

SUPPLEMENTARY INFORMATION

Amygdalar function reflects common individual differences in emotion and pain regulation success

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Supplementary Methods

Emotion regulation session: normative picture ratings.

Normative ratings for the IAPS pictures are given by a large (~100) number adult participants using a 9-point scale. In the valence dimension, “1” represents “low pleasure” and “9” represents “high pleasure”. Similarly, in the arousal dimension, “1” represents “low arousal” and “9” represents “high arousal”. The means and standard deviations of the normative ratings for the pictures adopted in the study were as follows: for the negative pictures, valence_{SET1}: $M = 2.97$, $SD = 0.66$; arousal_{SET1}: $M = 5.30$ $SD = 0.93$; valence_{SET2}: $M = 2.98$, $SD = 0.69$; arousal_{SET2}: $M = 5.29$ $SD = 0.91$, and for the neutral pictures, valence_{SET1}: $M = 5.02$, $SD = 0.36$; arousal_{SET1}: $M = 2.75$ $SD = 0.57$; valence_{SET2}: $M = 5.04$, $SD = 0.47$; arousal_{SET2}: $M = 2.81$ $SD = 0.50$.

Pain regulation session: participant-tailored nociceptive thermal stimuli.

The level of nociceptive stimulation was chosen on the basis of the participants’ own ratings. Stimulation began at 32°C and increased by 0.7°C/s. Participants were asked to stop the stimulation by pressing a button when their pain reached an 8 on an 11-point scale, where 0 represented no pain and 10 represented the worst pain imaginable. This was repeated 10 times, with a 30 s break between each presentation. The mean temperature from the final 5 trials was used as their nociceptive thermal stimulus, as the first few temperatures chosen as an 8 are typically lower and show greater variability than the latter ones.

Pain regulation session: heart rate acquisition and processing.

We recorded pulse oximetry at 1000 Hz throughout the pain regulation task. Heartbeats were identified using in-house software for each run, where missed beats were manually added prior to computing of inter-beat intervals (IBIs). IBIs were converted to

heart rate (beats per minute) using the formula: $BPM = 60 * 10^3 / (IBI)$ (Hugdahl, 1995). Data were missing from 2 participants, and data of 1 additional participant were excluded due to excessive motion artifact. Hence, the final sample for analyses of heart rate consisted of 14 participants. Autonomic arousal attributable to pain regulation was operationalized as the difference in mean heart rate between the enhance and suppress conditions.

Pain regulation session: pupil diameter.

To verify that participants were engaged during the pain regulation task, and to rule out that the instructions of suppress and enhance pain differed in terms of the cognitive load they posed on participants, we measured pupil diameter throughout the experiment.

Horizontal pupil diameter data were acquired continuously at 60 Hz using an iView X system (v. 1.3.31) with a remote eye-tracking device (SensoMotoric Instruments, Teltow, Germany). Data were processed and smoothed using algorithms written by Siegle et al. (2002) with MatLab software (MathWorks, Natick, MA), modified in our lab. Blinks were eliminated by using local regression slopes and amplitude thresholds. Mean pupil diameters were computed for eyes-open 500 ms epochs for 1 s prior to heat onset to 12 seconds after. Data were visually inspected, and participants that had fewer than 50% of the trials available due to eyes closed or poor data recording were discarded. The data of 2 participants did not meet this criterion, and hence data of fourteen participants were used for the analyses of pupil diameter. Change in pupil diameter was calculated by subtracting the mean for the 500 ms bin that preceded reappraisal instruction from the 500 ms bins following regulatory instruction for the suppress and enhance conditions (for a total of 8 s).

We confirmed participants were engaged in the pain regulation task by comparing the degree of pupil dilation during the regulatory conditions against the passive condition. We found a significant quadratic effect, $F(2,26) = 6.02$, $p = .029$, indicating that pupil dilation was equivalent in the two active regulatory conditions of enhance ($M = 101.16$, $SEM = 13.85$) and suppress ($M = 117.39$, $SEM = 22.39$) pain, and was significantly greater than when participants were instructed to simply maintain ($M = 84.86$, $SEM = 15.37$) their responses to the pain. In other words, this provides empirical evidence that

levels of engagement in the task (i.e., effort) was successfully matched across the two active regulatory conditions.

Supplementary Results

Participant-chosen temperatures are not statistically related to either pain or emotion regulation success.

Participant-tailored temperature data was missing for one participant. With the remaining sample of 16 participants, the mean temperature chosen was 48.18°C ($SD = .98$). Although there was a negative relationship between participant-chosen temperatures used during the pain regulation task and regulatory ability as indexed by changes in pain unpleasantness ratings as a function of regulatory goal, it did not reach statistical significance, $r(14) = -.47, p > .06$. In addition, emotion regulation success was not correlated with participant-chosen temperature, $r(14) = -.14, p > .59$. Finally, participant-chosen temperature was unrelated to amygdalar hemodynamic response changes as a function of pain, $r(14) = .06, p > .8$, or emotion regulatory goal $r(14) = -.14, p > .5$.

Importantly, emotion regulation success remained a significant predictor of changes in pain unpleasantness ratings, $t(15) = 3.39, p < .01$, as well as of changes in amygdalar activation during pain regulation, $t(15) = 2.78, p = .02$, after entering participant-chosen temperatures as covariates in these two regression models. Similarly, amygdalar changes following emotion regulation instruction also remained a significant predictor of changes in pain unpleasantness ratings, $t(15) = 3.42, p < .01$, as well as of changes in amygdalar activation during pain regulation, $t(15) = 4.71, p < .01$, after entering participant-chosen temperatures as covariates in these regression models.

Other brain regions showing cross-paradigm associations with behavioral or physiological markers of regulatory success in emotion and pain regulation

Although our primary prediction regarding common neural circuitry sensitive to contextual modulation across pain and emotion paradigms involved the amygdala, we also verified whether activity in other brain regions associated with regulatory success within each emotion and pain regulation paradigms could be predicted from markers of regulatory success from the other, namely, corrugator EMG and pain unpleasantness ratings. To that end, we extracted the cluster means of each of the within-paradigm neural

correlates of regulatory success in emotion and pain regulation (shown in Table I and II, respectively), collapsed across left and right hemispheres (when bilateral activation was identified), and ran bivariate correlations with the cross-paradigm marker of regulatory success (i.e., we correlated the mean activity for each area identified as a neural correlate of emotion regulation success with changes in pain unpleasantness ratings during pain regulation, and did the analogous analysis to assess whether the areas associated with pain regulation success were also associated with changes in corrugator EMG during the emotion regulation paradigm). The results of those bivariate Pearson's correlations are shown in Table SI & SII. Table SI shows how strongly each of the neural correlates of emotion regulation success (originally obtained by regressing changes in corrugator EMG voxelwise on the (enhance – suppress) contrast during emotion regulation; see Table I) was associated with (enhance – suppress) changes in pain unpleasantness ratings during pain regulation. Similarly, Table SII shows how strongly each of the neural correlates of pain regulation success (originally obtained by regressing changes in pain unpleasantness ratings voxelwise on the (enhance – suppress) contrast during pain regulation; see Table II) was associated with (enhance – suppress) changes in corrugator EMG during emotion regulation. Brain regions in Tables SI & SII are displayed in the same order they were originally shown in Tables I & II of the current report.

Supplementary Table SI. Association (Pearson's r) between changes in pain unpleasantness ratings during pain regulation and change in activity of each brain region (cluster mean) significantly associated with emotion regulation success; (enhance – suppress).

Brain region	Size (mm ³)	Pain Unpleasantness Ratings
Hippocampus	1232	.68*
Middle Frontal Gyrus (BA 6)	1968	.54*
Frontal Pole (BA 10)	5944	.59*
Temporal Pole	1600	.49*
Frontal Orbital Cortex (BA 25)	1304	.09
Precentral Gyrus	1280	.26
Inferior Frontal Gyrus (BA 44)	1408	.17
<i>(pars opercularis)</i>		
Inferior Frontal Gyrus (~BA 45)	280	.34
<i>(pars triangularis)</i>		

* significant at $p < .05$.

Supplementary Table SII. Association (Pearson's r) between changes in corrugator EMG activity during emotion regulation and change in activity of each brain region (cluster mean) significantly associated with pain regulation success; (enhance – suppress).

Brain region	Size (mm ³)	Corrugator EMG
Cerebellum	9328	.24
Hippocampus	1576	.32
Occipital Cortex	8104	.52*
Brainstem	2400	.22
Parahippocampal Gyrus	296	.26
Thalamus	96	-.03
Pallidum	512	.35

* significant at $p < .05$.

Disentangling enhance and suppress contributions to the common regulatory skill across emotion and pain regulation paradigms

To evaluate the relative contribution of enhance and suppress abilities in underlying the common regulatory skill across emotion and pain paradigms, we modeled the passive (maintain) condition by convolving each 8-s event of the maintain condition with a canonical hemodynamic response function (γ) at the single-subject general linear model. Next, we extracted the parameter estimates for the (enhance – maintain) and (maintain – suppress) contrasts from the amygdalar neural correlates of regulatory success for each emotion and pain regulation paradigms reported in this study (identified by the voxelwise regression of (enhance – suppress) changes in corrugator EMG and pain unpleasantness ratings in each emotion and pain paradigms, respectively). Table SIII below shows how cross-paradigm relations compared with one another as a function of

active regulatory condition used in relation to the passive control condition (i.e., enhance – maintain vs. maintain – suppress).

Supplementary Table SIII – *Comparison of the predictive power (Pearson’s r) of each (enhance – maintain; EM) vs. (maintain – suppress; MS) contrasts on the prediction of pain regulation outcomes from emotion regulation indices ($N = 17$)*

Prediction	Contrast		$Z_{r\text{diff}}$
	EM	MS	
COR EMG → Pain Unpleasantness	-.056	.508*	-1.63
COR EMG → Pain Regulation Amy	-.306	.424†	-2.03*
Emotion Regulation Amy → Pain Unpleasantness	.296	.567*	-.894
Emotion Regulation Amy → Pain Regulation Amy	.048	.46†	-1.1

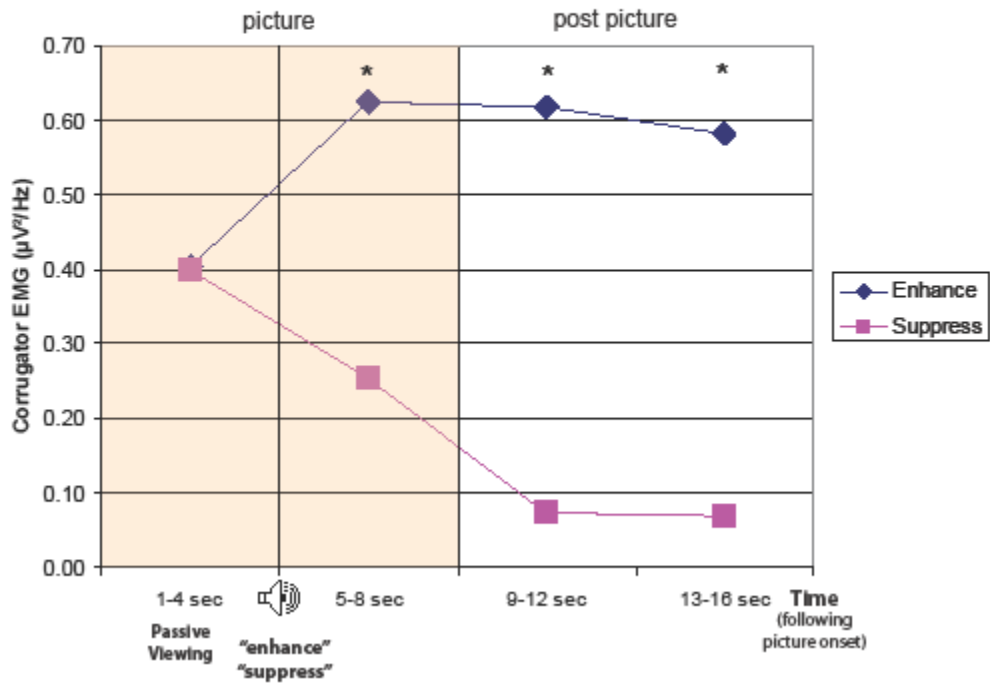
* significant at $p < .05$.

† significant at $p < .1$.

diff = difference; Amy = amygdala; COR EMG = Corrugator Electromyography; Pain Unpleasantness = pain unpleasantness self-reported ratings.

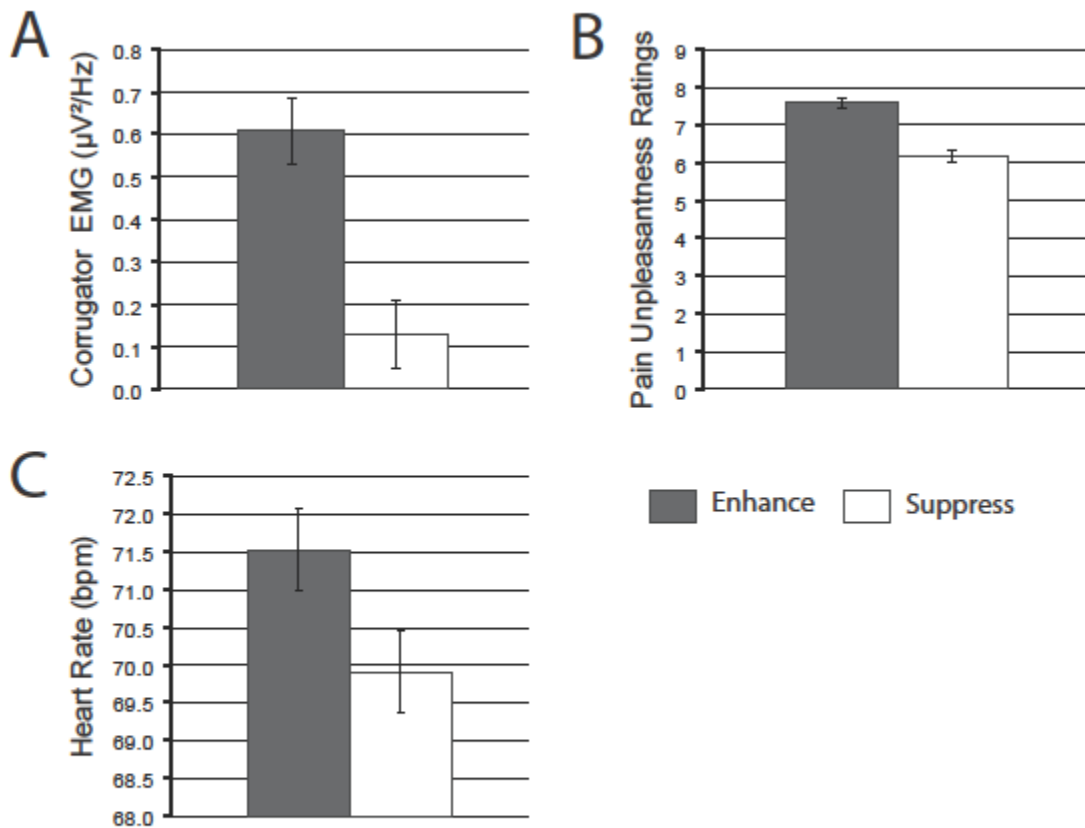
Supplementary Figure 1. Corrugator EMG change by regulatory instruction over time (n = 17).

Supplementary Figure 1



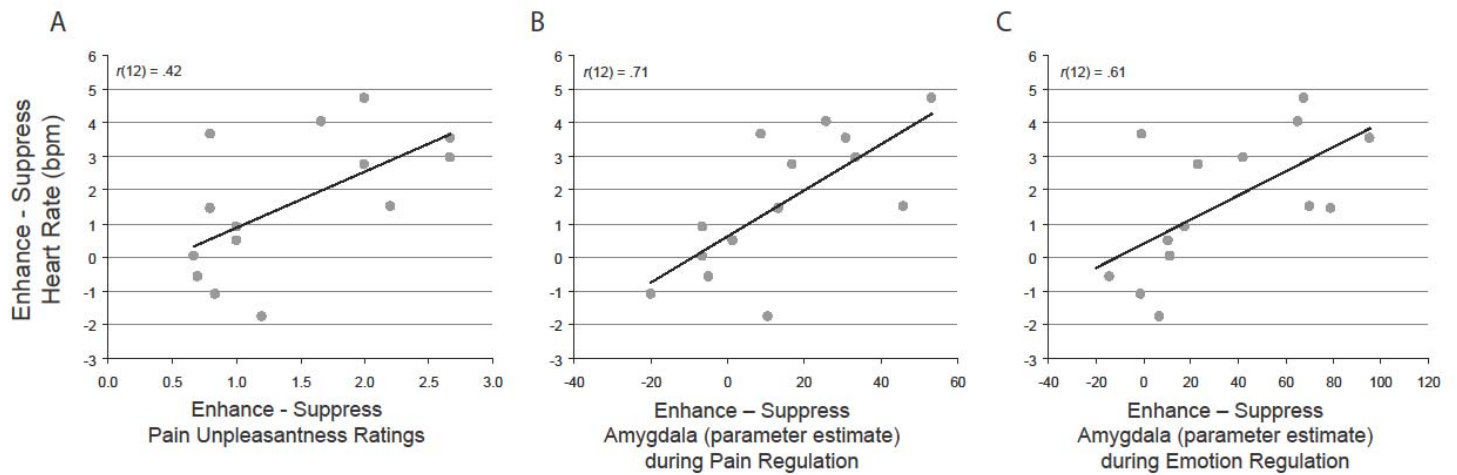
Supplementary Figure 2. The effects of reappraisal on emotion and pain processing. A- Effects of Emotion Regulatory Instruction on Corrugator EMG (n = 17). B - Effects of Pain Regulatory Instruction on Pain Unpleasantness Ratings (n = 17). C- Effects of Pain Regulatory Instruction on Heart Rate (n = 14). Error bars represent the SEM difference between the two conditions.

Supplementary Figure 2



Supplementary Figure 3. A- Heart rate changes as a function of pain regulatory instruction correlate with changes in pain unpleasantness ratings. B- Heart rate changes as a function of pain regulatory instruction correlate with changes in amygdalar engagement during pain regulation. C- Heart rate changes as a function of pain regulatory instruction correlate with changes in amygdalar engagement during emotion regulation (n = 14).

Supplementary Figure 3



Reference

Hugdahl, K. (1995). *Psychophysiology: The Mind–Body perspective*. Cambridge.:
Harvard Univ. Press.