On the implicit influence of pain cues on cognitive effort: Evidence from cardiovascular reactivity

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Evidence from Cardiovascular Activity

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Abstract

To extend previous findings on the impact of implicit affect on behavior, two experiments investigated the influence of priming pain cues on cognitive effort. Effort was assessed as cardiovascular reactivity (PEP, SBP, DBP, and HR) during an easy or difficult cognitive task integrating briefly presented and masked pain-related words. The control condition included neutral words (Experiment 1) or anger-related words (Experiment 2). The pain primes were expected to increase the perceived difficulty of the task and to result in stronger effort during the easy task, compared to the control condition, and to lower effort during the difficult task, due to disengagement. Overall, cardiovascular reactivity of both experiments supported the predictions. Moreover, pain primes increased self-reported subjective difficulty. Finally, most participants could not report the content of the primes. Findings are discussed regarding the influence of implicit processes in pain experience and regarding the self-regulatory consequences of the influence of pain on effort mobilization.

Keywords: effort; cardiovascular reactivity; priming; implicit affect; pain

Introduction

Accumulating evidence indicates that implicit processes, broadly defined as processes that are automatic (see De Houwer & Moors, 2012), have a reliable influence on behavior (see Bargh & Chartrand, 1999; Custers & Aarts, 2005; Dijksterhuis & Aarts, 2010; Hassin, Uleman, & Bargh, 2004, for reviews). Although methodological issues and empirical findings on priming are currently highly debated (Weingarten et al., 2016), it is reasonable to conceive that individuals have to handle most of the complex and abundant surrounding information in an automatic way due to the limitations of conscious processing (e.g., Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Therefore, understanding and predicting how implicitly processed stimuli can influence behavior represents an important issue in modern psychology.

Besides attitudes, stereotypes, and goals, priming research also found evidence for a behavioral influence of implicit affect (e.g., Gendolla & Silvestrini, 2011; Winkielman, Berridge, & Wilbarger, 2005), which can be defined as the automatic activation of mental representations associated with affective states (Quirin, Kazén, & Kuhl, 2009). However, as presented in more details below, mainly basic emotions, such as joy, sadness, anger, or fear, have been investigated so far. The aim of the present research is to extend these findings to the phenomenon of pain, which includes a strong affective component, is crucial for survival, and involves huge human and economic costs (Breivik, Collett, Ventafridda, Cohen, & Gallacher, 2006). To investigate the implicit influence of pain cues on behavior, the present research focused on effort, defined as the amount of resources people mobilize to execute instrumental behavior (Gendolla & Wright, 2009), and assessed cardiovascular reactivity as a measure of effort mobilization (Wright, 1996).

Implicit Affect and Effort

Previous research found reliable evidence for an influence of implicit affect on effort mobilization during cognitive tasks (e.g., Freydefont, Gendolla, & Silvestrini, 2012; Gendolla & Silvestrini, 2011; Lasauskaite Schüpbach, Gendolla, & Silvestrini, 2014). A recent theoretical framework, the implicit-affect-primes-effort model (IAPE model; Gendolla, 2012, 2015), provides a rationale and predictions for this influence. According to this model, implicit affect influences the perceived difficulty of the task at hand, which determines in turn effort mobilization as predicted by motivational intensity theory (Brehm & Self, 1989).

The rationale of this model is that individuals learn during their lifetime that performing cognitive tasks is harder in some affective states than in some others. For instance, individuals experience that performing a task while in a sad mood is more difficult than in a joyful mood (see Brinkmann & Gendolla, 2008). Accordingly, the IAPE model predicts that the concept of sadness is associated in memory with the concept of difficulty whereas the concept of joy is associated with the concept of ease. When these affective concepts are implicitly activated during task performance, for instance by means of priming, it is expected that the concepts of difficulty or ease are also activated and become more accessible. This increased accessibility is predicted to influence the judgment of task difficulty, which, as other judgments, is determined by all accessible information (see Bower, 1981). In turn, subjective difficulty influences effort as predicted by motivational intensity theory (Brehm & Self, 1989), which postulates that, when task difficulty is fixed and known, effort is determined by subjective difficulty as long as success is possible and the required effort is justified.

The IAPE model proposes that sadness and fear are associated with the concept of difficulty, whereas joy and anger are associated with ease. Interestingly and importantly for the present research, anger is predicted to be associated with ease because despite its negative valence, anger is typically linked with experiences of high coping potential, which is predicted to lead to lower perceived difficulty. The predictions related to these basic emotions were supported by a series of empirical studies (Chatelain & Gendolla, 2015; Chatelain, Silvestrini, & Gendolla, 2016; Freydefont & Gendolla, 2012; Freydefont et al., 2012; Gendolla & Silvestrini, 2011; Lasauskaite Schüpbach et al., 2014; Silvestrini & Gendolla, 2011). However, the model aims to apply to any affective states that are associated with ease or difficulty. As presented in the next section, the present research draws on the assumption that pain can be considered as an affective state associated with difficulty.

Priming Pain and Effort

Pain is currently defined as an unpleasant sensory and emotional experience (Merskey, 1986), which clearly indicates that pain can be considered as an affective state. Moreover, reliable evidence shows that pain impairs concomitant cognitive performance (e.g., Buhle & Wager, 2010). This effect suggests that pain and cognitive performance engage common and limited cognitive resources and that pain can be considered as an additional demand on these resources leading to performance impairment. Consequently, it is expected that performing a task when experiencing pain is perceived as harder than performing the same task without pain, and that individuals have learned this association through a semantic link in memory between the concept of pain and the concept of difficulty. Therefore, based on the rationale of the IAPE model, implicitly activating the concept of pain in the context of task performance should jointly activate the concept of difficulty, which should become more accessible, increase subjective task demand, and influence in turn effort mobilization. This prediction was tested for the first time in a recent study investigating the influence of implicitly activating the concept of pain on effort mobilization assessed as cardiovascular reactivity (Silvestrini, 2015).

In this study, participants were exposed to pain-related or neutral words primed during a difficult cognitive task. Moreover, they could earn a high or a moderate incentive in case of success in the task. Cardiovascular reactivity was assessed during a habituation period and during task performance. Results fully supported the predictions. Participants exposed to pain primes mobilized more effort when they had the opportunity to receive a high incentive in case of success compared to the low incentive condition where they disengaged. Participants primed with neutral words invested a moderate effort regardless of the incentive condition. Moreover, participants perceived themselves as less capable to perform the task when primed with pain cues than with neutral cues. These findings were interpreted as showing that pain primes increased perceived task difficulty leading to higher effort than neutral primes when the high incentive justified this effort and to disengagement when incentive did not justify the required effort. Therefore, these findings supported the predictions of the IAPE model applied to pain. To replicate these findings and to further test the impact of pain primes on effort mobilization, the two present experiments manipulated task difficulty instead of task incentive and assessed cardiovascular reactivity as a measure of effort mobilization.

Effort Mobilization and Cardiovascular Reactivity

In more than hundred studies, cardiovascular parameters have been used to assess effort mobilization during cognitive tasks (see Gendolla & Wright, 2005; Gendolla, Wright, & Richter, 2012; Wright & Kirby, 2001, for reviews). This approach was first proposed by Wright (1996) who integrated the predictions of motivational intensity theory (Brehm & Self, 1989) together with the work of Obrist (1981) on cardiovascular psychophysiology. This line of research showed that especially sympathetic activity on the heart reflects effort mobilization in active goal pursuit. Therefore, as in previous studies using this paradigm, the present experiments rely on cardiovascular parameters mainly influenced by sympathetic activity on the heart to assess effort. Among them, the pre-ejection period (PEP; the time interval between the onset of ventricular depolarization and the opening of the aortic valve) is the non-invasive parameter that is most directly influenced by sympathetic activity on the heart through heart contractility (e.g., Newlin & Levenson, 1979). Also systolic blood pressure (SBP; the maximal pressure between two heartbeats) is determined by heart contractility and has been used in many studies using this paradigm. However, PEP represents a more direct measure of sympathetic activity on the heart than SBP because SBP is more strongly influenced by peripheral resistance than PEP. Diastolic blood pressure (DBP; the minimal pressure between two heart beats) and heart rate (HR; the number of beats per minute) are still less sensitive to myocardial sympathetic activity due to the influence of peripheral resistance and parasympathetic activity, respectively. However, DBP and HR should always be assessed together with PEP to control for pre-load and after-load effects on PEP reactivity (Sherwood et al., 1990).

The Present Experiments

In the two present experiments, participants worked on an objectively easy vs. difficult short-term memory task adapted from Sternberg (1966). During the task, participants were exposed to briefly presented (53 ms) and masked words related to pain vs. neutral words (Experiment 1) or vs. anger words (Experiment 2) as the control conditions. Participants primed with pain words were predicted to perceive the task as more difficult than in the control condition. Accordingly, cardiovascular reactivity—especially PEP and SBP reactivity—was predicted to be stronger in the pain/easy condition than in the control/easy condition, due to the increased difficulty induced by the pain primes. In contrast, a very low reactivity was expected in the pain/difficult condition. Here, the objective difficult condition and the increased difficulty induced by the pain primes were predicted to result in a too high subjective difficulty. This too high subjective difficulty was expected to lead to very low effort because the high required effort was not justified by task importance resulting in disengagement. A stronger reactivity was expected in the control/difficult condition due to the objectively difficult task leading to high but not too high subjective difficulty. These predictions on effort are presented in Figure 1.

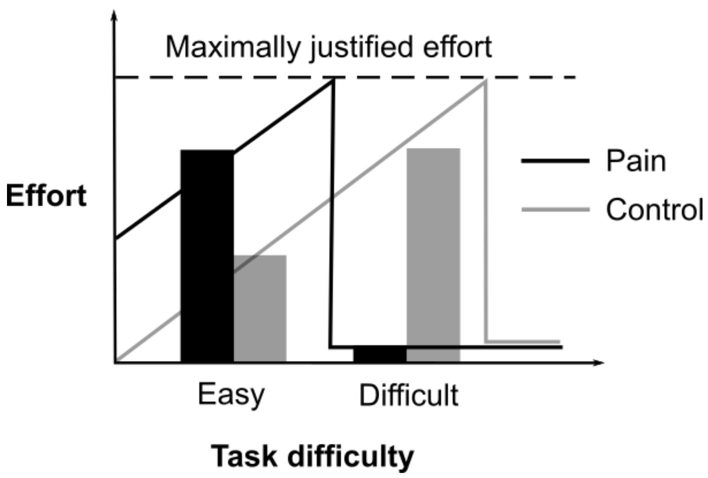

Figure 1. Theoretical predictions for the easy and the difficult conditions integrating pain-related or control words.

DBP and HR were expected to show a similar but presumably weaker pattern than PEP and SBP because they are less sensitive to myocardial sympathetic activity. Given that performance in a task also depends on variables such as ability and strategy, and not only on exerted effort (Locke & Latham, 1990), predictions for task performance were not straightforward as those for effort. Task performance may reflect the predicted effort but could also be influenced by other factors. For instance, priming the concept of pain could mainly impair task performance as physical pain (Buhle & Wager, 2010), and as found in a previous study (Silvestrini, 2015).

Experiment 1: Pain vs. Neutral Primes

Experiment 1 tested the prediction that priming pain leads to increased subjective difficulty and influence effort using neutral words as the control condition. Participants performed a habituation period followed by an objectively easy or difficult short-term memory task integrating pain-related or neutral words. Effort-related cardiovascular reactivity was assessed continuously during habituation and task performance.

Method

Participants and Design

Ninety-six University students (78 women, mean age 22 years) were randomly assigned to a 2 (prime: pain, neutral) × 2 (difficulty: easy, difficult) between-persons design. Sample size was determined according to previous studies showing word priming effects on effort mobilization and which included about 15 participants per cell (Gendolla & Silvestrini, 2010; Silvestrini, 2015; Silvestrini & Gendolla, 2013). However, to further increase the power of the study, sample size was extended to a minimum of 20 participants per cell. One hundred time slots were proposed and 96 students participated to the experiment. No additional participants were included once the study was completed. Participation was voluntary and recompensed with course credits. All participants provided signed informed consent and the study protocol was approved by the ethics committee of the Department of

Psychology of the University of Geneva. One participant was excluded due to a self-reported heart murmur and two participants were excluded due to a low reported level in French (more than 3 on a 7-point Likert scale assessing difficulties in reading and understanding French) resulting in a final sample of *N* = 93 (75 women). The participants were distributed in the different conditions as follows: *n* = 24 in the pain/easy condition, *n* = 23 in the neutral/easy condition, *n* = 22 in the pain/difficult condition, and *n* = 24 in the neutral/difficult condition.

Apparatus and Physiological Measures

The procedure was computerized with a script running on E-prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA). PEP (in milliseconds) and HR (in beats per minute) were assessed using a Cardioscreen 1000 system (Medis, Ilmenau, Germany), that continuously measured ECG (electrocardiogram) and ICG (impedance cardiogram) signals. Four pairs of spot electrodes were attached on the right and the left side of the base of participants' neck and on the left and right middle axillary line at the height of the xiphoid to sample (1000 Hz) thoracic impedance and electrocardiogram signals (Scherhag, Kaden, Kentschke, Sueselbeck, & Borggrefe, 2005).

Systolic and diastolic blood pressures were measured with a Vasotrac APM205A monitor (Medwave, St. Paul, Minnesota, USA). The Vasotrac system uses applanation tonometry with a pressure sensor placed on the wrist on top of the radial artery applying a varying force on the artery. Internal algorithms yield systolic and diastolic pressure each 12-15 heart beats, i.e. 4-5 values per minute (see Belani et al., 1999, for a validation study). All cardiovascular measures and signals were directly stored on computer disk.

Procedure

The experiment was announced as a study on physiological responses during a cognitive task. Participants were seated in a comfortable chair in front of a desktop computer. After having obtained informed consent and preparation for the physiological measures, the experimenter—who was hired and unaware of both the hypotheses and the experimental condition—left the participant alone and went to an adjacent control room. The experiment started with the rating of two positive (*happy* and *joyful*) and two negative (*sad* and *depressed*) hedonic tone items of the UWIST scale (Matthews, Jones, & Chamberlain, 1990) on scales ranging from 1 (*not at all*) to 7 (*very much*) to control for differences in affective state before the manipulation that may influence subsequent effort mobilization (Brinkmann & Gendolla, 2008). This was followed by a habituation period (8 min) to determine participants' cardiovascular baseline values. Participants watched a hedonically neutral documentary film and cardiovascular activity was assessed continuously. After baseline assessment participants received instructions for a Sternberg-type short-term memory task (Sternberg, 1966).

Task trials started with a fixation cross (1 sec) followed by a word related to pain vs. a neutral word (53 ms) that was backward masked by a string of the letter "X" (133 ms). The prime words (pain: *pain*, *suffer*, *burn*, *sting*; neutral: *color*, *describe*, *border*, *seam*) were similar than in the study of Silvestrini (2015). They were selected according to a pretest and matched in length and frequency of occurrence in French. Moreover, instead of primes, half of the trials presented senseless series of letters created by juggling the letters of the pain and neutral primes to prevent fast habituation to the prime words. The mask was followed by a string of 4 (easy condition) or 7 (difficult condition) letters presented for 1 sec and followed by another backward mask (a string of the letters "X") and a target letter above the mask. Participants had to indicate if that letter was part of the previously presented string by pressing a "yes" or a "no" key within a response time window of 2 sec. The words and strings were displayed in capital letters and in bold (Verdana, font size = 26, screen resolution = 1280 x 1024, screen size = 11.8'' x 15''). Participants first performed 10 training trials that comprised correctness feedback and only senseless series of letters as primes. Then participants performed 32 experimental trials without feedback (i.e., in the pain condition: 16 trials with pain words, each pain word being presented four times, and 16 trials with senseless strings of letters as primes; in the neutral condition: 16 trials with neutral words, each neutral word being presented four times, and 16 trials with senseless strings of letters as primes). The sequence of prime presentation was randomly determined for eight successive trials integrating the four pain (or neutral) words and the four senseless series of letter. This randomization procedure was repeated four times (32 trials) with the rule of not presenting successively twice the same prime. After responding, the message “response entered” appeared for 4 sec minus participants’ reaction time, assuring that all participants worked for the same time (5 min). The inter-trial interval varied between 2 to 5 seconds.

After the task participants rated perceived task demand (“How difficult was it for you to succeed in the task?”), perceived capacity (“Did you feel capable to succeed in the task?”), success importance (“Was it important for you to succeed in the task?”), and value of success (“How valuable was it for you to succeed in the task?”) using 7-point Likert scales (1 = *not at all*, 7 = *very much),* and also rated again the 4 UWIST scale mood items to test for possible affective changes due to the priming. Moreover, participants were asked to indicate their native language and to rate whether they had difficulties to read and understand French on a scale ranging from 1 (*no difficulty at all*) to 7 (*yes, some difficulties*). Then, participants were interviewed in a funnel debriefing procedure (Chartrand & Bargh, 1996) about the study purpose and what they had seen during the trials. Participants who mentioned “flickers”, i.e. briefly perceived visual stimuli, were asked about their content.

Data Analyses

R-peaks in the ECG signal were identified using a threshold peak-detection algorithm and visually confirmed (ectopic beats were deleted). Only artifact-free cardiac cycles were included. ICG analysis software (Richter, 2010) computed the change in thoracic impedance (first derivate). The resulting dZ/dt signal was ensemble averaged (1 min periods) using the detected R-peaks (Kelsey et al., 1998). B-point location was estimated based on the RZ interval (Lozano et al., 2007), visually inspected, and corrected as recommended (Sherwood et al., 1990). PEP was determined as the time interval between R-onset in the ECG signal and B-point in the ICG signal (Berntson, Lozano, Chen, & Cacioppo, 2004). Shorter PEP indicates a stronger beta-adrenergic impact on the heart—i.e., a stronger effort.

We tested our theory-based predictions with an a priori contrast—the most powerful and thus most appropriate statistical tool to test predicted patterns of cell means (Rosenthal & Rosnow, 1985; Wilkinson & The Task Force on Statistical Inference, 1999). As outlined above, we expected a pattern of cardiovascular reactivity—especially PEP and SBP—with stronger response in the pain/easy and neutral/difficult conditions (contrast weight = + 3), lower response in the easy/neutral condition (contrast weight = - 2), and the lowest response in the difficult/pain condition (contrast weight = - 4). One-tailed tests were used for additional cell comparisons testing directed predictions. Task performance (accuracy and reaction times) and task ratings were analyzed with conventional 2 (prime) x 2 (difficulty) between-persons ANOVAs. Moreover, mood scores were analyzed with a 2 (prime) x 2 (difficulty) x 2 (time) mixed-model ANOVA with repeated measures on the last factor. Due to technical measurement problems, there were missing data for some participants. Therefore, the sample sizes slightly varied across the analyses of the single dependent variables: $N = 88$ for PEP, $N = 89$ for SBP and DBP, and $N = 93$ for HR.

Results

Cardiovascular Baselines

Cardiovascular baseline values were calculated by averaging the last 3 min of the habituation period, which were highly consistent (αs > .98). We calculated cardiovascular baseline values from the three last minutes of the habituation period, because there was a decline in SBP values over the first 5 minutes. However, for the last 3 minutes of the habituation period, PEP and SBP values were stable and did not differ significantly from one minute to another (ps > .13). Cell means and standard errors are presented in Table 1. Preliminary 2 (prime) × 2 (difficulty) ANOVAs on these baseline scores did not reveal any main effect or interaction between the conditions (all ps > .26). Reactivity scores were obtained by subtracting the baseline values from the averaged task-related values (αs > .88).

Preliminary correlational analyses did not reveal any significant association between baseline and reactivity scores (all *p*s > .05).

Table 1

Cell Means, Standard Errors (in Parentheses), and Cell Sample Sizes (in Square Brackets) of Cardiovascular Baseline Values in Experiment 1

	Easy		Difficult	
	Pain	Neutral	Pain	Neutral
PEP	97.59 (2.15) [22]	99.95 (2.30) [22]	99.22 (2.49) [19]	99.57 (1.78) [24]
SBP	131.17 (3.88) [24]	126.83 (3.83) [22]	126.49 (3.44) [22]	125.57 (3.42) [21]
DBP	77.30 (2.88) [24]	71.98 (2.79) [22]	72.12 (2.65) [22]	71.51 (2.13) [21]
HR	77.15 (2.64) [24]	74.41 (2.50) [23]	74.50 (1.70) [22]	74.50 (2.75) [24]

Note: PEP: pre-ejection period; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate. Units of measure are milliseconds for PEP, millimeters of mercury for SBP and DBP, and beats per minute for HR.

Cardiovascular Reactivity

Pre-Ejection Period. The a priori contrast on PEP reactivity was marginally significant, $F(1, 84) = 1.78$, $p = .093$, $\eta^2 = .02$. As depicted in Figure 2 (Panel A), PEP reactivity showed the anticipated pattern in the easy condition and also when comparing the pain/easy and the pain/difficult conditions. However, reactivity in the neutral/difficult condition was lower than expected.

Systolic Blood Pressure. The a priori contrast on SBP reactivity was significant, $F(1, 85) = 5.78$, $p = .009$, $\eta^2 = .06$. As depicted in Figure 2 (Panel B), SBP reactivity showed the anticipated pattern. Follow-up comparisons revealed that SBP response in the pain/easy condition ($M = 3.21$, $SE = 1.29$) was stronger than in the pain/difficult condition ($M = -1.60$, $SE = 1.32$), $t(85) = 2.39$, $p = .009$, $\eta^2 = .06$. Moreover, SBP response in the neutral/difficult condition ($M = 2.75$, $SE = 1.55$) was also stronger than in the pain/difficult condition, $t(85) = 2.10$, $p = .019$, $\eta^2 = .05$. Finally, SBP response in the pain/difficult condition was marginally lower than in the neutral/easy condition ($M = 1.43$, $SE = 1.61$), $t(85) = 1.47$, $p = .072$, $\eta^2 = .02$. Other comparisons were not significant (all *p*s > .18).

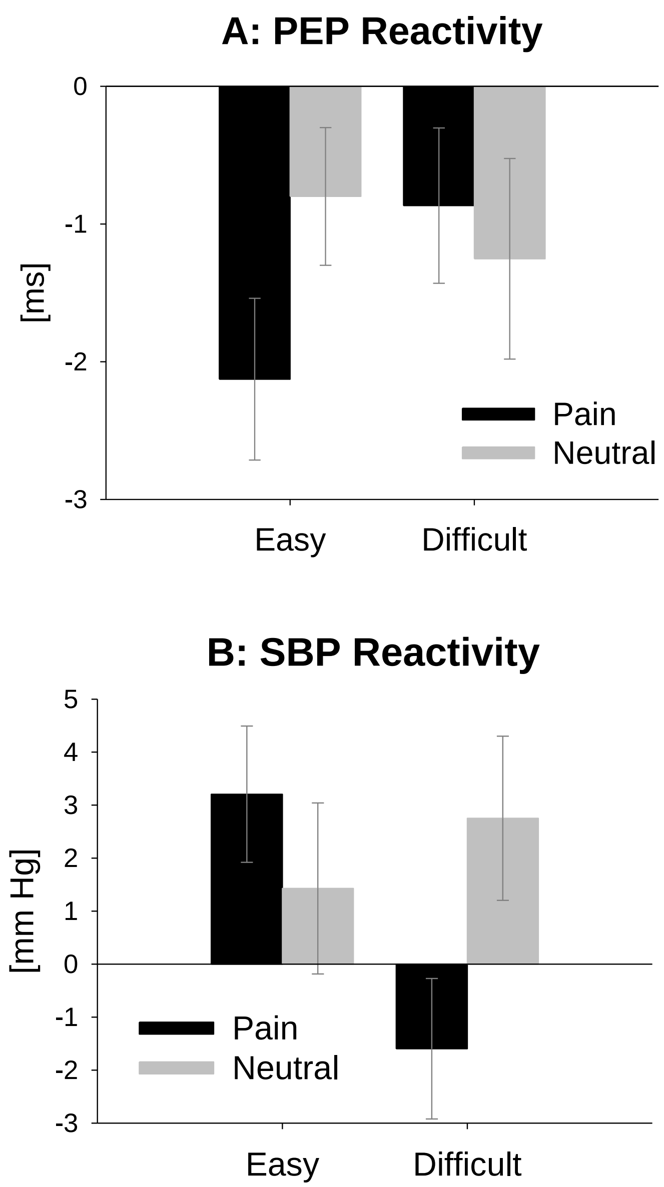

Figure 2. Cell means and standard errors of cardiac pre-ejection period (PEP, Panel A) and systolic blood pressure (SBP, Panel B) responses during task performance in Experiment 1.

Diastolic Blood Pressure and Heart Rate. The a priori contrast on DBP reactivity was significant, $F(1, 85) = 3.04$, $p = .042$, $\eta^2 = .03$. Cell means and standard errors were as follow: pain/easy ($M = 1.75$, $SE = 1.01$), neutral/easy ($M = 0.76$, $SE = 1.29$), pain/difficult ($M = -0.91$, $SE = 1.16$), neutral-prime/difficult ($M = 1.62$, $SE = 1.08$). Follow-up comparisons revealed that DBP response in the pain/difficult condition was lower than in the pain/easy condition, $t(85) = 1.68$, $p = .048$, $\eta^2 = .03$, and marginally lower than in the neutral/difficult condition, $t(85) = 1.55$, $p = .062$, $\eta^2 = .03$. Other comparisons were not significant (all *p*s > .15).

The a priori contrast on HR reactivity was not significant, $F(1, 89) = 0.01$, $p = .473$, $\eta^2 = .00$. Cell means and standard errors were as follow: pain/easy (*M* = 2.37, *SE* = 0.60), neutral/easy (*M* = 1.27, *SE* = 0.60), pain/difficult (*M* = 3.09, *SE* = 0.65), neutral/difficult (*M* = 2.52, *SE* = 0.46).

Task Performance

Participants were more accurate in the easy (*M* = 95.96%, *SE* = 0.99) than in the difficult (*M* = 83.26%, *SE* = 2.13) condition, as revealed by a main effect of difficulty, $F(1, 89) = 29.22$, $p < .001$, $\eta^2 = .25$, in a 2 (prime) x 2 (difficulty) ANOVA. Other effects were not significant (*p*s > .19). Also a 2 (prime) x 2 (difficulty) ANOVA on the reaction times of correct responses only revealed a main effect of difficulty, $F(1, 89) = 15.49$, $p < .001$, $\eta^2 = .15$, due to faster responses in the easy (*M* = 837.32, *SE* = 25.31) than in the difficult (*M* = 976.64, *SE* = 24.04) condition (other *p*s > .27).

Task Ratings and Mood Scores

In support of a successful task difficulty manipulation, participants perceived the difficult condition as more demanding (*M* = 4.33, *SE* = 0.25) than the easy (*M* = 2.15, *SE* = 0.18) condition, $F(1, 89) = 52.99$, $p < .001$, $\eta^2 = .37$. The main effect of prime was also significant, $F(1, 89) = 4.20$, $p = .043$, $\eta^2 = .05$, due to higher perceived demand in the pain (*M* = 3.50, *SE* = 0.30) than in the neutral (*M* = 2.96, *SE* = 0.23) condition. However, this main effect was qualified by a marginal interaction between primes and task difficulty, $F(1, 89) = 3.72$, $p = .057$, $\eta^2 = .04$. Cell means and standard errors are depicted in Figure 3. Focused cell comparison indicated that the interaction emerged because perceived task demand was higher in the pain/difficult condition (*M* = 4.95, *SE* = 0.35) than in the neutral/difficult (*M* = 3.75, *SE* = 0.33), the pain/easy (*M* = 2.17, *SE* = 0.29), and the neutral/easy (*M* = 2.13, *SE* = 0.23) conditions (*t*s > 2.79, *p*s < .01). There was no difference between the pain/easy and the neutral/easy conditions (*p* > .93). Moreover, perceived task demand was also higher in the neutral/difficult condition than in the neutral/easy and the pain/easy condition (*t*s > 3.75, *p*s < .001).

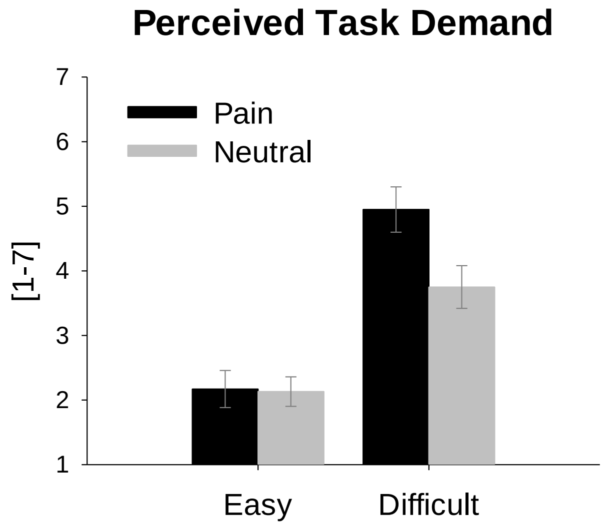

Figure 3. Cell means and standard errors of perceived task demand in Experiment 1.

A 2 x 2 ANOVA on perceived capacity only revealed a main effect of task difficulty, $F(1, 89) = 9.19$, $p = .003$, $\eta^2 = .09$, due to higher perceived capacity in the easy ($M = 5.45$, $SE = 0.22$) than in the difficult condition ($M = 4.54$, $SE = 0.21$). Other effects were not significant (*p*s > .14). Two x 2 ANOVAs on success importance and value did not reveal any significant effect (all *p*s > .51). Also, a 2 (prime) x 2 (difficulty) x 2 (time) ANOVA on mood scores did not reveal any reliable effect (all *p*s > .15). Cell means and standard errors of perceived capacity, success importance and value, and mood scores are presented in Table 2.

Table 2

Cell Means and Standard Errors (in Parentheses) of Perceived Capacity, Success Importance and Value, and Mood Scores in Experiment 1

	Easy		Difficult	
	Pain	Neutral	Pain	Neutral
Perceived Capacity	5.50 (0.30)	5.39 (0.33)	4.14 (0.30)	4.92 (0.28)
Success Importance	5.25 (0.32)	5.26 (0.24)	5.00 (0.36)	5.38 (0.24)
Value of Success	4.71 (0.27)	4.70 (0.23)	4.77 (0.33)	4.71 (0.22)
Mood Baseline	21.17 (0.58)	19.04 (1.30)	20.14 (0.75)	19.96 (0.85)
Mood After Task Performance	21.63 (0.58)	19.26 (1.30)	20.09 (0.79)	21.04 (0.67)

Note: *n* = 24 in the pain/easy condition, *n* = 23 in the neutral/easy condition, *n* = 22 in the pain/difficult condition, and *n* = 24 in the neutral/difficult condition.

Funnel Debriefing

The funnel debriefing procedure revealed that 34% of the participants mentioned having seen a flicker, letter, or word in the trials, but only 5 participants reported having seen words related to pain and 4 participants could mention some of the primed neutral words. This suggests that 90% of the participants processed the primes without awareness of their content.

Interim Discussion

The results of Experiment 1 partially confirmed our predictions about the influence of pain primes on effort-related cardiovascular reactivity. The contrast was marginally significant for PEP, our most reliable measure of effort mobilization. However, the obtained pattern showed, as expected, stronger reactivity in the pain/easy condition than in the neutral/easy and the pain/difficult conditions. In contrast, reactivity was lower than expected in the neutral/difficult condition—i.e. the control condition. This effect might be due to a too high level of objective task difficulty leading to disengagement for some participants in the neutral/difficult condition where reactivity was expected to be stronger.

However, the contrast for SBP reactivity was significant. The obtained pattern indicated, as predicted, a stronger reactivity in the pain/easy and the neutral/difficult conditions than in the neutral/easy and the pain/difficult conditions. The contrast was also significant for DBP, which presented a similar pattern than SBP. HR reactivity did not show the anticipated pattern but this measure is much less sensitive to effort mobilization as discussed in the introduction.

In further support of the predictions, participants perceived the task as more difficult when primed with pain words. This effect mainly occurred in the objectively difficult condition, whereas in the easy condition, the evaluation of task difficulty was not affected by the pain primes. Only a main effect of task difficulty was found for task performance. Most important, the funnel debriefing indicated that most of the participants couldn't mention the primed words indicating that the implicit presentation of the primes was successful.

Given the mixed evidence found for cardiovascular reactivity in the difficult condition, Experiment 2 was designed to further investigate the influence of pain primes on effort-related cardiovascular reactivity using a different control condition.

Experiment 2: Pain vs. Anger Primes

To further test the influence of pain primes on effort mobilization, Experiment 2 was conducted on a different sample than Experiment 1 and exposed participants to pain vs. anger words during an easy or a difficult task. As in Experiment 1, we predicted that participants primed with pain words would perceive the task as more difficult. However, to maximize cell differences and also to exclude the alternative hypothesis that pain primes influence effort due to its negative valence, Experiment 2 used anger words in the control condition. The IAPE model proposes that anger, despite its negative valence, is associated with a high coping potential, which is predicted to result in lower perceived difficulty. Therefore, predictions for Experiment 2 were similar as in Experiment 1 but stronger differences between conditions were expected.

Method

Participants and Design

Eighty-two University students (65 women, mean age 22 years) were randomly assigned to a 2 (prime: pain, anger) × 2 (difficulty: easy, difficult) between-persons design. No additional participants were included once the study was completed. Participation was voluntary and recompensed with course credits. All participants provided signed informed consent and the study protocol was approved by the ethics committee of the Department of Psychology of the University of Geneva. Three participants were excluded due to a low reported level in French (more than 3 on a 7-point Likert scale assessing difficulties in reading and understanding French) resulting in a final sample of N = 79 (65 women). The participants were distributed in the different conditions as follows: *n* = 20 in the pain/easy condition, *n* = 21 in the anger/easy condition, *n* = 19 in the pain/difficult condition, and *n* = 19 in the anger/difficult condition.

Apparatus and Physiological Measures

PEP and HR were assessed with the same apparatus as in Experiment 1. Due to technical problems with the Vasotrac, SBP and DBP were measured with another device than in Experiment 1, a Dinamap ProCare monitor (GE Medical Systems, Information Technologies Inc., Milwaukee, WI) that uses oscillometry. A blood pressure cuff placed over the brachial artery above the elbow of participants' non-dominant arm was automatically inflated in 1 min intervals.

Procedure and Data Analyses

The procedure was similar than in Experiment 1 with the exception that the control condition included words related to anger as primes. Anger words (*anger, furious, irritated, exasperating*) were selected according to a pre-test and matched with pain words in terms of length and frequency of occurrence in French. Regarding data analyses, PEP and HR were determined as in Experiment 1. The theory-based predictions were tested using the same a priori contrast on cardiovascular reactivity: pain/easy and anger/difficult conditions (contrast weight = + 3), anger/easy condition (contrast weight = - 2), and pain/difficult condition (contrast weight = - 4). One-tailed tests were used for additional cell comparisons testing directed predictions. Task performance (accuracy and reaction times) and task ratings were analyzed with conventional 2 (prime) x 2 (difficulty) between-persons ANOVAs. Moreover, mood scores were analyzed with a 2 (prime) x 2 (difficulty) x 2 (time) mixed-model ANOVA with repeated measures on the last factor. Due to technical measurement problems, there were missing data for some participants. Therefore, the sample sizes slightly varied across the analyses of the single dependent variables: *N* = 77 for PEP, *N* = 79 for SBP and DBP, and *N* = 78 for HR.

Results

Cardiovascular Baselines

Cardiovascular baseline values were calculated by averaging the last 3 minutes of the habituation period, which were highly consistent ($\alpha > .98$). As in Experiment 1, there was a decline in assessed values over the first 5 minutes. For the last 3 minutes of the habituation period the values were stable and did not differ significantly from one another (ps > .20). Cell means and standard errors are presented in Table 3. Preliminary 2 (prime) × 2 (difficulty) ANOVAs on these baseline scores did not reveal any main effect or interaction between the conditions (*p*s > .30), with the exception of a significant interaction for HR, $F(1, 74) = 4.47$, $p = .038$, $\eta^2 = .06$. Reactivity scores were obtained by subtracting the baseline values from the averaged task-related values ($\alpha > .98$). Preliminary analyses revealed a significant association between baseline and reactivity scores for DBP, $r(79) = -.30$, $p = .008$, and HR, $r(78) = -.25$, $p = .027$ (other *p*s > .64). Therefore, DBP and HR reactivity scores were adjusted regarding their respective baseline values.

Table 3

Cell Means, Standard Errors (in Parentheses), and Cell Sample Sizes (in Square Brackets) of Cardiovascular Baseline Values in Experiment 2

	Easy		Difficult	
	Pain	Anger	Pain	Anger
PEP	99.26 (2.10) [19]	97.80 (2.30) [20]	97.50 (2.66) [19]	97.34 (2.40) [19]
SBP	100.22 (1.68) [20]	100.40 (1.49) [21]	98.84 (1.90) [19]	100.18 (2.55) [19]
DBP	55.50 (1.75) [20]	55.00 (1.78) [21]	52.66 (1.20) [19]	55.42 (1.24) [19]
HR	79.67 (2.41) [20]	72.70 (2.74) [20]	73.68 (2.64) [19]	77.26 (2.12) [19]

Note: PEP: pre-ejection period; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate. Units of measure are milliseconds for PEP, millimeters of mercury for SBP and DBP, and beats per minute for HR.

Cardiovascular Reactivity

Pre-Ejection Period. The a priori contrast on PEP reactivity was significant, $F(1, 73) = 3.08$, $p = .042$, $\eta^2 = .04$. As depicted in Figure 4 (Panel A), PEP reactivity showed the anticipated pattern. As predicted, follow-up comparisons revealed stronger PEP response in the pain (M = - 3.33, SE = 0.82) than in the anger condition (M = -1.23, SE = 0.73) when the task was easy, $t(73) = 1.85$, $p = .034$, $\eta^2 = .04$. Moreover, PEP response in the pain/easy condition was stronger than in the pain/difficult condition (M = -1.07, SE = 0.74), $t(73) = 1.97$, $p = .026$, $\eta^2 = .05$. PEP responses in the anger/difficult condition (M = -1.83, SE = 0.92) did not differ from the other conditions (all ps > .09) and other comparisons were not significant (all ps > .25).

Systolic Blood Pressure. The a priori contrast on SBP reactivity was significant, $F(1, 75) = 5.34$, $p = .012$, $\eta^2 = .07$. As depicted in Figure 4 (Panel B), SBP reactivity showed the anticipated pattern. Follow-up comparisons revealed stronger SBP response in the pain (M = 3.79, SE = 0.93) than in the anger condition (M = 1.38, SE = 0.69) when the task was easy, $t(75) = 1.68$, $p = .049$, $\eta^2 = .04$. Moreover, SBP response in the pain/easy condition was stronger than in the pain/difficult condition (M = 0.74, SE = 1.23), $t(75) = 2.07$, $p = .021$, $\eta^2 = .05$. SBP response in the anger/difficult condition (M = 3.08, SE = 1.25) was marginally different than in the anger/easy condition, $t(75) = 1.56$, $p = .061$, $\eta^2 = .03$. Other comparisons were not significant (all ps > .12).

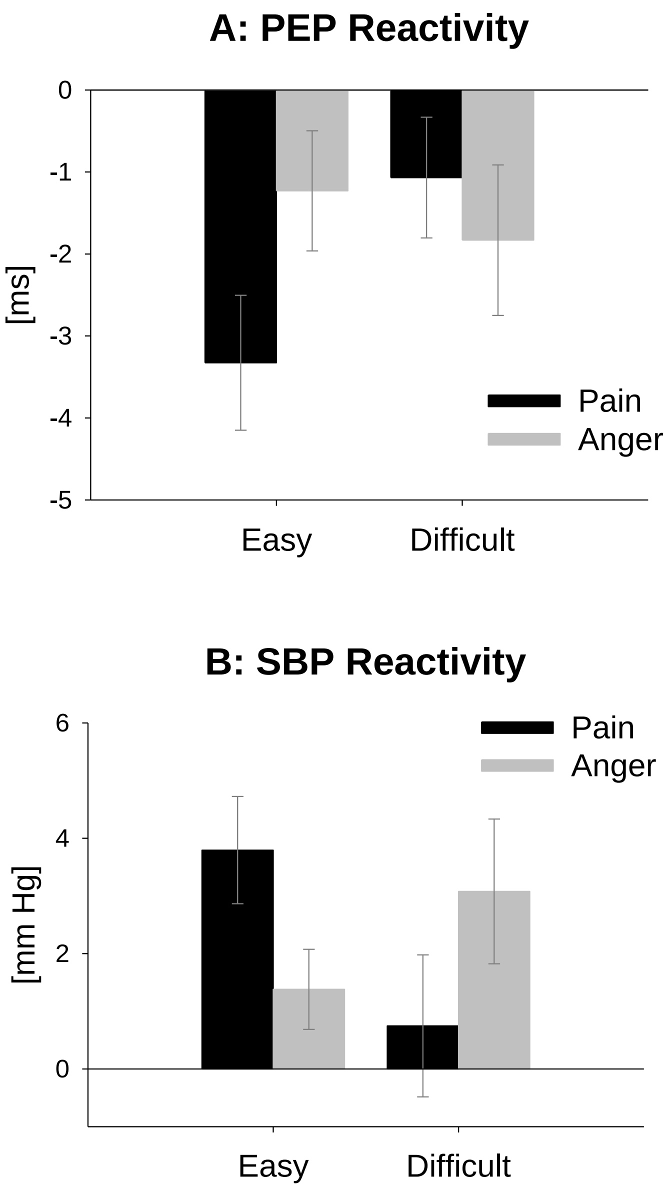

Figure 4. Cell means and standard errors of pre-ejection period (PEP, Panel A) and systolic blood pressure reactivity (SBP, Panel B) during task performance in Experiment 2.

Diastolic Blood Pressure and Heart Rate. The a priori contrast on baseline-adjusted DBP reactivity was significant as well, $F(1, 75) = 2.88$, $p = .047$, $\eta^2 = .04$. Follow-up comparisons revealed stronger DBP response in the pain ($M = 3.21$, $SE = 0.77$) than in the anger condition ($M = 0.93$, $SE = 0.71$) when the task was easy, $t(75) = 2.45$, $p = .008$, $\eta^2 = .07$. Moreover, DBP response in the pain/easy condition was stronger than in the pain/difficult condition ($M = 1.15$, $SE = 0.59$), $t(75) = 2.16$, $p = .017$, $\eta^2 = .06$. DBP response in the anger/difficult condition (*M* = 1.30, *SE* = 0.56) did not differ from the others conditions and other comparisons were not significant (all *p*s > .35).

The a priori contrast on baseline-adjusted HR reactivity was not significant, $F(1, 74)$ = 0.83, $p = .203$, $\eta^2 = .01$. Cell means and standard errors were as follow: pain/easy (*M* = 2.34, *SE* = 0.61), anger/easy (*M* = 1.38, *SE* = 0.76), pain/difficult (*M* = 1.93, *SE* = 0.75), anger/difficult (*M* = 2.33, *SE* = 0.61).

Task Performance

Participants were more accurate in the easy (*M* = 95.96%, *SE* = 0.77) than in the difficult condition (*M* = 81.99%, *SE* = 1.20), as revealed by a main effect of difficulty, $F(1, 75)$ = 96.15, $p < .001$, $\eta^2 = .56$, in a 2 (prime) x 2 (difficutly) ANOVA. Other effects were not significant (*p*s > .94). Participants were also faster in the easy (*M* = 774.65, *SE* = 24.76) than in the difficult condition (*M* = 963.47, *SE* = 28.36), as revealed by a main effect of difficulty, $F(1, 75) = 24.87$, $p < .001$, $\eta^2 = .25$, in a 2 (prime) x 2 (difficutly) ANOVA. Other effects were not significant (*p*s > .36).

Task Ratings and Mood Scores

Participants rated the difficult task as more demanding (*M* = 3.97, *SE* = 0.14) than the easy task (*M* = 1.80, *SE* = 0.20), as revealed by a main effect of difficulty, $F(1, 75) = 77.96$, $p < .001$, $\eta^2 = .51$, in a 2 (prime) x 2 (difficulty) ANOVA. Other effects were not significant (*p*s > .62).

Participants felt less capable to perform the difficult task (*M* = 4.37, *SE* = 0.16) than the easy task (*M* = 5.76, *SE* = 0.21), as revealed by a main effect of difficulty, $F(1, 75)$ = 28.07, $p < .001$, $\eta^2 = .27$, in a 2 (prime) x 2 (difficulty) ANOVA. The main effect of prime was not reliable ($p > .19$). However, the Prime x Difficulty interaction was significant, $F(1, 75)$ = 4.49, $p = .037$, $\eta^2 = .06$. As depicted in Figure 5, participants in the easy condition felt less capable to perform to task when primed with pain cues (*M* = 5.30, *SE* = 0.36) than with anger cues (*M* = 6.19, *SE* = 0.19), $t(75) = 2.47$, $p = .008$, $\eta^2 = .08$. In the difficult condition, perceived capability was not different between the pain (*M* = 4.47, *SE* = 0.22) and the anger condition (*M* = 4.26, *SE* = 0.23), *t*(75) = 0.56, *p* = .288, η^2 = .00.

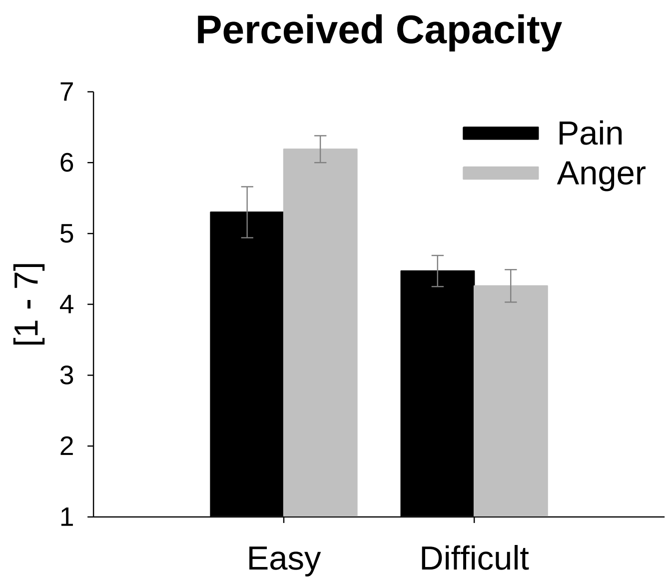

Figure 5. Cell means and standard errors of perceived capacity in Experiment 2.

Participants rated the easy task as more important (*M* = 5.15, *SE* = 0.18) than the difficult task (*M* = 4.37, *SE* = 0.20), as revealed by a main effect of difficulty, *F*(1, 75) = 8.67, *p* = .004, η^2 = .10, in a 2 (prime) x 2 (difficulty) ANOVA. Other effects were not significant (*p*s > .05). Finally, a 2 (prime) x 2 (incentive) x 2 (time) ANOVA on the mood scores did not reveal any effect (*p*s > .12). Means and standard errors of perceived difficulty, success importance, and mood scores are presented in Table 4.

Table 4

Cell Means and Standard Errors (in Parentheses) of Perceived Task Demand, Success Importance, and Mood Scores in Experiment 2

	Easy		Difficult	
	Pain	Anger	Pain	Anger
Perceived Task Demand	1.90 (0.18)	1.71 (0.21)	4.00 (0.31)	3.95 (0.28)
Success Importance	5.35 (0.18)	4.95 (0.30)	4.68 (0.24)	4.05 (0.32)
Mood Baseline	21.80 (0.72)	21.43 (0.79)	19.53 (1.08)	22.37 (0.83)
Mood After Task Performance	21.45 (0.81)	22.10 (0.75)	19.47 (0.70)	21.74 (0.83)

Note: *n* = 20 in the pain/easy condition, *n* = 21 in the anger/easy condition, *n* = 19 in the pain/difficult condition, and *n* = 19 in the anger/difficult condition.

Funnel Debriefing

The funnel debriefing procedure revealed that 38% of the participants mentioned having seen a flicker, letter, or word in the trials, but only 4 participants reported having seen words related to pain and 7 participants could mention some of the primed anger words. This suggests that 86% of the participants processed the primes without awareness of their content.

General Discussion

In summary, the findings of the present experiments revealed stronger PEP, SBP, and DBP reactivity when participants were primed with pain words compared to neutral words in the easy task condition. In contrast, this effect was reversed when the task was difficult. Moreover, participants rated the task as more demanding or perceived themselves as less capable when primed with pain words compared to neutral words. Finally, no reliable effects were observed on HR, task performance, and mood ratings, and most participants could not report the content of the primes.

Together, the two present experiments replicate previous findings on the influence of pain primes on effort (Silvestrini, 2015) and offer additional support to the predictions of the IAPE model applied to pain. Activating the concept of pain led to increased perceived difficulty and influenced effort mobilization as predicted by motivational intensity theory (Brehm & Self, 1989). When the task was easy, priming pain-related words led to stronger effort-related cardiovascular reactivity than priming neutral or anger words. Here, the increase in subjective difficulty induced by priming the concept of pain resulted in stronger effort than the control conditions whereas the required effort did not exceed the maximally justified effort (cf. Figure 1). However, when the task was difficult, priming pain led to weaker effort-related cardiovascular reactivity than the control conditions. Here, the increase in subjective difficulty induced by priming pain and the objective difficult task resulted in a required effort that exceeded the maximally justified effort leading to disengagement.

This pattern was fully supported by SBP and DBP reactivity in both experiments. PEP reactivity showed the anticipated pattern in both experiments but was only marginally significant in Experiment 1. As discussed earlier, PEP reactivity in Experiment 1 was lower than expected in the neutral/difficult condition suggesting that perhaps the task was slightly too difficult leading to disengagement for some participants. In support of this explanation, the pattern of PEP reactivity in Experiment 2 was significant when anger words were used as primes. According to the IAPE model, priming anger was expected to lead to a reduced subjective difficulty compared to a neutral condition. Considering that the difficult task was too difficult using neutral primes in Experiment 1, it was expected that using anger primes should result in a slightly less difficult task leading to less disengagement and more effort—which was effectively observed in Experiment 2. Most important, using anger primes as the control condition also allowed discarding the alternative explanation that pain primes influence effort because of the negative valence of pain. Indeed, although anger is an affective state of negative valence, the predictions and findings were completely different compared to pain suggesting that valence does not explain the observed effect of pain primes. Rather, the IAPE model proposes that implicit affects influence effort through their association with the concept of difficulty or ease, which is independent of valence.

However, it is also of note that disengagement in the pain/difficult condition was less pronounced for PEP reactivity than for SBP or DBP in both experiments. This effect suggests that disengagement is perhaps harder to observe using a measure that is highly sensitive to beta-adrenergic activity such as PEP. Moreover, recent research investigating physical effort and using obviously impossible tasks did not find a complete disengagement of the participants (Stanek & Richter, 2016). This suggests that individuals may engage little effort in a task even when the required effort exceeds the maximally justified effort, either to comply with experimental demand or because they simply enjoy the task. Finally, HR reactivity did not show the anticipated pattern, which is not surprising because HR is determined by both sympathetic and parasympathetic activity, and the latter can mask the influence of the former.

In further support of the predictions of the IAPE model applied to pain, participants reported increased subjective difficulty in both experiments although this effect emerged differently in Experiment 1 and 2. In Experiment 1, participants perceived the difficult task as more demanding when they were primed with pain words compared to neutral words. This effect was not observed in the easy task and also not reliable on the perceived capability item. In contrast, participants in Experiment 2 perceived themselves as less capable to perform the easy task when primed with pain words compared to anger words. However, this effect was not observed in the difficult task and also not reliable on the perceived task demand item. Altogether, these findings show an impact of pain primes on self-reported perceived difficulty. However, it remains hard to explain why this effect emerged on perceived task demand related to the difficult condition in Experiment 1 and on perceived capacity related to the easy condition in Experiment 2. It could be that various uncontrolled factors, such as when the experiment was run (beginning or end of the semester) or whether participants already performed a similar task in a previous experiment or not, might have influenced and biased these self-reports explaining such variability.

The present findings did not replicate previous evidence on the influence of pain primes on task performance (Silvestrini, 2015). Whereas physical pain is associated with impairment in cognitive performance (Buhle & Wager, 2010), the present experiments did not find any effect of pain primes on accuracy or response times. Moreover, no effects emerged on mood scores, which suggest that pain primes did not influence the affective states of participants but rather impacted effort mobilization through the activation of mental representations. In support of this implicit influence, the funnel debriefing procedure indicated that very few participants could mention the content of the primes suggesting that the large majority of the participants processed the primes implicitly.

The present findings support the idea of an implicit influence of pain cues on behavior. According to the IAPE model and to the definition of implicit affect, this effect occurred due to the activation of mental representations associated with the concept of pain. Previous research supported the notion of pain-related implicit memory in chronic pain patients, showing that these patients had stronger neurophysiological responses to words related to pain and presented at perception threshold, compared to body-related or neutral words (Flor, Knost, & Birbaumer, 1997). Moreover, another study revealed stronger pain-related implicit associations, assessed by means of an adapted implicit association test, in chronic pain patients compared to healthy subjects (Grumm, Erbe, von Collani, & Nestler, 2008). Investigating healthy subjects, another study found evidence for implicit learning of enhanced pain sensitization, i.e. without subjects' awareness of reinforcement contingencies (Hölzl, Kleinböhl, & Huse, 2005). Altogether, these findings support the view that pain-related representations are stored in memory and can be activated through priming. In a broader perspective, this phenomenon is also clearly visible in classical aversive conditioning where neutral situations are associated in memory with painful stimuli, which shows the importance of pain in the detection of potential threat to the organism and also the importance of mental representations in the processing of potential painful situations or stimuli.

The present studies include at least two limitations that may be discussed. First, participants were recruited in the context of fulfillment of course credits and were not systematically screened for health or health-related behaviors. Given that cardiovascular activity can be influenced by numerous variables, such as smoking, caffeine, or medication, it is possible that such variables influenced the findings of the present studies. However, it is important to note that the present studies were based on an experimental approach that is expected to randomly distribute the effect of inter-individual variables across conditions and therefore to neutralize or at least reduce their potential impact. Second, the sample of the present studies included mainly women and did not allow testing for possible gender effects. This issue raises the question of the generalization of the findings to men. However, it is of note that the IAPE model does not propose different predictions for men and women and that gender was not a critical variable in the present studies. To overcome this limitation, future studies may include a similar number of men and women to further test gender effects and extend the findings to both gender.

To conclude, the present studies showed that implicit pain cues influenced effort defined as the amount of resources people mobilize to execute instrumental behavior (Gendolla & Wright, 2009). As presented in the introduction, it is reasonable to expect that individuals experiencing pain perceive a concurrent task as more difficult than without pain because pain and cognitive performance engage common cognitive processes that are somehow limited (Buhle & Wager, 2010). Therefore, pain is predicted to influence effort mobilization because, according to motivational intensity theory (Brehm & Self, 1989), effort is determined by subjective difficulty as long as success is possible and the required effort is justified. So far, evidence on the influence of physical pain on effort is lacking. However, the present findings support the prediction of a systematic influence of pain on effort. In a clinical context, the issue of effort would deserve more attention for several reasons. First, pain is strongly associated with other effortful self-regulatory processes such as emotion or attention regulation, which suggest that the cost of effortful processes may transfer from one process to the others (Solberg Nes, Roach, & Segerstrom, 2009). Second, clinical observations reveal that chronic pain patients frequently complain about fatigue, which can be related to repeated effort mobilization induced by pain and concomitant self-regulatory processes. Finally, it is reported that chronic pain patients frequently disengage from their daily activity (Breivik et al., 2006) and the present research offers a theoretical framework predicting that chronic pain patients may disengage due to too high perceived difficulty to accomplish various activities while experiencing pain. This view offers some perspectives for the patients' care by showing that adapted difficulty levels or increased incentives may help patients to stay engaged in various activities.

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