation) for achieving a goal and can be influenced by various factors such as needs, instrumentality, or incentives. High incentives increase success importance and thus the magnitude of justified effort.

Therefore, for difficult tasks, high incentive justifies the high required effort, whereas low incentive should lead to disengagement. Numerous studies have supported motivational intensity theory's predictions especially regarding effort-related responses in the cardiovascular system (see Gendolla et al., 2012, 2019; Richter et al., 2016; Wright, 1996, for reviews).

1.3 Effort-Related Cardiovascular Response

Wright (1996) has integrated motivational intensity theory with Obrist's active coping approach (1981), which posits that beta-adrenergic sympathetic impact on the myocardium responds to different levels of task engagement (Obrist, 1976, 1981). Accordingly, the purest non-invasive effort measure is cardiac pre-ejection period (PEP)—the time interval between the left ventricular excitation and the opening of the aortic valve (Berntson et al., 2004). This is because PEP reflects myocardial contractile force, which depends on beta-adrenergic sympathetic impact (Newlin & Levenson, 1979). Numerous studies found that PEP reactivity responds to variations in task difficulty (e.g., Richter et al., 2008) and incentives (e.g., Richter & Gendolla, 2009), as predicted by motivational intensity theory.

Also systolic blood pressure (SBP) has been used as effort indicator in many studies (see Wright & Kirby, 2001). This is because SBP is systematically influenced by cardiac contractility through its impact on cardiac output. However, SBP also depends on peripheral vascular resistance, which is not systematically influenced by beta-adrenergic activity (Levick, 2010). There is also evidence that diastolic blood pressure (DBP) can respond together with PEP and SBP (e.g., Brinkmann & Gendolla, 2007). However, DBP is still more strongly influenced by peripheral resistance than SBP. Also heart rate (HR) can reflect effort (e.g., Richter & Gendolla, 2007; Zafeiriou & Gendolla, 2017) but only when it relies more on sympathetic than parasympathetic activity, which is not always the case (Berntson et al., 2004). Therefore, PEP is considered as the most sensitive and reliable effort measure among these cardiovascular activity indices because it is the purest indicator of beta-adrenergic sympathetic impact

(Kelsey, 2012; Wright, 1996). However, blood pressure and HR should always be assessed together with PEP to mirror possible cardiac preload and vascular afterload effects on PEP (Sherwood et al., 1990).

1.4 Pain's Impact on Effort-Related Cardiovascular Response

Drawing on the literature on pain's role in cognitive processes, we posit that pain increases subjective difficulty during the execution of cognitive tasks. This is because pain adds supplementary demand in cognitive functioning (Buhle & Wager, 2010), presumably due to its negative affective component and its attention capture (Eccleston & Crombez, 1999; Legrain et al., 2009). Imbedding this idea into motivational intensity theory, we expect that pain should influence effort due to its impact on subjective task difficulty. Supporting this idea, we previously found that painful stimulations indeed increased subjective task difficulty and effort-related cardiovascular responses in an easy memory task (Cancela & Silvestrini, 2021). Another study found that pain increased effort to compensate for pain's disruptive effects on task performance in a demanding cognitive task (Pickering et al., 2021). To fully understand how pain influences effort, we relied on motivational intensity theory (Brehm & Self, 1989) and highlighted the combined effect of pain and effort justification by monetary incentive on effort-related cardiovascular response.

1.5 The Present Studies

In two experiments, participants performed a difficult cognitive task (4-back task in Experiment 1; short-term memory task in Experiment 2) during which we administered individually-adjusted painful or nonpainful thermal stimulations. Additionally, participants expected a low or high monetary incentive for success defined as meeting a performance standard. Effort was assessed as cardiovascular responses, especially PEP, during task performance.

Due to pain's additional demand in cognitive functioning (Buhle & Wager, 2010), we expected the tasks to be perceived as more difficult when participants received painful stimulations. Therefore, drawing on motivational intensity theory (Brehm & Self, 1989), we predicted the lowest effort when

participants received painful stimulations together with low incentive. We did so because low incentive should not justify the high effort required by the subjectively high demand due to pains' difficulty increasing effect in the objectively hard task, leading to disengagement. In contrast, we expected the highest effort when participants received painful stimulations and expected high monetary incentive for success, because the high incentive should justify the high effort required by the objectively difficult task with pain. That is, pain should lead to high or low effort in dependance on the value of monetary success incentive. For the nonpainful heat conditions, we expected moderate effort regardless of incentive. This was because the effort required by the difficult task without pain should be justified in both incentive conditions. Our effort predictions are depicted on Figure 1. We did not have clear predictions about task performance, which can vary together with effort but is also determined by other factors such as capacity, persistence, or strategies (Locke & Latham, 1990).

2. Experiment 1

Our first study tested our predictions using a difficult 4-back task. Sessions started with a calibration procedure to individually determine the adjusted temperatures for painful and nonpainful stimulations. This was followed by a habituation period to assess cardiovascular baseline activity. Then, participants completed 4 experimental conditions in which they performed the 4-back task with concurrent painful or nonpainful thermal stimulations while they expected low or high monetary incentive for successful performance. Cardiovascular activity was assessed simultaneously.

2.1 Method

2.1.1 Participants and Design

Thirty healthy volunteers (15 women, 15 men; mean age 22 years [18-33]) were recruited by announcement at the University of Geneva and received 40 Swiss Francs for their participation (about 42 USD). Participants reported by email before the experiment and again orally on the day of their experimental session that they were not taking any medication and were free of acute or chronic pain,

and cardiovascular, neurological, or psychological disease. Moreover, only women using means of contraception were included in the study to assure that they were not pregnant. The study followed a 2 (Stimulation: pain, heat) x 2 (Incentive: low, high) within-persons design. The sample size was based on an a priori power analysis with G*Power 3 software (Faul et al., 2007). We aimed at detecting significant effects (alpha 5%) of medium size (η^2 = 0.06) with 80% power, which required a sample of 20 participants. However, we decided to collect data from 30 participants to compensate for possible data loss due to technical issues with the pain manipulation and the physiological measures. We did not exclude any participants from the statistical analyses and we did not recruit additional participants after data analyses.

2.1.2 Material

The experimental procedure was programmed with MATLAB using the Psychtoolbox (Brainard, 1997). The used materials and procedures had been approved by the ethics commission of the State of Geneva.

2.1.2.1 Thermal Stimulations

We used a computer-controlled thermal stimulator and a 25 x 50-mm fluid-cooled Peltier thermode (MSA Thermotest, Somedic SenseLab, Sösdala, Sweden) to administer painful and nonpainful stimulations. The thermode was placed on the left side of the participant's left leg below the middle of the tibia and delivered thermal stimulations ranging from 41°C to 49°C. The baseline temperature was set to 36°C and each stimulation lasted 16 seconds (3 seconds of temperature increase, 10 seconds of plateau, and 3 seconds of temperature decrease).

2.1.2.2 Cognitive Task

Participants performed a 4-back task. Sequences of single letters were presented on the computer screen and participants determined for each appearing letter whether it was identical with the letter presented 4 positions earlier or not, which is objectively difficult. Trials started with a fixation cross

(500 ms) followed by a letter that appeared for 3000 ms. Participants responded during each letter presentation by pressing a green “yes” or red “no” key, respectively, with two fingers of their dominant hand, and received the neutral feedback “response entered” or “please respond faster” in case of a lacking response (500 ms). The task took about 3 minutes and comprised 48 trials including 13 target (yes-responses) and 35 non-matched trials (no-responses).

2.1.2.3 Physiological Apparatus

PEP (in milliseconds [ms]) and HR (in beats per minute [bpm]) were assessed by measuring electrocardiogram (ECG) and impedance cardiogram (ICG) signals with a CardioScreen 2000 system (medis, Ilmenau, Germany). Four pairs of electrodes were placed on the left and right side of the base of participant’s neck and on the left and right middle axillary line at the level of the xiphoid. The resulting signals were sampled at 1000 Hz. Additionally, we assessed SBP and DBP (in millimeters of mercury [mmHg]) by means of a NIBP SunTech module (medis, Ilmenau, Germany) integrated in the CardioScreen 2000, using oscillometry. A blood pressure cuff was placed over the brachial artery above the elbow of the participant’s nondominant arm, which was automatically inflated in 1-min intervals.

2.1.3 Procedure

After giving signed consent and answering demographic questions (age, sex, and medical history), participants took a seat in a comfortable chair in front of a computer. The experimenter then attached the electrodes, blood pressure cuff, and the thermode on the participant.

Sessions started with a calibration period to determine the temperature of the painful and nonpainful stimulations. For each participant, we gradually increased and decreased the stimulation temperature 3 times. The first stimulation was administered at 39°C and the temperature of the following stimulations increased by steps of 2°C until participants rated the stimulation to be at least 7 of 10 on a modified visual analog scale (VAS; [0] no sensation, [1] nonpainful warmth, [2] just painful, [5] moderate pain, [8] strong pain and [10] the strongest pain). From there, the temperature decreased by

steps of 2°C until participants rated pain to be lower than 1 of 10. In the second stimulation, the temperature increased by steps of 1°C until pain ratings reached 7 of 10 and then decreased until the ratings were 4 of 10. In the last stimulation, the temperature increased and decreased by steps of 0.5 °C following the same turning point rules as during the previous stimulations. We created a scatterplot for each participant displaying the administered temperature on the x-axis and pain responses on the y-axis. By visual inspection, we selected the nonpainful temperature as corresponding to pain ratings of 1/10 on the VAS – i.e., nonpainful warmth. Moreover, we selected the painful temperature as corresponding to pain ratings of 7/10 – i.e., moderately intense pain. In the main experiment, participants consistently received their individually determined temperatures for the painful and nonpainful stimulations.

After the pain calibration, participants performed 19 practice trials of the 4-back task. Each trial ended with feedback indicating correct, incorrectly, or too slow responses. After this task practice, the experimenter started the main experiment and left the participants alone.

The main procedure started with a hedonically neutral film (8 minutes) showing the river Rhône in Geneva for the cardiovascular baseline activity measures. ECG and ICG signals were continuously measured and blood pressure was recorded each minute. All measures were automatically registered.

Next, participants performed the four experimental conditions in random order. They worked on the difficult 4-back task and concurrently received 5 painful (pain condition) or nonpainful thermal stimulations (heat condition). The thermal stimulations were administrated at approximately 20 seconds, 56 seconds, 1 minute 36 seconds, 2 minutes 16 seconds, and 2 minutes 56 seconds after block onset (range of interstimulation intervals = 36 to 40 seconds). Before each condition block, participants were informed that they could earn 1 Swiss Franc (about 1 USD) in the low incentive condition or 12 Swiss Francs (about 12 USD) in the high incentive condition if they made at least 80% correct responses in the task. Again, ICG and ECG signals were continuously recorded and blood pressure was measured each minute during the task. At the end of each block, participants rated their experienced pain associated

with the thermal stimulations they had received using the VAS and subjective task difficulty on a 10-point scale (1 = *not at all difficult*, 3.5 = *moderately difficult*, 7 = *extremely difficult,* 10 = *impossible*). Participants had 2-minute breaks between the condition blocks. After the last experimental block, the apparatus was removed and participants were thanked, debriefed, and received their remuneration. An experimental session took about one and a half hours. An overview of the study procedure is presented in Figure 2.

2.1.4 Data Analysis

The data and data coding for the here reported studies are available on Yareta—the open access data archiving server of the University of Geneva: https://doi.org/10.26037/yareta:ntobob5vv5e6xgwhetznzjavye

ECG and ICG signals were analyzed offline (50 Hz low pass filter) with Bluebox 2 (version 1.22) software (Richter, 2010). R-peaks were identified using a threshold peak-detection algorithm and visually confirmed (Lippman et al., 1994). The first derivative of the change in thoracic impedance was computed, and the resulting dZ/dt signal was ensemble averaged over periods of 1 minute using the R-peaks (Kelsey & Guethlein, 1990). R-onset and B-point were automatically scored for each artefact-free ensemble average. B-point location was estimated based on the RZ interval as proposed by Lozano et al. (2007), visually inspected, and corrected if necessary as recommended by Sherwood et al. (1990). PEP was determined as the time interval (in ms) between the ECG R-onset and the ICG B-point (Berntson et al., 2004). Shorter PEP indicates stronger beta-adrenergic sympathetic impact on the heart and therefore higher effort intensity. HR (in bpm) was calculated by means of the detected R-peaks. Values of blood SBP and DBP (in mmHg) were stored in 1-min intervals. For researchers interested in more detailed hemodynamic responses that were unrelated to our hypotheses, analyses of cardiac output and total peripheral resistance are accessible in the Supplementary Materials.

We tested our theory-based predictions with a priori contrast analyses, which are the most powerful and thus most appropriate statistical tool to test predicted patterns of means (Furr & Rosenthal, 2003; Rosenthal et al., 1985; Wilkinson & The Task Force on Statistical Inference, 1999). We predicted that monetary incentive would moderate pain's impact on effort by defining the magnitude of justified effort in the objectively difficult task, in which pain should increase subjective task difficulty. As it was depicted in Figure 1, we thus expected the lowest cardiovascular reactivity in the Pain/Low-Incentive condition (contrast weight = -2) due to high subjective task difficulty but low justified effort, leading to disengagement. The strongest reactivity was predicted for the Pain/High-Incentive condition (contrast weight = + 4) due to high subjective task difficulty and high justified effort. For the nonpainful heat condition, we expected intermediate reactivity in both incentive conditions, (contrast weights = -1), because there was no pain that increased subjective demand and already the low incentive should have been sufficient to justify the necessary effort. Due to our directed hypotheses, we applied one-tailed tests for directed follow-up cell contrasts that further tested the predicted differences between the conditions.

Finally, to test for potential time effects during the 3 minutes long blocks, we tested Contrast x Time interactions for each cardiovascular reactivity index. We analysed time effects using a linear contrast expecting a decrease in cardiovascular reactivity from the first to the last minute of the task—i.e., habituation or learning (Framorando & Gendolla, 2018; Silvestrini & Gendolla, 2011). In case of significant interactions, we tested our contrast on cardiovascular reactivity for each of the 3 minutes of the experimental blocks. As we had no specific theory-based predictions about task performance effects, response accuracy and reaction times for correct responses and also the ratings of subjective task difficulty and pain were analyzed with conventional explorative 2 (Stimulation) x 2 (Incentive) repeated measures ANOVAs.

We excluded reaction times exceeding the mean for each participant and condition for more

than 2 *SD*s. Moreover, extreme values and outliers of each cardiovascular reactivity and behavioural measure were recoded using winsorized means (k = 5) (Leys et al., 2019; Tukey & McLaughlin, 1963). We replaced scores above 95th and below the 5th percentile by the value of the observations at the 95th and the 5th percentile, respectively. We measured accuracy as the percentage of correct responses (hits and correct responses to non-matched trials) over the total trials.

2.2 Results

2.2.1 Cardiovascular Baselines

We used the STATISTICA software package (version 13.1, StatSoft Inc, Tulsa, OK) to analyze the data. A preliminary repeated measures ANOVA of the baseline PEP and SBP measures found a time main effect on SBP (p < .001) but not on PEP (p = .149). The SBP baseline scores decreased from the first to the third minute (ps < .01), remained stable until the sixth minute (ps > .05), decreased until the seventh minute (p < .001) and remained stable again until the eighth minute (p = .289). Consequently, we computed baseline scores by averaging measures of the last two minutes (rs > .96) for PEP (M = 99.72, SE = 2.31), SBP (M = 116.47, SE = 1.84), DBP (M = 72.28, SE = 1.35) and HR (M = 77.2, SE = 2.10).

2.2.2 Cardiovascular Reactivity

Cardiovascular change (delta-) scores were computed for each participant and each cardiovascular measure by subtracting the baseline scores from the 1-min scores obtained during the experimental conditions (Llabre et al., 1991), which showed high internal consistency (Cronbach's alphas > .93).

We first tested for significant associations between the cardiovascular baseline and reactivity scores with repeated measures ANCOVAs with the baseline scores as covariates. There were neither statistically significant main effects of covariates on any reactivity measures (ps > .12) nor interactions between the covariates and the experimental conditions (ps > .11). Baseline scores were therefore not further considered as covariates in the subsequent analyses. Moreover, additional preliminary 2 (Sex) $\times$ 2

(Stimulation) x 2 (Incentive) repeated measures ANOVA did not reveal any significant sex main or interaction effects (*p*s > .32). Participants' sex was therefore also not further considered.

2.2.2.1 Pre-Ejection Period Reactivity

The a priori contrast was significant for PEP reactivity, $F(1,29) = 9.80$, $p = .004$, $\eta_p^2 = .25$, whereas the Contrast x Time interaction was not significant ($p = .879$). As depicted in Figure 3 (Panel A), the pattern of PEP reactivity largely supported our predictions with the strongest reactivity in the Pain/High-Incentive condition ($M = -5.54$, $SE = 1.07$) and the lowest reactivity in the Pain/Low-Incentive condition ($M = -3.02$, $SE = 1.18$). A focused cell contrast revealed that this difference was significant, $t(29) = 3.32$, $p = .001$, $\eta_p^2 = .28$. This indicates that monetary incentive moderated pain's impact on effort. Moreover, PEP reactivity in the Heat/Low-Incentive ($M = -3.48$, $SE = 0.92$) and in the Heat/High-Incentive conditions ($M = -4.86$, $SE = 1.29$) fell in between these conditions. However, further cell comparisons were not significant (*p*s > .06).

2.2.2.2 Systolic Blood Pressure Reactivity

The a priori contrast was also significant for SBP reactivity, $F(1,29) = 9.47$, $p = .005$, $\eta_p^2 = .25$, whereas the Contrast x Time interaction was not ($p = .627$). Figure 3 (Panel B) shows that also the pattern of SBP reactivity followed our effort-related predictions with the strongest reactivity in the Pain/High-Incentive condition ($M = 10.59$, $SE = 1.42$) and the lowest reactivity in the Pain/Low-Incentive condition ($M = 8.22$, $SE = 1.16$). A cell contrast found that this difference was significant, $t(29) = 3.25$, $p = .002$, $\eta_p^2 = .27$. Moreover, SBP reactivity in the Heat/High-Incentive ($M = 9.92$, $SE = 1.15$) and in the Heat/Low-Incentive conditions ($M = 8.45$, $SE = 1.06$) fell in between these conditions, but they also tended to differ, $t(29) = 1.97$, $p = .06$, $\eta_p^2 = .12$. Other comparisons were not significant (*p*s > .16).

2.2.2.3 Diastolic Blood Pressure Reactivity

The a priori contrast, $F(1,29) = 3.12$, $p = .088$, $\eta_p^2 = .10$, and the Contrast x Time interaction ($p = .468$) were both not significant. Cell means and standard errors were as follows: Pain/Low-Incentive ($M =$

7.12, *SE* = 0.73), Heat/Low-Incentive (*M* = 6.83, *SE* = 0.60), Pain/High-Incentive (*M* = 7.70, *SE* = 0.65) and Heat/High-Incentive (*M* = 7.65, *SE* = 0.74).

2.2.2.4 Heart Rate Reactivity

Neither the a priori contrast, $F(1,29) = 1.58$, $p = .219$, $\eta_p^2 = .05$, nor the Contrast x Time interaction were significant ($p = .066$). Cell means and standard errors were as follows: Pain/Low-Incentive (*M* = 7.13, *SE* = 0.93), Heat/Low-Incentive (*M* = 6.18, *SE* = 1.04), Pain/High-Incentive (*M* = 8.08, *SE* = 1.26) and Heat/High-Incentive (*M* = 8.27, *SE* = 0.95).

2.2.3 Task Performance

A 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of response accuracy did not reveal any significant effect (*p*s > .16; average *M* = 81.21%, *SE* = 1.53). Also, the ANOVA of reaction times (in ms) for correct responses did not reveal any significant effect (*p*s > .16). The average reaction time was *M* = 1160.34 ms (*SE* = 50.08). Cell means and standard errors of the percentage of correct responses and reaction times are reported in the Supplementary Materials, Table S2.

2.2.4 Pain Ratings

A 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the pain ratings revealed a strong Stimulation main effect, $F(1,29) = 194.39$, $p < .001$, $\eta_p^2 = .87$. Accordingly, painful stimulations were as intended perceived as more painful (*M* = 59.10, *SE* = 3.07) than nonpainful stimulations (*M* = 13.74, *SE* = 1.63). This indicates a successful pain manipulation. Other ANOVA effects were not significant (*p*s > .48). Cell means and standard errors of pain ratings can be found in the Supplementary Materials, Table S2.

2.2.5 Subjective Task Difficulty

The 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of participants' subjective task difficulty ratings revealed the expected significant Stimulation main effect, $F(1,29) = 20.34$, $p < .001$, $\eta_p^2 = .41$. As predicted, the task was perceived as more difficult in the pain (*M* = 6.67, *SE* = 0.21) than in the heat condition (*M* = 6.00, *SE* = 0.24), supporting our idea that pain increases subjective demand. No

other ANOVA effects were significant (*p*s > .10). As depicted in Figure 4, cell means and standard errors were as follows: Pain/Low-Incentive (*M* = 6.53, *SE* = 0.24), Heat/Low-Incentive (*M* = 5.92, *SE* = 0.30), Pain/High-Incentive (*M* = 6.81, *SE* = 0.23) and Heat/High-Incentive (*M* = 6.09, *SE* = 0.22).

2.3 Interim Discussion

The results of Study 1 largely supported our theory-based predictions about the moderating effect of monetary incentive on pain's impact on effort-related cardiovascular response. According to the verbal measures, pain was efficiently manipulated and increased, as expected, subjective task difficulty. This supports the idea that pain adds supplementary demand to cognitive functioning and increases subjective task difficulty in cognitive tasks (Buhle & Wager, 2010; Legrain et al., 2009). Most important, the *a priori* contrast was significant for PEP, our most reliable measure of effort, and SBP. In support of our predictions, the observed cardiovascular reactivity patterns showed the strongest response in the Pain/High-Incentive condition compared to the Pain/Low-Incentive condition, in which reactivity was the weakest. This supports our expectation that high monetary incentive should justify the very high necessary effort for the objectively difficult 4-back task with simultaneous pain. In contrast, the low monetary incentive did not justify the high necessary effort, leading to disengagement. Accordingly, high incentive could indeed compensate the effort deficit induced by pain during a difficult task. These results indicate for the first time a moderation of experienced pain's impact on effort by monetary incentive, supporting the principles of motivational intensity theory (Brehm & Self, 1989) under consideration of the demand increasing effect of pain.

As a limitation of our findings, focused cell comparisons for PEP (and SBP) reactivity did not reveal significant differences between the pain and heat conditions within the low and high incentive conditions. Considering that participants' pain ratings indicated a clearly successful pain induction makes it difficult to explain this limitation. Nevertheless, Experiment 1 provided support for our central theory-based prediction that monetary incentive moderates pain's impact on effort-related cardiovascular

response. To follow up on this new finding, we conducted a second study that addressed the present experiment's limitation. To conceptually replicate the findings of Study 1, we basically applied the same methods with only some few changes in the procedure. More specifically, we reduced the low monetary incentive to reduce the magnitude of justified effort. We did so to find a clearer disengagement in the Pain/Low-Incentive condition than in Study 1. Moreover, to generalize the findings to another type of cognitive task, we used a difficult short-term memory task adapted from Bijleveld (2018).

3. Experiment 2

To conceptually replicate the findings of our first study, we basically applied the same methods with some few changes in the procedure. More specifically, we used a difficult short-term memory task adapted from Bijleved (2018) and we reduced the low monetary incentive to reduce the magnitude of justified effort. Accordingly, we expected to observe a stronger disengagement in the Pain/Low-Incentive condition, the strongest effort-related cardiovascular responses in the Pain/High-Incentive condition, and reactivity in the heat conditions falling in between these conditions. As in Experiment 1, we assessed cardiovascular activity during habituation and task performance.

3.1 Method

We recruited again 30 participants (15 women, 15 men; mean age 22 years [18-29]). The inclusion criteria and the experimental design were the same as in our first study. We also used the same apparatus and individual calibration procedure as in Experiment 1 to induce painful and nonpainful thermal stimulations and assessed PEP, SBP, DBP, and HR as in the first study.

3.1.1 Cognitive Task

The task was adapted from Bijleveld (2018). Trials started with a fixation cross (1000 ms) followed by the first 9 digits string (1000 ms), a distractor string of 9 letters (2000 ms), and the second 9-digit string (2000 ms). Participants were instructed to indicate whether the first and the last strings were identical or not by pressing a green "yes" or a red "no" key while the last string was presented. This was

followed by the neutral feedback “response entered” or “please respond more quickly” in case of a lacking response (1500 ms). The intertrial interval randomly varied between 1000 and 2000 ms. Each task block lasted about 3 minutes and comprised 20 trials including 10 target (yes-responses) and 10 non-matched trials (no-responses). Before the task, participants completed 4 practice trials with response correctness feedback.

3.1.2 Procedure

Participants started with the thermal stimulation calibration period, followed by the cardiovascular baseline assessment period with the same neutral film as in Experiment 1, the task practice trials, and the 4 task performance blocks. The thermal stimulations were administered at approximately 9 seconds, 54 seconds, 1 minute 30 seconds, 2 minutes 6 seconds, and 2 minutes 42 seconds after block onset (range of interstimulus intervals = 36 – 45 seconds). In the low incentive condition, participants expected to earn 0.10 Swiss Francs (about 0.10 USD) for giving at least 90% correct responses in the short-term memory task. The high monetary success incentive for attaining this performance standard was again 12 Swiss Francs (about 12 USD). Finally, as incentive manipulation check, participants rated the subjective value of monetary incentive on a 10-point scale (1 = *not high at all*, 10 = *extremely high*) in addition to subjective task difficulty ratings on a 7-point scale (1 = *not at all difficult*, 7 = *extremely difficult*) and same pain ratings assessed in the first study.

3.1.3 Data Analysis

The data were analyzed in the same way as in Experiment 1. Preliminary repeated measures ANOVAs of the PEP and SBP baseline measures yielded a time main effect for both measures ($ps < .001$). Both PEP and SBP decreased from the first to the fourth minute and then remained stable. Therefore, cardiovascular baseline scores were constituted by averaging the values assessed in last five minutes of the baseline period (Cronbach’s $\alpha s > .94$). The baseline scores were as follows: PEP ($M = 98.03$, $SE = 1.79$), SBP ($M = 111.44$, $SE = 1.54$), DBP ($M = 65.73$, $SE = 0.96$) and HR ($M = 72.71$, $SE = 1.69$).

Cardiovascular change (delta-) scores were calculated for each participant and for each cardiovascular measure as in the first study (Cronbach's αs > .86). Extreme values and outliers were again recoded using winsorization (k = 5) (Leys et al., 2019; Tukey & McLaughlin, 1963).

Within-persons ANCOVAs testing for significant associations between baseline and reactivity scores revealed no significant covariate main or interaction effects (ps > .15). Moreover, additional preliminary 2 (Sex) × 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA did not find any Sex main effects (ps > .49), but significant Sex x Stimulation (p = .021) and Sex x Incentive interactions (p = .044) on DBP. No other effects were significant (ps > .29). However, including Sex as an additional factor in the analysis did not change the main findings on DBP. Therefore, we did not further consider it in the main analyses.

Given that we tested the same hypotheses as in Experiment 1, we applied the same a priori contrast (weights -2, -1, +4, -1) to test our theory-based prediction about incentive's moderator effect of pain's impact on effort-related cardiovascular response in a difficult task. The task performance and self-report measures were subjected to conventional explorative repeated measures ANOVAs.

3.2 Results and Discussion

3.2.1 Pre-Ejection Period Reactivity

The a priori contrast was significant, $F(1,29) = 8.00$, p = .008, η_p^2 = .22, whereas the Contrast x Time interaction was not (p = .232). As depicted in Figure 5 (Panel A), the pattern of PEP reactivity corroborated our predictions. According to additional cell contrasts, PEP reactivity was stronger in the Pain/High-Incentive (M = -2.74, SE = 0.82) than in the Pain/Low-Incentive condition (M = -1.09, SE = 0.64), $t(29) = 2.12$, p = .022, η_p^2 = .13, replicating the key finding of Experiment 1 and supporting again our hypothesis that monetary incentive moderates pain's impact on effort. PEP reactivity in the Pain/High-Incentive condition was also significantly stronger than in the Heat/High-Incentive condition

(*M* = -0.65, *SE* = 0.90), *t*(29) = 3.09, *p* = .002, η_p^2 = .25. Other comparisons, including those with the Heat/Low-Incentive condition (*M* = -0.94, *SE* = 0.91), were not significant (*p*s > .21).

3.2.2 Systolic Blood Pressure Reactivity

In contrast to Experiment 1, neither the a priori contrast, *F*(1,29) = 2.25, *p* = .145, η_p^2 = .07, nor the Contrast x Time interaction were significant (*p* = .994) for SBP reactivity. Cell means and standard errors were as follows: Pain/Low-incentive (*M* = 7.00, *SE* = 0.99), Heat/Low-Incentive (*M* = 5.18, *SE* = 0.86), Pain/High-Incentive (*M* = 7.97, *SE* = 0.88), and Heat/High-Incentive (*M* = 8.55, *SE* = 0.99).

3.2.3 Diastolic Blood Pressure Reactivity

Both the a priori contrast, *F*(1,29) = 6.96, *p* = .013, η_p^2 = .19, and the Contrast x Time interaction, *F*(1,29)= 6.77, *p* = .014, η_p^2 = .19, were significant for diastolic reactivity. The interaction emerged because the contrast was significant during the second and third minutes of the task (*p*s < .03), but not during the first minute (*p* = .448). Cell contrasts for the entire task revealed stronger reactivity in the Pain/High-Incentive condition (*M* = 6.33, *SE* = 0.58) than in the Pain/Low-Incentive condition (*M* = 5.56, *SE* = 0.49), *t*(29) = 1.93, *p* = .032, η_p^2 = .11. Reactivity in the Pain/Low-Incentive condition was also stronger than in the Heat/Low-Incentive condition (*M* = 4.38, *SE* = 0.60), *t*(29) = 2.76, *p* = .005, η_p^2 = .21. Moreover, DBP reactivity was stronger in the Heat/High-Incentive condition (*M* = 5.94, *SE* = 0.68) compared to the Heat/Low-Incentive condition, *t*(29) = 3.25, *p* = .003, η_p^2 = .27. The difference between the Pain/High-incentive and the Heat/High-incentive conditions was not significant (*p* = .220).

3.2.4 Heart Rate Reactivity

The a priori contrast was significant, *F*(1,29) = 6.60, *p* = .016, η_p^2 = .19, whereas the Contrast x Time interaction was not, (*p* = .253). As PEP reactivity, HR reactivity showed the expected effort-related patter, which is depicted in Figure 5 (Panel B). Cell contrasts revealed stronger reactivity in the Pain/High-Incentive condition (*M* = 4.33, *SE* = 0.87) than in the Pain/Low-Incentive condition (*M* = 2.82, *SE* = 0.76), *t*(29) = 2.69, *p* = .006, η_p^2 = .20, and the Heat/High-Incentive condition (*M* = 3.57, *SE* = 0.69),

$t(29) = 1.70$, $p = .05$, $\eta_p^2 = 0.09$. Other comparisons, including those with the Heat/Low-incentive condition ($M = 3.19$, $SE = 0.57$), were not significant (ps > .25).

3.2.5 Task Performance

A 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the percentage of correct responses did not reveal any significant effects (ps > .54). In general, response accuracy was rather low, supporting our intention to create an objectively difficult task ($M = 65.46\%$, $SE = 1.47$). Also, a 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the reaction times did not reveal any significant effects ($M = 1143.83$ ms, $SE = 19.44$; ps > .16). Cell means and standard errors of the percentage of correct responses and reaction times are presented in the Supplementary Materials, Table S4.

3.2.6 Pain Ratings

According to a 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the pain ratings, there was a Stimulation main effect, $F(1,29) = 864.48$, $p < .001$, $\eta_p^2 = .97$. The painful stimulation ($M = 65.14$, $SE = 1.97$) was as intended perceived as far more painful than the nonpainful stimulation ($M = 9.60$, $SE = 0.78$), speaking for a successful manipulation. Other effects were not significant (ps > .06). Cell means and standard errors of pain ratings can be found in the Supplementary Materials, Table S4.

3.2.7 Subjective Task Difficulty

A 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the subjective task difficulty ratings revealed a significant Stimulation main effect, $F(1,29) = 4.86$, $p = .036$, $\eta_p^2 = .14$. As expected, the task was perceived as more difficult in the pain condition ($M = 5.40$, $SE = 0.22$) than in the heat condition ($M = 5.19$, $SE = 0.22$). This supports again our idea that pain increases subjective task demand. No other ANOVA effects were significant (ps > .17). As depicted in Figure 6, cell means and standard errors were as follows: Pain/Low-Incentive ($M = 5.34$, $SE = 0.24$), Heat/Low-Incentive ($M = 5.25$, $SE = 0.23$), Pain/High-Incentive ($M = 5.47$, $SE = 0.21$), and Heat/High-Incentive ($M = 5.13$, $SE = 0.22$).

3.2.8 Incentive Ratings

A 2 (Stimulation) x 2 (Incentive) repeated measures ANOVA of the incentive ratings revealed a strong Incentive main effect, $F(1,29) = 121.87$, $p < .001$, $\eta_p^2 = .81$. Accordingly, high monetary incentive ($M = 7.16$, $SE = 0.32$) was as intended perceived as higher than low monetary incentive ($M = 2.53$, $SE = 0.39$). This indicates a successful incentive manipulation. No other ANOVA effects were significant ($ps > .91$). Cell means and standard errors of incentive ratings are reported in Supplementary Materials, Table S4.

3.2.9 Conclusions

Experiment 2 conceptually replicated the key findings of our first study in a different demanding cognitive task and provided stronger evidence for the moderating effect of incentive on pain's impact on effort. As predicted, pain again increased subjective task difficulty, supporting the idea that pain increases perceived demand in cognitive functioning (Buhle & Wager, 2010). Most important, participants experiencing pain showed stronger PEP and HR reactivity when they expected high incentive compared to low incentive. These findings advocate again for our idea that high motivational incentive can justify the high effort that is required when pain is experienced during an objectively difficult task.

4. General Discussion

Aiming at better understanding how pain can influence cognitive effort, the present two studies tested the moderating effect of monetary incentive on pain's impact on effort-related cardiovascular response. Integrating evidence that pain increases demand during cognitive performance (e.g., Buhle & Wager, 2010; Cancela & Silvestrini, 2021) with the principles of motivational intensity theory (Brehm & Self, 1989), we predicted that pain would increase subjective difficulty and that the resulting effect on effort intensity would be moderated by monetary success incentive. Specifically, we anticipated the highest effort in the Pain/High-Incentive condition (high required and justified effort) and the lowest effort in the Pain/Low-Incentive condition (high required but unjustified effort), while effort in the

nonpainful conditions should fall in between these two conditions (moderate required and justified effort). Both of our experiments found support for our predictions. As expected, both studies found the anticipated impact of pain on subjective task difficulty: participants perceived the task as more difficult when they received painful stimulations compared to nonpainful stimulations. We had expected this pain effect on subjective demand because pain captures attention. The latter is necessary for serving pain's function as danger signal for the organism (Eccleston & Crombez, 1999; Legrain et al., 2009) but can distract from ongoing cognitive activity. Most important, pain-influenced subjective demand interacted as predicted with success incentive to determine effort-related cardiovascular response.

In both studies, the analyses of cardiovascular reactivity offered statistical support to our predictions. In Experiment 1, the a priori contrast was significant for PEP, our most reliable measure of effort (Kelsey, 2012; Richter et al., 2016; Wright, 1996), and also SBP reactivity. As expected, we found the strongest responses in the Pain/High-Incentive condition and the weakest reactivity in the Pain/Low-Incentive condition. That is, monetary incentive moderated pain's effect on effort as predicted. Reactivity in the heat conditions fell in between these two conditions. These results are in line with our hypotheses, suggesting that high incentive is necessary to justify the effort required by pain during a difficult task.

In further support of our predictions, Experiment 2 replicated the significant a priori contrast effect for PEP reactivity, which here also emerged for HR. For both measures we found again stronger reactivity when participants received painful stimulations and expected high incentive for success than when they expected low incentive. Importantly, PEP and HR reactivity in the Pain/High-Incentive condition was also significantly stronger than in the conditions in which participants received nonpainful thermal stimulations. These findings replicated the key findings of Experiment 1 and provided stronger evidence for incentive's moderating effect on pain's impact on effort. Accordingly, high incentive is necessary to justify the high effort that is required to accomplish an objectively difficult task while

experiencing pain. The a priori contrast was also significant for DBP. Nevertheless, the reactivity pattern only roughly supported our predictions. However, this is not surprising as DBP is mainly influenced by alpha-adrenergically determined peripheral resistance rather than beta-adrenergic activity. It is of note that neither of our two studies found significant decreases in DBP or HR. Accordingly, our PEP effects can hardly be attributed to cardiac preload or vascular afterload effects (Sherwood et al., 1990). Rather, they reflect beta-adrenergic sympathetic impact and thus effort (Kelsey, 2012; Wright, 1996).

In summary, the core results of our two present studies provide the first evidence that incentive moderates pain's impact on cognitive effort and support our integration of pain effects on cognitive processing with the principles of motivational intensity theory. Accordingly, high incentive can justify the high effort for succeeding in objectively difficult tasks, while low incentive does not. This shows for the first time that it is possible to counteract an effort deficit in difficult tasks while experiencing pain. Moreover, our results match previous findings on the impact of pain primes on effort (Silvestrini, 2015, 2018), which was also moderated by monetary incentive. The same was found in studies that primed fear, sadness, or ageing (Chatelain & Gendolla, 2016; Freydefont & Gendolla, 2012; Zafeiriou & Gendolla, 2017). However, while those affective influences on effort worked on the implicit level, the present two studies provide the first evidence for the combined effect of *experienced* pain and incentive on effort-related cardiovascular response.

Regarding our task performance measures, our studies did not reveal any significant manipulation effects on response accuracy or reaction times. This is not surprising, because the effort-performance link is complex and performance depends beside effort also, or maybe even more, on capacity and strategies (Locke & Latham, 1990). This is the reason why we have not made any predictions for performance effects in our studies, which were designed to investigate effort (i.e., a behavioral input variable) rather than performance (i.e., behavioral output). Our core predictions about the moderation of pain's impact on effort-related cardiovascular response were supported. In this

context, it is of note that our manipulations were successful. In both studies, participants' pain ratings indicated successful pain inductions and in Experiment 2, participants rated the high monetary incentive as higher than the low monetary incentive. Moreover, the subjective difficulty of the administered cognitive tasks was rated as high in general, and in the pain conditions as higher than in the nonpainful thermal stimulation conditions. That is, we can interpret our manipulation effects as valid.

In a larger perspective, our findings have clinical implications. Patients with chronic pain often report fatigue (Covington, 1991; Van Damme et al., 2018) and disengagement (Affleck et al., 2001; Crombez et al., 2016). Our theoretical framework could explain these effects. First, we suggest that during easy to moderately difficult tasks, pain calls for extra effort by increasing subjective difficulty, which can contribute to fatigue. This is in line with suggestions of Van Damme et al. (2018), who proposed that chronic pain increases effort in goal pursuit, which can result in the development of fatigue. Second, when tasks are too challenging, i.e., when they require very high effort, patients could disengage because the high required effort frequently exceeds what is justified. In our studies, high incentive was necessary to justify high effort in objectively difficult tasks with pain. Low incentive could not justify the high required effort and led to low effort, reflecting disengagement. This suggests that increasing motivation can compensate for effort deficits when daily life activities are too challenging and allow individuals to stay engaged in these activities. Consequently, high motivational incentive could help chronic pain patients to stay engaged in difficult actions. Likewise, also setting easier goals could help chronic pain patients to stay engaged.

Despite the evidence for our successful manipulations and effort effects, the present studies also have limitations. In Experiment 1, focused comparisons did not find significant differences in PEP and SBP responses between the pain and heat conditions in the low and high incentive conditions. As discussed earlier, methodological issues related to the administered 4-back task and the incentive manipulation might explain this. However, there is evidence that individuals do not always completely disengage from

a task even if the required effort is not justified by success importance (Stanek & Richter, 2021). This could explain why participants still engaged in the difficult task despite pain in the low incentive condition. In addition, it appears that monetary incentive tended to have an unexpected slight impact in the heat conditions. This could suggest that task difficulty was not completely clear for the participants, perhaps because it is almost impossible to personally monitor one's task performance during the execution of the 4-back task. Moreover, most of the recruited participants were university students. Given their usually low monetary income, they may perceive the monetary compensation for their study participation as highly important, leading to general high potential motivation (and effort) to succeed (e.g., Richter & Gendolla, 2009). Future studies might investigate other populations in which monetary incentives are probably not that important (e.g., patients with chronic pain). This issue raises the question of the generalization of our findings to patients with chronic pain. Actually, we would expect stronger effects in patients due to their persistent pain, which strongly interferes with cognitive performance (Gatchel et al., 2007). Therefore, future studies should investigate the moderating effect of incentives on pain's impact on effort in patients with chronic pain. Moreover, we would predict that our model would generalize to other types of motivational incentive, including those which are not tangible – e.g., ego-involvement (Gendolla & Richter, 2005, 2006) or the satisfaction of psychological needs (Mazeres et al., 2019, 2021). We expect similar findings with any kind of motivational incentive that should increase task importance.

Experiment 2 found a significant difference between the pain and heat conditions when incentive was high. However, we did not find this difference in the low incentive condition. Looking at the cognitive performance data of Experiment 2 reveals that the task was very difficult (by average 65% correct responses). Therefore, the very low incentive in that study did probably not justify the necessary effort to succeed in this task, resulting in low effort due to disengagement in both pain and heat conditions. Also, the cardiovascular reactivity in the Heat/High-Incentive condition was low rather than

moderate in comparison with the Pain/High-Incentive condition. This may suggest that pain could also increase success importance, maybe because pain acts as a warning signal. This could have increased task relevance because exerting effort may inhibit pain sensation (e.g., Buhle & Wager, 2010), which is compatible with evidence that increased SBP leads to decreased pain sensation (Inagaki & Gianaros, 2022; Makovac et al., 2020). This might suggest that stronger effort could help to regulate pain. Future studies should directly investigate this possible impact of pain on potential motivation during task performance. However, another explanation for this limitation could be related to the experimental design we have used. The applied within-persons design could have led to demand effects in the sense that participants tried to guess the study's predictions because they had to perform the same task under different pain and incentive manipulations and adapted their behavior accordingly (Charness et al., 2012; Rosenthal, 1976). Therefore, it would be relevant to replicate our studies with between-persons designs to avoid the disadvantages of within-persons design.

4.1 Conclusions

We interpret our findings as providing the first evidence that monetary incentive can moderate experienced pain's impact on effort-related cardiovascular response. Although the cardiovascular reactivity patterns were not fully occurring as predicted, the core effect that monetary incentive determines whether people mobilize high or low resources when they experience pain was replicated. Pain increased subjective task difficulty, and high incentive could justify the high effort that was required when participants experienced pain in an objectively difficult task. Moreover, our results have clinical implications regarding patients with chronic pain: appropriate motivational incentive and feasible objectives should help them to stay engaged in their daily actions.

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Figure Captions

Figure 1. Predicted pain and incentive effects on effort according to the principles of motivational intensity theory (Brehm & Self, 1989). Panel A shows the predictions when incentive and justified effort are low. Panel B shows the predictions when incentive and justified effort are high. The grey bars indicate the predictions for difficult tasks as those administered in the present studies.

Figure 2. Overview of the study protocol. Participants completed the four experimental blocks in randomized order. PL, Pain/Low-Incentive; PH, Pain/High-Incentive; HL, Heat/Low-Incentive, HH, Heat/High-Incentive.

Figure 3. Cell means and standard errors of pre-ejection period reactivity (PEP, Panel A) and systolic blood pressure (SBP, Panel B) in Experiment 1. $^{**}p < 0.01$; $^{***}p \leq 0.001$.

Figure 4. Cell means and standard errors of subjective task difficulty in Experiment 1.

Figure 5. Cell means and standard errors of pre-ejection period reactivity (PEP, Panel A) and heart rate (HR, Panel B) in Experiment 2. $^{*}p < 0.05$; $^{**}p < 0.01$.

Figure 6. Cell means and standard errors of subjective task difficulty in Experiment 2.

Figure 1

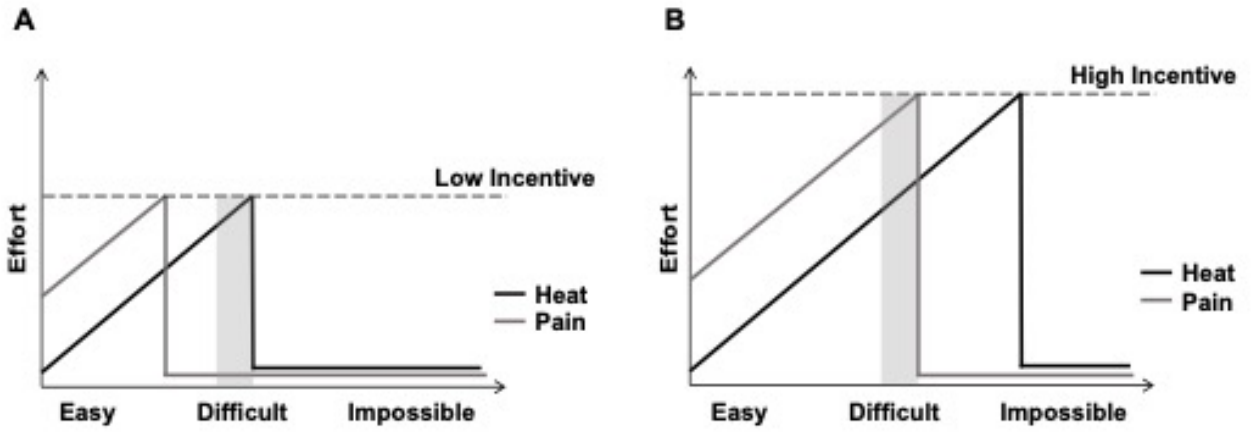

A
Low Incentive
Effort
Heat
Pain
Easy
Difficult
Impossible
B
High Incentive
Effort
Heat
Pain
Easy
Difficult
Impossible

Figure 2

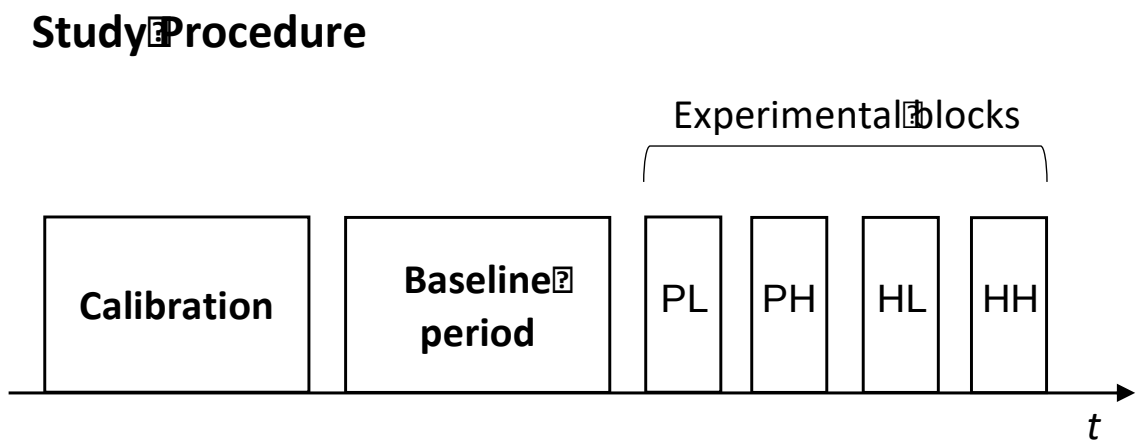

Study Procedure
Experimental blocks
Calibration
Baseline period
PL
PH
HL
HH
t

Figure 3

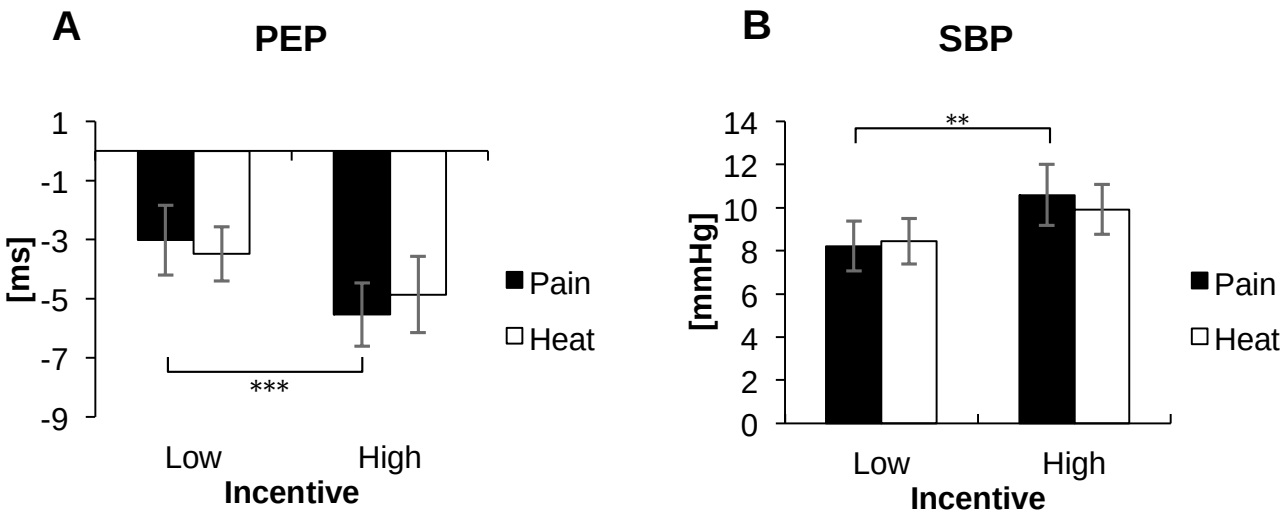

A
PEP
1
-1
-3
-5
-7
-9
[ms]
***
Low
High
Incentive
Pain
Heat
B
SBP
14
12
10
8
6
4
2
0
[mmHg]
**
Low
High
Incentive
Pain
Heat

Figure 4

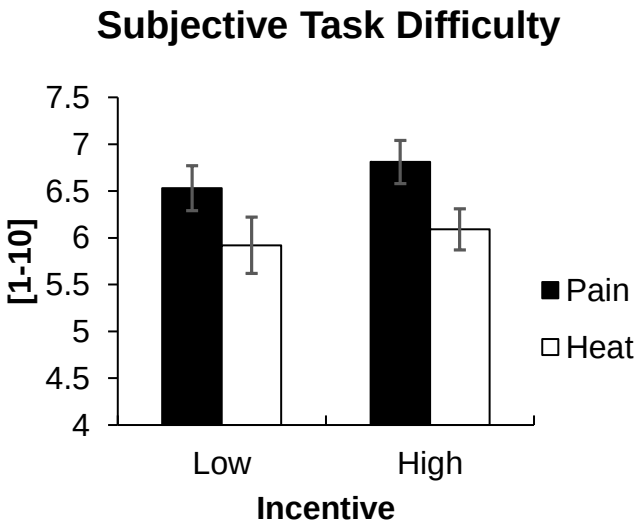

Subjective Task Difficulty
7.5
7
6.5
6
5.5
5
4.5
4
[1-10]
Pain
Heat
Low
High
Incentive

Figure 5

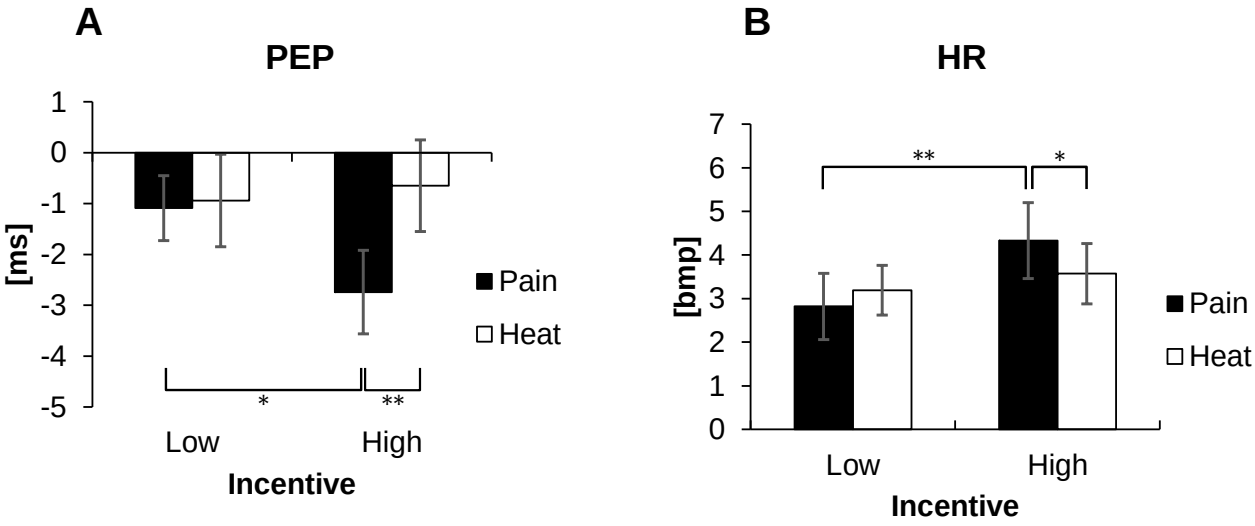
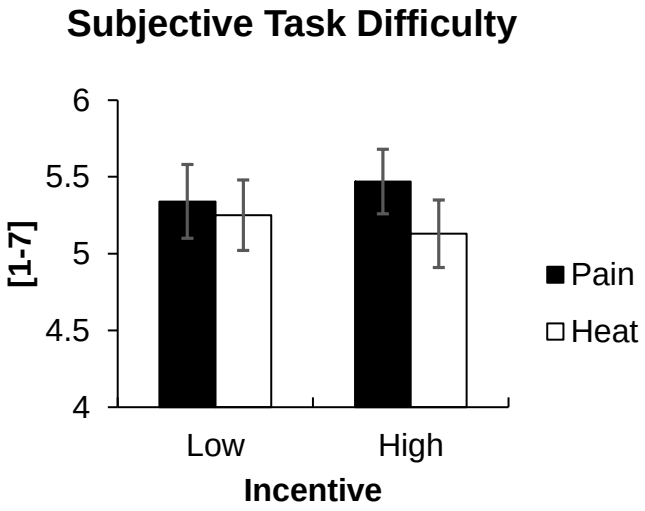

A
PEP
[ms]
1
0
-1
-2
-3
-4
-5
*
**
Low
High
Incentive
Pain
Heat
B
HR
[bmp]
7
6
5
4
3
2
1
0
**
*
Low
High
Incentive
Pain
Heat

Figure 6


Subjective Task Difficulty
6
5.5
5
4.5
4
[1-7]
Low
High
Incentive
Pain
Heat