NeuroImage 230 (2021) 117817

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

With a little help from my friends: The effect of social proximity on emotion regulation-related brain activity

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ARTICLE INFO

Keywords:
Reappraisal
Social support
Social proximity
Interpersonal emotion regulation
Functional magnetic resonance imaging
Amygdala

ABSTRACT

When experiencing negative emotions, individuals often reach out for social support to help regulate their emotions. In times of an acute crisis, however, close friends might not be available, and physical closeness might be impossible. This functional magnetic resonance imaging (fMRI) study investigated the effect of social proximity on the effectiveness of social support for regulating emotions and the underlying neural mechanisms. Participants regulated their emotions in response to negative images either alone (intrapersonal regulation), or with help of a picture and supporting sentence provided by the best friend, or by a stranger (interpersonal regulation). Regulation success was enhanced for the support of friends compared to regulating alone or with the support of strangers. This effect was accompanied by the interplay of large-scale brain networks involved in processing emotions, social cognition, and cognitive control. Interpersonal regulation appeared to be implemented by lateral prefrontal regions. The amygdala showed increased activation for strangers. The activation profile of the social cognition network suggests a role in supporting empathic and mentalizing processes. The results highlight the power of social connectedness for boosting emotion regulation ability and the different neural networks that contribute to this effect.

1. Introduction

In emotionally challenging situations, such as being in lock-down during the COVID-19 pandemic, people often seek out support from family, friends, partners, or even strangers (e.g., via helplines) with the goal to alter one's affective state (Rime, 2009), or to dampen stress (Uchino and Garvey, 1997). For many people in lock-down, social support is limited to online contact thereby lacking physical closeness. However, even outside the context of the pandemic, relying on social support via video and chat functions has become increasingly common. Regulating one's own emotions through social interaction using empathic, supportive, and prosocial behaviors is referred to as interpersonal emotion regulation (Dixon-Gordon et al., 2015; Niven, 2017; Zaki and Williams, 2013). In contrast to intrapersonal emotion regulation (i.e. regulating emotions without others), little attention has been devoted to the efficacy and neural underpinnings of this process.

Neurally, Reek et al. (2016) proposed a framework for the implementation of interpersonal emotion regulation in the brain, which is based on three neural systems: (1) a cognitive control system, (2) social cognition and empathy system, and (3) an emotion generation system. These systems reflect the interactive nature of interpersonal emotion regulation. According to Zaki and Williams (2013), interpersonal emotion regulation can be characterized by an "observer" supporting a "target" in their attempt to change their emotional experience. The observer responds to the emotional response of the target and attempts to regulate the target's emotions via strategies to enhance cognitive control (Reek et al., 2016). In the target, this should involve the neural cognitive control system (system I), including the dorsolateral prefrontal cortex (dlPFC), ventrolateral prefrontal cortex (vlPFC), and anterior cingulate cortex (ACC) as well as the orbitofrontal cortex (OFC) and parietal cortex (e.g., Morawetz et al., 2017b, 2020); in addition, the involvement of the social cognition system (system II) related to empathy and mentalizing would occur, including dorsal premotor regions, temporo-parietal junction (TPJ), dorsal medial prefrontal cortex (dmPFC) and precuneus (Bernhardt and Singer, 2012; Decety and Jackson, 2004; Jauniaux et al., 2019). The target's emotional response is based on the emotion-generation system (system III), which involves the amygdala and ventral striatum (Ochsner et al., 2012). The amygdala has also been suggested to be involved in social perception (detecting, decoding, and interpreting of social signals), social affiliation (motivating

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https://doi.org/10.1016/j.neuroimage.2021.117817
Received 25 September 2020; Received in revised form 18 January 2021; Accepted 21 January 2021
Available online 30 January 2021

prosocial or affiliative behaviors), and regulating interpersonal distance (Bickart et al., 2014; Kennedy et al., 2009; Laird et al., 2015).

In this study, we focused on the effect of social proximity on interpersonal emotion regulation. Previous research demonstrated that the presence of a close other diminished negative affect and attenuated activity in a network associated with salience, vigilance, and regulatory self-control (i.e., dlPFC, vlPFC, posterior parietal cortex, and dorsal ACC), whereas threat-related activity was increased when a person was accompanied by a stranger or when alone (Coan et al., 2006, 2013, 2017; Kawamichi et al., 2015). These findings have been discussed in light of social baseline theory, which proposes that the presence of other people helps individuals to conserve important and often metabolically costly somatic and neural resources through the social regulation of emotion (Beckes and Coan, 2011). These results suggest that neural activation in lateral PFC regions, parietal, and cingulate cortex during interpersonal emotion regulation might depend on the proximity to the observer, i.e. the person providing emotional support.

The current study examined the neural mechanisms underpinning interpersonal emotion regulation initiated remotely by observers of different social closeness using functional magnetic resonance imaging (fMRI) and univariate as well as multivariate analyses approaches. The targets used reappraisal to down-regulate their emotions in response to negative pictures. In three regulation conditions, support (i.e. interpersonal emotion regulation) was provided by an observer, who was either the best friend, or a stranger, or no support was provided (intrapersonal emotion regulation). We predicted that social proximity (in the absence of physical closeness) would make a significant contribution to reducing negative affect and that this would be accompanied by an increase in activity in neural circuits associated with emotion regulation and social cognition (system I and system II), especially in the lateral prefrontal cortex (dlPFC and vlPFC) and parietal cortex (TPJ). For strangers, the same (potentially weaker) advantage in emotion regulation was predicted as for close friends (Coan et al., 2006). Alternatively, however, strangers might trigger a stress response (Coan et al., 2017), which could be counterproductive and might lead to increased activation in the amygdala (system III).

2. Methods

Here we report two studies: a behavioral pilot experiment (that was conducted few months before the fMRI experiment) and an fMRI experiment to investigate the effect of social proximity on emotion regulation, which served to replicate the effects of the behavioral pilot experiment and investigate the neural correlates of this process. The two experiments used identical experimental paradigms with two independent samples and are therefore described together in this section. Session 1 was identical for both experiments, while session 2 took either place in a behavioral testing room in front of a computer (behavioral pilot experiment) or inside the MRI scanner (fMRI experiment).

2.1. Participants

Participants in both experiments gave written, informed consent to participate. The studies were approved by the local ethics committee of Freie Universität Berlin.

Behavioral pilot experiment: We tested 32 right-handed, healthy participants with normal or corrected to normal vision (28 female; mean age = 23.69 years, SD = 3.77). 22 participants had a best friend of the same sex and 10 participants of the opposite sex. (Note that we did not conduct a formal power analysis prior to the behavioural pilot study, but we aimed for ~30 pilot participants to establish whether an effect was likely to exist, after which we progressed with the fMRI study.)

fMRI experiment: We tested 38 right-handed, healthy participants with normal or corrected to normal vision. One participant was excluded due to technical problems with data acquisition. The final sample consisted of 37 participants (31 female; mean age = 22 years, SD = 2.58). The best friend was in 29 cases of the same sex and 8 cases of the opposite sex.

2.2. Stimuli

2.2.1. Instruction statements for interpersonal conditions

Seventy-two different German statements (adapted from Xie et al., 2016) were used to instruct reappraisal for the interpersonal conditions (*Friend* & *Stranger*). The statements included 6 different tactics (McRae et al., 2012):

(1) “situation-based: reality challenge” (e.g., “This is not real.”),
(2) “distancing” (e.g., “This doesn’t affect you.”),
(3) “acceptance” (e.g., “Life goes on.”),
(4) “situation-based: change future consequences” (e.g., “The situation will improve with time.”),
(5) “explicitly positive” (e.g., “Everything will be fine.”), and
(6) “problem-solving” (e.g., “Calm down.”).

These reappraisal statements were rated online by an independent sample (n = 35; 30 female; mean age = 28.88 years, SD = 9.04) on valence (“How do you feel about this statement?”), arousal (“How arousing is this statement”) and social proximity (“How close would you feel to someone who would say this to you?”) on a Likert scale from 1 to 100 (very negative/very calm/very distant to very positive/very exciting/very close). Half of the statements used a formal way of addressing participants (i.e. the German “Sie”, used to address unfamiliar people) during the *Stranger* condition and half an informal way (i.e. the German “Du”, used to address friends and close acquaintances) during the *Friend* condition, while the content and wording of the statements were kept identical. This manipulation was used to increase the ecological validity of the experiment. Overall, statements using a formal way of address were rated as more distant compared to statements using an informal way of instruction ($t(34) = -6.36$, $p < 0.001$, Cohen’s $d = 1.49$). However, the different ways of being addressed did not affect the perceived valence (formal vs. informal: $t(34) = -1.68$, $p = 0.102$, Cohen’s $d = 0.2$) or arousal (formal vs. informal: $t(34) = 0.63$, $p = 0.53$, Cohen’s $d = -0.07$) of the statements, which were rated as relatively neutral on average on both dimensions (mean valence = 48.85, SD = 8.49; mean arousal = 47.98, SD = 7.99). Hence, the two ways of addressing people only affected social proximity, and they were used to create the interpersonal emotion regulation conditions – *Stranger* and *Friend*.

2.2.2. Emotional stimuli & pictures for regulation conditions

Stimuli consisted of 144 aversive pictures from the International Affective Picture System (IAPS) (Bradley and Lang, 2007) according to the normative ratings, which are available on a Likert scale from 1 (very negative/very calm) to 9 (very positive/very arousing): mean valence = 2.85, SD = 0.56, mean arousal = 5.65, SD = 0.78. The stimulus set was divided into four sets of 36 images that were matched in content, valence, and arousal across the four experimental conditions to ensure that emotion induction was comparable.

Digital photos of the best friends were taken (in a black t-shirt against a white wall, covering the face to mid-chest, without jewelry), converted into black and white images, and used in the *Friend* condition. In addition, a picture of a female or male person (unknown to the participant) was used in the *Stranger* condition. The sex of the stranger was matched to the best friend to make the interpersonal emotion regulation conditions comparable and to reduce possible gender effects. Scrambled versions of these pictures were created and presented during the non-social conditions (*Look*, which was the control condition, and the intrapersonal condition, here simply referred to as *Decrease*) to match the trial structure of the interpersonal conditions.

2.2.3. Stimulus presentation

The stimulus presentation and response recording were controlled by Presentation (Version 14.1, Neurobehavioral Systems, USA). Inside the

MRI scanner, visual stimuli were presented in the center of the screen using dual-display goggles (VisuaStim, MR Research, USA).

2.3. Experimental cover story: session 1

During recruitment, participants were informed that the experiment would take place over two different days, and they were asked to bring their best friend to the lab for the first session. Best friends were explicitly defined as not having a sexual relationship with each other, i.e. no romantic partners. Upon arriving for session 1, participants and best friends were told to fill out a set of questionnaires on a computer in separate rooms to find out more about their friendship and how they support each other in stressful situations. We told both of them that this information would be used to modify the experiment for session 2. Also, the best friend was instructed to provide five supporting statements for the participant that could be used in emotionally difficult situations and was told that these statements would be used in the fMRI experiment (session 2). Participants were told that they would perform an emotion regulation task with the help of their best friend or a stranger during session 2. Of note, participants were told that a stranger also provided similar statements, which would be used in the experiment. This procedure was identical for the behavioral pilot experiment and the fMRI experiment.

2.4. Procedure: session 2

During session 2, participants were given instructions for and training on the experimental task they would perform. The training consisted of 8 trials (2 trials per condition) to familiarise the participants with the trial design and the emotional state rating scale.

In the experiment, a standard emotion regulation task was used, which was adapted from previous studies (Morawetz et al., 2017a, 2016a, 2016b). In each trial, participants were asked to either regulate their emotions in response to viewing an aversive picture or to attentively view the picture in the control condition. Four task conditions were implemented (**Fig. 1A**): (1) In the *Look* condition, participants were first presented with a scrambled image and underneath the instruction to view the following aversive image attentively and allow themselves to experience/feel any emotional responses, which it might elicit without manipulating their emotions. This constituted the control condition. (2) In the *Decrease* condition, participants viewed a scrambled image along with the instruction to actively reduce the intensity of negative emotions. Importantly, no specific tactic was instructed, just a general statement to down-regulate their emotions was presented. During the training, participants were told that they could use any strategy that would help them to down-regulate their emotions e.g., by distancing themselves, reducing the personal relevance, etc. (Eippert et al., 2007; Ochsner et al., 2004; Urry et al., 2009). Importantly, participants were told not to substitute negative emotions with positive emotions as this would result in distraction from negative emotions rather than a reappraisal of the depicted situation (Webb et al., 2012). This condition was non-social and required intrapersonal emotion regulation. (3) In the *Friend* condition, participants viewed a photo of their best friend along with a regulation statement (using the informal form of addressing the participant) and were asked to use this sentence to decrease their emotions in response to the subsequently presented aversive image. (4) In the *Stranger* condition, participants viewed a photo of a stranger along with a matched statement (using the formal form of addressing the participant) and were asked to use this sentence to decrease their emotions in response to the subsequently displayed negative image. The *Friend* and *Stranger* conditions represented the social, interpersonal emotion regulation conditions.

Each trial started with a regulation statement underneath the presentation of the respective picture (5 s) indicating the experimental condition. To further increase or decrease social proximity, the name of the friend or the stranger was presented along with the photo (for example:

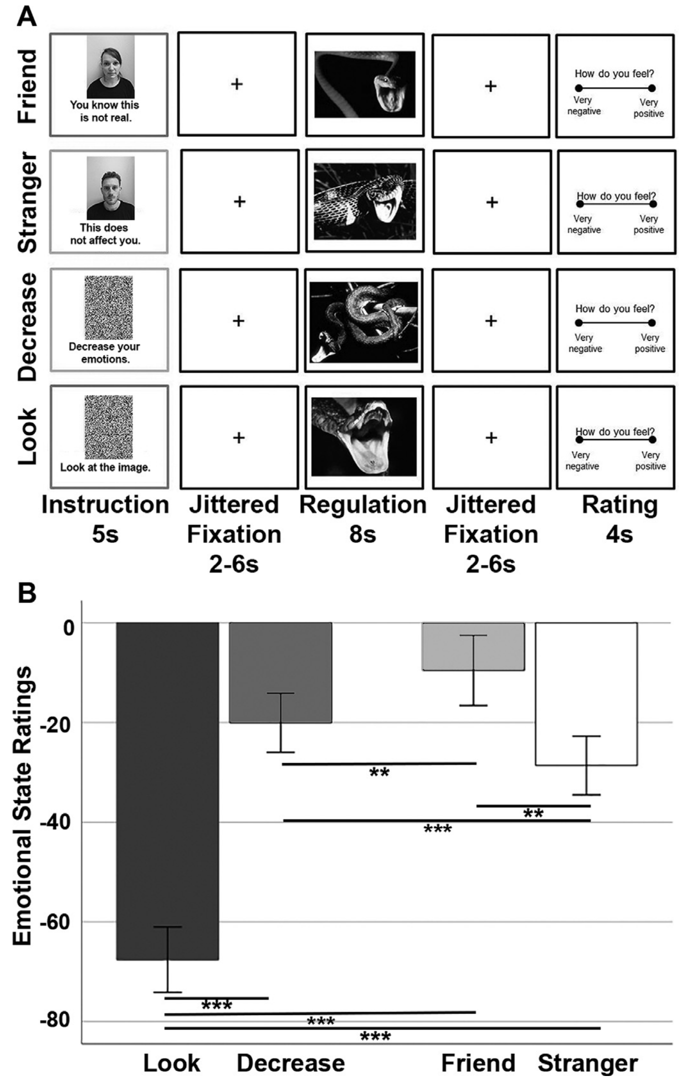

Fig. 1. **A** Experimental task design. Four experimental conditions were implemented. In the instruction phase, participants saw a picture of either their best friend (*Friend* condition), a stranger (*Stranger* condition) or a scrambled version of these images in the *Decrease* condition and the *Look* condition. In the *Friend* and *Stranger* conditions, a reappraising statement, attributed to the depicted person, was displayed below the picture, which should help the participants to regulate their emotions. Aversive images were presented in the following phase, and participants were asked to use the statements to reappraise the depicted situations. In the *Decrease* condition, they could freely choose their own regulation strategy, and in the *Look* condition, they were asked to experience the emotion without regulation. Each trial concluded with an emotional state rating on a scale from "very negative" to "very positive".
B Results of the emotional state ratings following each trial of the fMRI experiment. Participants felt less negative after regulating their emotions in the *Friend, Decrease* and *Stranger* condition compared to the *Look* condition. The regulation with the help of a friend was most effective. ** $p < 0.01$; *** $p < 0.001$. Error bars indicate standard error of the mean.

Laura says: "Keep calm."). This was followed by a fixation cross for a jittered duration of 2–6 s. Subsequently, an aversive image was presented for 8 s during which the instructed strategy had to be applied. Again, this was followed by a fixation cross for a jittered duration of 2–6 s. After this, participants were asked to rate their current emotional state (from "very negative" to "very positive"; arbitrarily scaled off-line from −200 to +200 for the analyses) using a two-button fiber optic response pad (fORP, Cambridge Research Systems Ltd.). The response window was

4 s. Finally, a central fixation cross was presented for a jittered duration of 2–6 s, concluding the trial.

Participants performed six runs. Each run consisted of 24 trials, containing images that were balanced concerning content, valence, and arousal. The order of aversive images and conditions was pseudo-randomized within runs. One trial lasted 29 s on average, one run lasted about 12 min. The experiment consisted of 144 trials and was either conducted in front of a computer (behavioral pilot experiment) or inside the MRI scanner (fMRI experiment). The behavioral pilot experiment lasted 1 h and the fMRI experiment resulted in ~1 h 12 min of scanning.

2.5. Psychometric measures

In session 1 participants completed several questionnaires on intra- and interpersonal emotion regulation, relationship quality of the friendship, and personality traits (for a detailed description of the measures please see Supplementary Material).

2.6. fMRI data acquisition

Whole-brain functional and anatomical images were acquired using a 3.0 T Magnetom TrioTim MRI scanner (Siemens, Erlangen, Germany) using a 12-channel head coil. A high-resolution 3D T1-weighted dataset was acquired for each subject (176 sagittal sections, $1 \times 1 \times 1$ mm^3; 256×256 data acquisition matrix). Functional images were acquired using a T2*-weighted, gradient-echo echo-planar imaging (EPI) pulse sequence recording 37 sections oriented parallel to the anterior and posterior commissure at an in-plane resolution of $3 \times 3 \times 3$ mm^3 (interslice gap = 0; TE = 30 ms; TR = 2 s; FA = 90°; FoV = 192×192 mm^2; 64×64 data acquisition matrix). For each experimental run, 340 whole-brain volumes were recorded.

2.7. Data analyses

2.7.1. Emotional state ratings

We used repeated measured ANOVAs followed by t-tests (using SPSS Version 25) to test for effects of emotion regulation and differences between emotion regulation conditions.

2.7.2. fMRI data analysis

Preprocessing: Functional imaging data analysis was performed using SPM12 (Wellcome Centre for Human Neuroimaging, London, UK). As interleaved slice acquisition was used, slice time correction was included during the preprocessing of the fMRI data. In addition, standard preprocessing involved realignment to the mean image of the first run, spatial normalization to the standard EPI template (MNI template), and spatial smoothing with an 8 mm full-width at half-maximum (FWHM) isotopic Gaussian kernel.

Univariate regions of interest (ROI) analyses: To test the modulating effect of social conditions on emotion regulation, ROI analyses were performed on regions that previously have been implicated in the cognitive control of emotions (Morawetz et al., 2017b). In accord with Reeck et al. (2016), we defined ROIs within three neural systems that have been suggested to support social regulation: (1) system I that supports regulation and cognitive control, (2) system II involved in empathy, social cognition and/or inferring mental states, and (3) system III that targets emotion generation. We selected our ROIs based on our meta-analysis (Morawetz et al., 2017b) using the contrast *Reappraisal>Control condition* (the control condition in the meta-analysis was defined as the condition in which no emotion regulation was applied) to generate ROIs implicated in system I (5 ROIs: bilateral dlPFC, bilateral vlPFC, SMA) and in system II (4 ROIs: bilateral SMG, left MTG, left MFG/SFG). Using the reverse contrast *Control condition>Reappraisal* resulted in the definition of ROIs part of system III (2 ROIs: bilateral amygdala) (for details see **Table 1**). Marsbar (Version 0.44) toolbox for SPM12 (Brett et al., 2002) was used to create all ROIs. For each ROI, we applied the contrasts as described above.

Table 1
Regions of interest (ROIs).

Region	Side	x	y	z	Cluster size
System I: cognitive control					
Middle Frontal Gyrus/dlPFC	L	−43	13	42	7768
Middle Frontal Gyrus/dlPFC	R	42	19	42	4448
Inferior Frontal gyrus/vlPFC	L	−48	21	−1	14,544
Inferior Frontal gyrus/vlPFC	R	47	28	−6	8224
SMA	B	−2	17	53	16,152
System II: empathy, social cognition					
Superior/Middle Frontal Gyrus	L	−32	49	13	2400
Supramarginal Gyrus	L	−51	−56	30	7328
Supramarginal Gyrus	R	56	−54	34	3968
Middle Temporal Gyrus	L	−58	−37	−2	4720
System III: emotion generation					
Amygdala	L	−25	−3	−15	6056
Amygdala	R	23	−5	−15	4912

Note. Coordinates refer to MNI coordinate system.

A general linear model approach was then used for all ROIs. The first-level fixed-effects model was estimated for each participant to identify neural networks supporting emotion regulation and included the following regressors: instruction cue (duration 5 s), emotion regulation phase split by emotion regulation condition (*Look, Decrease, Friend,* and *Stranger*) (duration 8 s), and emotional state rating phase (duration 4 s). This model included motion parameters as nuisance covariates. The regressors were convolved with a canonical form of the hemodynamic response function.

In a second-level random-effects group analysis the emotion regulation conditions were compared. Importantly, we used the regressors for the emotion regulation phase, not the cueing phase, meaning that any visual differences between instruction screens could not bias the activation observed. We computed contrast images of brain activations associated with (1) emotion regulation in general [*Friend+Stranger+Decrease>Look*], (2) interpersonal versus intrapersonal regulation [*Friend+Stranger>Decrease*], (3) interpersonal emotion regulation [*Friend>Look; Stranger>Look; Friend>Decrease; Stranger>Decrease*], (4) intrapersonal emotion regulation [*Decrease>Look; Decrease>Friend; Decrease>Stranger*], and (5) emotion generation [*Look>Decrease; Look>Friend; Look>Stranger*]. T-statistics for each voxel were thresholded at cluster-defining threshold $p < 0.001$, corrected for multiple comparisons across the whole brain with family-wise error rate (FWE) at $p_{FWE} < 0.05$. For completeness, we additionally conducted whole-brain analyses for all contrasts that can be found in the Supplementary Material.

Multivariate region of interest (ROI) analyses: Given the increased sensitivity of MVPA compared to traditional mass-univariate approaches (Kriegeskorte and Bandettini, 2007; Woolgar et al., 2014), we applied MVPA to the predefined ROIs (Kriegeskorte et al., 2006) to find regions that differed in their fine-grained activation patterns with respect to social proximity (*Stranger* vs. *Friend*). In Decoding analysis I, we investigated regions that are generally involved in emotion regulation and asked whether these explicitly encoded social information about the source of emotional support. For this, we used the *a priori* defined ROIs from the meta-analysis on emotion regulation (**Table 1**; 11 ROIs). In Decoding analysis II, we additionally analyzed those regions from the present study that were found to be activated for interpersonal emotion regulation in the whole-brain univariate analyses, but showed no activation differences with respect to social proximity (i.e., interpersonal vs. intrapersonal regulation [*Friend+Stranger > Decrease];* Supplementary Material, Figure S1B and Table S2; resulting in 3 ROIs: Precuenus, left SFG, and left MTG). We reasoned that despite similar overall activation strength, fine-grained activation patterns within these regions might nevertheless represent social proximity. For both sets of MVPA analyses, all ROIs were first transferred back into individual subject space and then used as masks for the respective images to extract the relevant voxels.

We analyzed both the cuing phase (when the photos were presented) as well as the implementation phase (when emotion regulation was performed). All MVPA analyses were conducted using the standard approach as implemented in The Decoding Toolbox (Hebart et al., 2015) by applying support vector machine classifiers interfacing LIBSVM (Chang & Lin, 2011). For this, non-smoothed and non-normalized data from each participant were used as input for an identical GLM as described above for the univariate analyses. All trials were included independent of regulation success. The resulting beta-images for each condition, representing the model fit for the respective task phase of interest at each voxel, in turn, served as input for the classification, and the ROI masks were applied to these images.

Separate analyses were conducted for each ROI. First, for each participant, the parameter estimates from all voxels within the ROI for each run were transformed into pattern vectors, representing the spatial activation patterns associated with each regulation condition in the respective region. These pattern vectors were used as input for pattern classification analyses, conducted for each participant. Separate pattern classification analyses were conducted for each task phase (cueing and implementation), but since the general structure of the analysis was the same, it is described only once in the next section.

After extracting the pattern vectors, a linear support vector machine (SVM) was trained on the vectors from both conditions (*Friend* vs. *Stranger*) from all runs but one to estimate a decision boundary in N-dimensional space that distinguishes between spatial activation patterns associated with the two interpersonal regulation conditions. This is referred to as the “training data set”. The trained classifier was then tested on data from the independent left-out run, i.e. the “test data set”. A six-fold cross-validation was performed by repeating the classification process independently with the pattern vectors from each run as the “test data set” while training the classifier on data from the remaining runs. The average accuracy of all cross-validation steps for each participant reflected how well the patterns of activation within a particular ROI allowed classifying the interpersonal regulation conditions. In other words, this decoding accuracy provided an index for whether this region encoded information about the social proximity between *Friend* and *Stranger*.

Statistical significance was assessed by testing decoding accuracy values across participants for each ROI (chance level was 50% for two interpersonal conditions) using Bonferroni correction (for the number of ROIs). Note, that using independent cross-validation as well as a selection of ROIs that was not based on a difference contrast between *Friend* and *Stranger* conditions circumvented circular inference at any stage of the analyses (Kriegeskorte et al., 2009). The use of the same number of exemplars for each condition and each run guaranteed that both interpersonal regulation conditions were always equally represented in the training and test data.

3. Results

3.1. Psychometric measures & emotional state ratings

First, we characterized the relationship between participants and their best friends by analyzing the questionnaire responses (Supplementary Material, **Table S1**). To summarise, samples from both the behavioral pilot and the fMRI experiment demonstrated comfort with closeness and perceived most social support from their friends and significant others during times of stress. Participants rated their feelings towards their friend as highly positive and satisfactory and as providing high emotional security. Participants subjectively perceived the degree of closeness with their friend as high. The detailed results of the psychometric measures are reported in the Supplementary Material in **Table S1**.

Second, we confirmed that in both experiments participants felt less negative after regulating their emotions (*Decrease, Friend,* and *Stranger*) compared to the control condition, and social proximity amplified this effect, as reflected by reduced negative emotional state ratings in the *Friend* condition compared to the *Stranger* condition (for all tests see **Table 2**; illustrated in **Fig. 1B** for the fMRI experiment).

Third, we investigated the effect of psychometric measures related to intrapersonal and interpersonal emotion regulation, the relationship between friends and personality (Supplementary Material **Table S1**) on behavioral emotion regulation success. Only one variable predicted emotion regulation success during the *Friend* condition after adjusting the α-level for multiple comparisons ($p_{corr} < 0.001$): self-validation (subscale of the MFQ) showed a significant positive association with emotion regulation success (β=0.38, t = 3.44, p = 0.001). Detailed results can be found in the Supplementary Material.

3.2. fMRI results

Univariate region-of-interest (ROI) analyses: To identify brain regions within the emotion regulation network that might be modulated by social proximity, we used a set of independent ROIs stemming from a meta-analysis on emotion regulation (Morawetz et al., 2017b) (see **Table 1** for details). Betas were extracted from 11 ROIs including the lateral prefrontal cortex (dlPFC, vlPFC, and SFG/MFG), parietal cortex (SMG/TPJ), temporal regions (MTG), SMA, and the amygdala. Using t-tests we compared all task conditions within each ROI after adjusting the α-level for multiple comparisons ($p_{corr} < 0.008$). Note again that all contrasts were conducted for the actual emotion regulation phase in which only the emotional stimulus was shown and no visual differences between conditions existed.

We determined regions with an activation profile (i) representing “general” emotion regulation and cognitive control, i.e. increased activity during regulation independent of the social aspect of the condition compared to the control condition [*Decrease+Friend+Stranger > Look; Decrease > Look; Friend > Look; Stranger > Look*]; (ii) differentiating between all regulation conditions scaled by social cognition, i.e. showing higher activity for the *Friend* (social high) and the *Stranger* (social low) condition compared to the *Decrease* condition (no social) [*Friend+Stranger > Decrease; Friend > Decrease; Stranger > Decrease*]; and (iii) relating specifically and only to social proximity, i.e. higher activity in the *Stranger* compared to the *Friend* condition, or the other way round, while not strongly activating for intrapersonal regulation compared to the control condition [*Stranger > Friend; Friend > Stranger*]. In other words, we aimed to categorize the ROIs according to their activation profile: general involvement in emotion regulation (related to system I), social cognition (related to system II), or emotion generation influenced by social proximity (related to system III).

The full results are reported in **Table 3** and summarised here with respect to the region profiles: Except for two ROIs (right dlPFC and left SFG/MFG), all ROIs demonstrated increased activity during emotion regulation compared to the control condition. However, the activity in bilateral dlPFC, vlPFC, and SMA was not influenced by social aspects of emotion regulation (illustrated in blue in **Fig. 2**). In contrast, several regions including bilateral SMG, left SFG/MFG, and left MTG demonstrated the highest activity for the *Friend* condition and lowest activation for the intrapersonal regulation condition, implying an activation profile sensitive to social cognition (illustrated in green in **Fig. 2**). Notably, neither SMG nor MTG showed significant activation for the intrapersonal regulation condition. Finally, only one region, namely the left amygdala showed the highest activity for the *Stranger* compared to the *Friend* condition, thus also demonstrating an activation profile scaling with social proximity, just the opposite direction compared to the left SMG (illustrated in purple in **Fig. 2**). Results of all t-tests are reported in **Table 3**. Effect sizes (Cohen’s *d*) of the significant comparisons were medium to large for all ROIs (**Table 3**). The results of the additional

Table 2
Post-hoc t-tests of emotional state ratings.

	Comparison	t	p	Cohen's d
Behavioral pilot experiment	Look > Decrease	−5.31	<0.001	−0.94
	Look > Stranger	−5.80	<0.001	−1.03
	Look > Friend	−7.06	<0.001	−1.25
	Decrease > Stranger	−0.73	0.471	−0.13
	Decrease > Friend	−4.26	<0.001	−0.75
	Stranger > Friend	−3.84	<0.001	−0.68
fMRI experiment	Look > Decrease	−7.22	<0.001	−1.19
	Look > Stranger	−6.91	<0.001	−1.14
	Look > Friend	−8.19	<0.001	−1.35
	Decrease > Stranger	2.79	0.008	0.46
	Decrease > Friend	−3.00	0.005	−0.49
	Stranger > Friend	−4.98	<0.001	−0.82

Note. Behavioral pilot experiment: df=31; fMRI experiment: df=36.

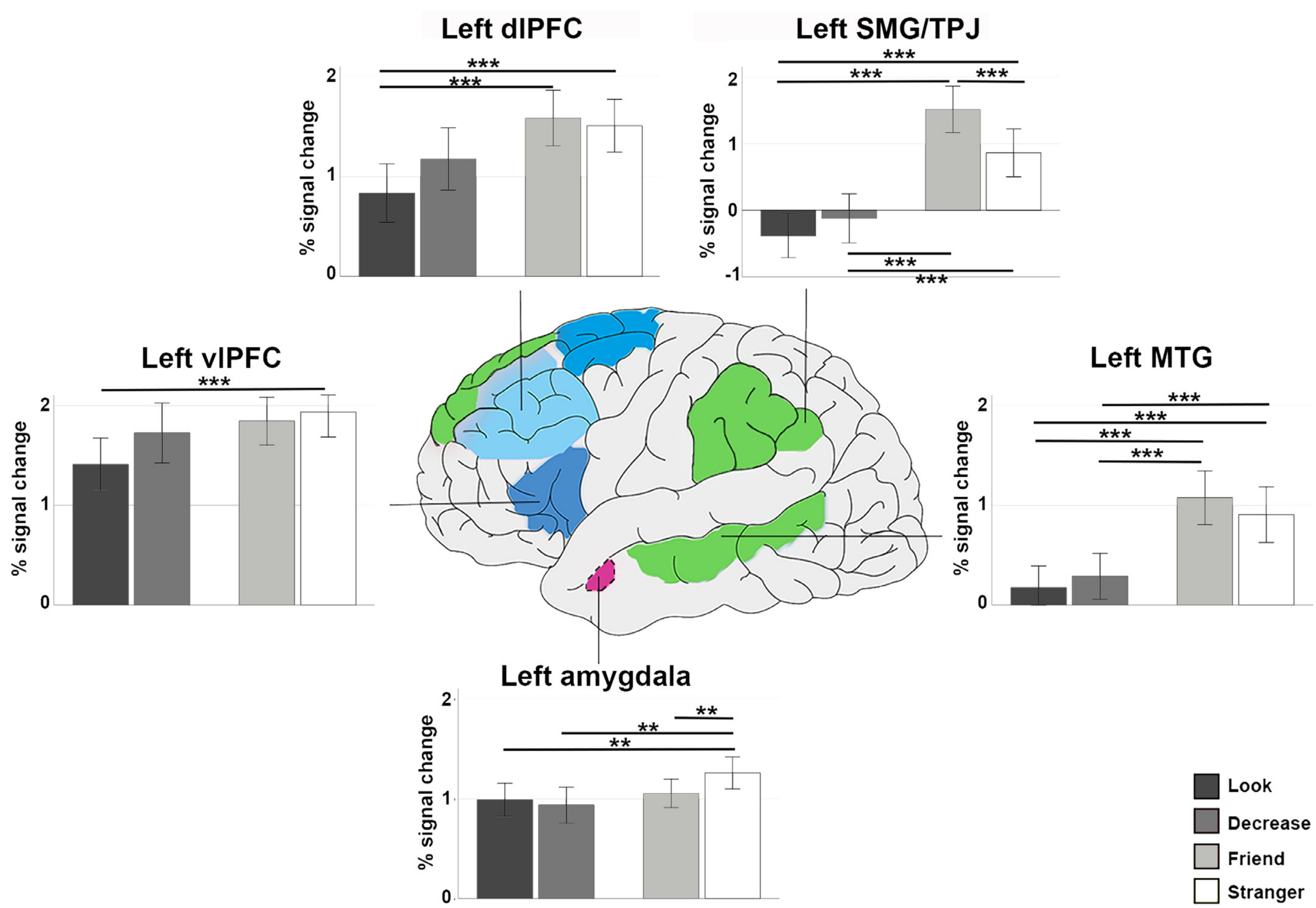

Fig. 2. Schematic illustration of brain regions involved in emotion regulation in general (blue, system I), differentially activated only for social regulation and showing higher activity for the *Friend* condition compared to the *Stranger* condition (green, system II), and activated for all condition but showing more activation for the *Stranger* condition compared to the *Friend* condition (purple, system III). Bar charts illustrate significant differences between task conditions. ** p<0.01 and *** p<0.001, corrected for multiple comparisons.

whole-brain analyses are reported in the Supplementary Material (**Figs. S1–S2, Tables S2–S4**).

Multivariate prediction of social proximity: The univariate whole-brain analysis did not show significant differences between *Stranger* and *Friend* conditions (Supplementary Material). In the next step, we aimed to detect social proximity-specific activation patterns within emotion regulation-related regions which were identified in a recent meta-analysis (Decoding analysis I) (Morawetz et al., 2017b). One participant had to be excluded from all MVPA due to only three completed runs which did not allow for a sufficiently powerful cross-validation analysis. We applied MVPA to the cueing phase and the implementation phase. The cueing phase served as a sanity check, as social proximity was introduced by presenting the photo of the stranger or best friend along with specific reappraisal statements. In the implementation phase, however, there were no existing perceptual differences between interpersonal regulation conditions, and neural representations were solely based on internal representations of social proximity.

Table 3
Results of ROI analyses.

		Left			Right		
ROI	Contrast	*t*	*p*	Cohen's d	*t*	*p*	Cohen's d
dlPFC	*Friend+Stranger+Decrease > Look*	6.117	**<0.001**	1.008	2.575	0.014	0.420
	Friend+Stranger > Decrease	4.600	**<0.001**	0.753	2.436	0.020	0.399
	Look > Decrease	−2.082	0.044	−0.342	−3.193	**0.003**	−0.525
	Look > Friend	−4.046	**<0.001**	−0.665	−6.063	**<0.001**	−0.997
	Look > Stranger	−4.374	**<0.001**	−0.719	−6.171	**<0.001**	−1.014
	Decrease > Friend	−1.927	0.062	−0.317	−2.658	0.012	−0.437
	Decrease > Stranger	−1.831	0.075	−0.301	−2.216	0.033	−0.364
	Friend > Stranger	0.717	0.478	0.118	1.144	0.260	0.188
vlPFC	*Friend+Stranger+Decrease > Look*	8.09	**<0.001**	1.333	6.44	**<0.001**	1.057
	Friend+Stranger > Decrease	4.24	**<0.001**	0.697	2.91	**0.006**	0.474
	Look > Decrease	−1.930	0.060	−0.319	−2.760	0.009	−0.455
	Look > Friend	−2.530	0.010	−0.417	−3.860	**<0.001**	−0.635
	Look > Stranger	−3.710	**0.001**	−0.611	−4.390	**<0.001**	−0.722
	Decrease > Friend	−0.510	0.610	−0.083	−0.680	0.490	−0.113
	Decrease > Stranger	−1.090	0.280	−0.179	−0.800	0.420	−0.132
	Friend > Stranger	−0.690	0.490	−0.114	−0.110	0.910	−0.019
SMA	*Friend+Stranger+Decrease > Look*	6.345	**<0.001**	1.046			
	Friend+Stranger > Decrease	2.577	0.014	0.419			
	Look > Decrease	−3.049	**0.004**	−0.501			
	Look > Friend	−3.832	**0.000**	−0.630			
	Look > Stranger	−3.576	**0.001**	−0.588			
	Decrease > Friend	−0.222	0.826	−0.036			
	Decrease > Stranger	0.295	0.770	0.048			
	Friend > Stranger	0.992	0.328	0.163			
SFG/MFG	*Friend+Stranger+Decrease > Look*	1.556	0.129	0.251			
	Friend+Stranger > Decrease	2.217	0.033	0.358			
	Look > Decrease	−4.014	**<0.001**	−0.660			
	Look > Friend	−8.458	**<0.001**	−1.390			
	Look > Stranger	−5.307	**<0.001**	−0.872			
	Decrease > Friend	−3.557	**0.001**	−0.585			
	Decrease > Stranger	−1.200	0.238	−0.197			
	Friend > Stranger	3.980	**<0.001**	0.654			
SMG	*Friend+Stranger+Decrease > Look*	4.12	**<0.001**	0.675	−1.019	0.315	−0.166
	Friend+Stranger > Decrease	6.19	**<0.001**	1.015	1.524	0.136	0.250
	Look > Decrease	−1.528	0.135	−0.251	−5.356	**<0.001**	−0.880
	Look > Friend	−7.921	**<0.001**	−1.302	−9.869	**<0.001**	−1.622
	Look > Stranger	−6.895	**<0.001**	−1.134	−7.224	**<0.001**	−1.188
	Decrease > Friend	−5.882	**<0.001**	−0.967	−4.699	**<0.001**	−0.773
	Decrease > Stranger	−4.469	**<0.001**	−0.735	−2.225	0.032	−0.366
	Friend > Stranger	3.792	**0.001**	0.623	3.987	**<0.001**	0.655
MTG	*Friend+Stranger+Decrease > Look*	3.931	**<0.001**	0.648			
	Friend+Stranger > Decrease	4.645	**<0.001**	0.759			
	Look > Decrease	−0.777	0.442	−0.128			
	Look > Friend	−5.436	**<0.001**	−0.894			
	Look > Stranger	−4.827	**<0.001**	−0.794			
	Decrease > Friend	−4.238	**<0.001**	−0.697			
	Decrease > Stranger	−3.521	**0.001**	−0.579			
	Friend > Stranger	1.384	0.175	0.228			
Amygdala	*Friend+Stranger+Decrease > Look*	6.424	**<0.001**	1.060	7.241	**<0.001**	1.184
	Friend+Stranger > Decrease	5.626	**<0.001**	0.925	5.628	**<0.001**	0.915
	Look > Decrease	0.514	0.611	0.084	0.013	0.990	0.002
	Look > Friend	−0.623	0.537	−0.102	−0.432	0.668	−0.071
	Look > Stranger	−2.861	**0.007**	−0.470	−2.794	**0.008**	−0.459
	Decrease > Friend	−1.008	0.320	−0.166	−0.454	0.653	−0.075
	Decrease > Stranger	−2.959	**0.005**	−0.486	−2.234	0.032	−0.367
	Friend > Stranger	−3.063	**0.004**	−0.504	−2.253	0.030	−0.370

Bold p-values indicate significance corrected for multiple comparisons ($p<0.008$).

In the cueing phase, *Friend* vs. *Stranger* could successfully be decoded from bilateral dlPFC and vlPFC, SMA, bilateral SMG, and the right amygdala. Several other regions also showed encoding of social proximity such as left SFG and MTG, but did not survive Bonferroni correction. During the implementation phase, *Friend* vs. *Stranger* could successfully be decoded only from the left dlPFC (for all results of Decoding analysis I see Fig. 3**A** and Table 4). These results demonstrate that in many reappraisal-related regions, including non-visual brain areas, information about social proximity was already represented early, and representations were still present in the lateral prefrontal cortex during emotion regulation.

Next, we investigated the regions implicated in interpersonal regulation specifically in our study that did not show significant average activation differences (left SFG, left MTG, and precuneus; Decoding analysis II). For the cueing phase, we found that social proximity could successfully be decoded from the left SFG and MTG as well as the precuneus. In the implementation phase left MTG and precuneus encoded social proximity, latter one surviving Bonferroni correction (all results of Decoding analysis II are shown in Fig. 3**B** and Table 4).

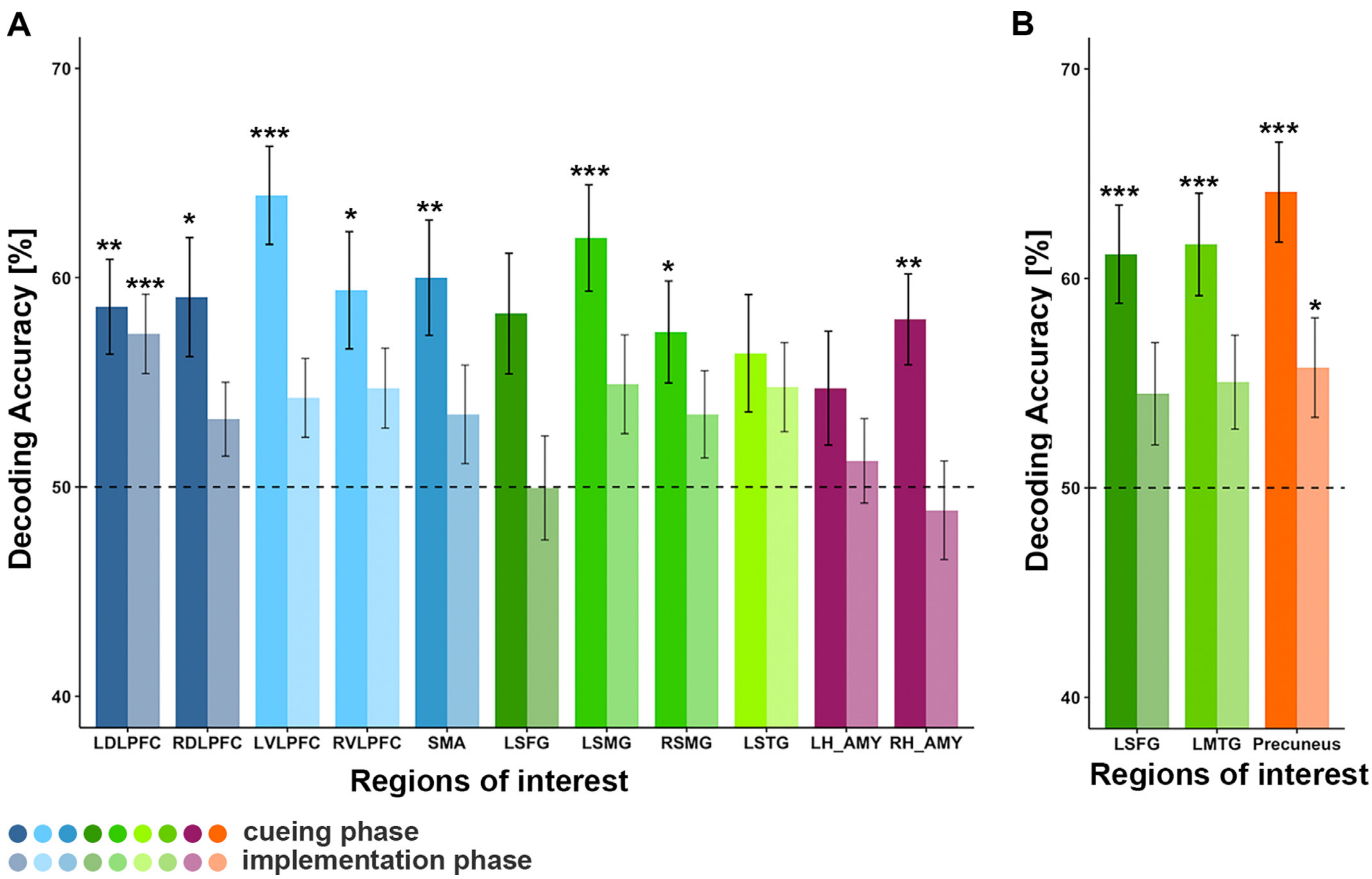

Fig. 3. Pattern classification results for interpersonal regulation. Decoding accuracies for *Friend* versus *Stranger*. Darker colours = cueing phase; Ligter colours = implementation phase.
A Results of the Decoding analysis I based on regions generally involved in emotion regulation (ROIs derived from a recent meta-analysis; see Table 1; Morawetz et al., 2017b). Colours are related to Fig. 3, indicating the cognitive control system in blue (system I), the empathy and social cognition system in green (system II) and the emotion generation system in purple (system III). LDLPFC: left dorsolateral prefrontal cortex; RDLPFC: right dorsolateral prefrontal cortex; LVLPFC: left ventrolateral prefrontal cortex; RVLPFC: right ventrolateral prefrontal cortex; SMA: supplementary motor area. LSFG: left superior frontal gyrus; LSMG: left supramarginal gyrus; RSMG: right supramarginal gyrus; LSTG: left superior temporal gyrus; LH_AMY: left amygdala; RH_AMY: right amygdala. **B** Results of the Decoding analysis II based on regions more activated for interpersonal compared to intrapersonal regulation. LSFG: left superior frontal gyrus; LMTG: left middle temporal gyrus.
Error bars represent standard errors. *** $p<0.001$, ** $p<0.01$, * $p<0.05$ significant from chance level (50%) (Bonferroni corrected).

4. Discussion

In times of crisis, such as the lockdown during the COVID-19 pandemic, social emotion regulation seems more relevant than ever. In the present study, we investigated whether social support delivered remotely via photos of close friends or strangers accompanied by supporting sentences, helped with downregulating negative emotions. We found that interpersonal emotion regulation was indeed more effective with the help of a friend compared to regulating without support. Additionally, regulating with the support of a stranger was less effective than regulating alone. Importantly, no single brain region alone directly mirrored these specific behavioral results as activation profiles either reflected social vs. non-social conditions or emotion regulation vs. no regulation. Only the SMG/TPJ, SFG/MFG, and the amygdala showed significant differences between *Friend* and *Stranger* conditions in the ROI analyses, but several other regions also allowed for decoding these conditions from multivariate patterns. This shows that the reported network as an entity coded for all relevant aspects of the process.

Most strikingly, we demonstrated that the ability to regulate emotions was modulated by the social support of a friend – even in the absence of physical closeness. This finding is consistent with social baseline theory, suggesting that the friend was perceived as a prosocial other with the goal to help diminish distress, thereby creating a condition of security, social bonding, and closeness (Beckes and Coan, 2011; Coan and Sbarra, 2015). Our questionnaires confirmed that the friends were indeed the individuals that our participants shared emotions with and received support from in everyday life. Hence, the mere knowledge that the reappraisal statement was provided by a close friend seemed to have helped improve participants' subjective emotional states (Rime, 2009; Wagner et al., 2014). Previous findings on the effectiveness of strangers to help regulate threats are inconsistent. Some studies reported that holding hands with a stranger resulted in a reduced regulation of the brain's response to the shock of threat (Coan et al., 2006; Johnson et al., 2013), while others reported that holding hands with strangers was ineffective (Coan et al., 2017). Our findings suggest that the support of the stranger might have been less effective, potentially because it was perceived as stressful or distracting. Alternatively, participants might have had the most trust in their friend to provide support (our questionnaire results confirmed high levels of trust), followed by high levels of trust in themselves, and the least trust in the stranger.

Our whole-brain fMRI analysis showed increased activity in the left SFG and MTG as well as the precuneus during interpersonal compared to intrapersonal emotion regulation. The same contrast in the ROI analyses revealed enhanced activity in the left dlPFC, bilateral vlPFC, left SMG, left MTG, and bilateral amygdalae. This means that responses in brain regions usually activated during intrapersonal emotion regu-

Table 4
MVPA results.

Regulation phase	MVPA	Region	Side	Decoding Accuracy M	SE	*t*-vaue	*p*-value
Cueing phase	Analysis I	Middle Frontal Gyrus/dlPFC	L	58.61	2.26	3.80	**0.001**
		Middle Frontal Gyrus/dlPFC	R	59.07	2.84	3.19	**0.003**
		Inferior Frontal gyrus/vlPFC	L	63.93	2.34	5.94	**<0.001**
		Inferior Frontal gyrus/vlPFC	R	59.39	2.79	3.35	**0.002**
		SMA	B	60.00	2.75	3.63	**0.001**
		Middle/Superior Frontal Gyrus	L	58.28	2.88	2.87	0.007
		Supramarginal Gyrus	L	61.89	2.54	4.67	**<0.001**
		Supramarginal Gyrus	R	57.40	2.43	3.04	**0.004**
		Middle Temporal Gyrus	L	56.38	2.80	2.27	0.03
		Amygdala	L	54.72	2.71	1.73	0.09
		Amygdala	R	58.00	2.17	3.68	**0.001**
	Analysis II	Superior Frontal Gyrus	L	61.15	2.34	4.75	**<0.001**
		Middle Temporal Gyrus	L	61.62	2.44	4.75	**<0.001**
		Precuneus	L	64.12	2.38	5.90	**<0.001**
Implementation phase	Analysis I	Middle Frontal Gyrus/dlPFC	L	57.31	1.89	3.85	**<0.001**
		Middle Frontal Gyrus/dlPFC	R	53.24	1.76	1.83	0.07
		Inferior Frontal gyrus/vlPFC	L	54.25	1.88	2.26	0.03
		Inferior Frontal gyrus/vlPFC	R	54.72	1.91	2.47	0.01
		SMA	B	53.47	2.35	1.47	0.15
		Middle/Superior Frontal Gyrus	L	49.95	2.48	−0.01	0.98
		Supramarginal Gyrus	L	54.90	2.35	2.08	0.04
		Supramarginal Gyrus	R	53.47	2.08	1.66	0.10
		Middle Temporal Gyrus	L	54.76	2.12	2.24	0.03
		Amygdala	L	51.25	2.01	0.61	0.54
		Amygdala	R	48.88	2.35	−0.47	0.64
	Analysis II	Superior Frontal Gyrus	L	54.49	2.44	1.83	0.07
		Middle Temporal Gyrus	L	55.04	2–24	2.25	0.03
		Precuneus	L	55.74	2.37	2.41	**0.02**

Note. One sample t-tests against chance level (50%). Bold p-values indicate significance corrected for multiple comparisons (Analysis I: $p<0.005$; Analysis II: $p<0.02$).

lation were amplified when social support was provided. The lateral prefrontal and parietal regions play a key role in the cognitive control of emotions and have been associated with working memory, action inhibition, and language processing (Dixon et al., 2017; Kohn et al., 2014; Morawetz et al., 2020). Importantly, none of these activation profiles entirely matched the behavioral finding that the *Stranger* condition was less effective than intrapersonal regulation. The social regulation conditions also required the processing of a photo in addition to a reappraisal statement. This might have additionally involved working memory functions (Rottschy et al., 2012) and semantic processing (Messina et al., 2015) as the photo and statement would have been kept in mind during the regulation phase, and to use the sentence for regulation, participants would have had to semantically re-process the meaning of the statement.

The left SFG/MFG and SMG/TPJ were the only ROIs showing a significant activation increase for the *Friend* over the *Stranger* condition. When compared to the *Look* condition, several regions, including SMG/TPJ, precuneus, SFG, ACC, MTG, and the temporal pole were more strongly activated for the *Friend* condition on a whole-brain level. These regions have been linked to verbal working memory and semantic processing [MTG, SFG/MFG, temporal pole] (Binder et al., 2009), to reappraisal via perspective-taking, mentalizing and cognitive empathy [SMG/TPJ] (De Waal and Preston, 2017; Jauniaux et al., 2019), socially-driven interactions [ACC] (Lavin et al., 2013), and self-referential processing [precuneus] (Northoff et al., 2006). Taken together, recruitment of these areas, in particular, left TPJ, might support complex social functions required for successful social interactions (Carter and Huettel, 2013; Cavanna and Trimble, 2006) and might reflect the processing of prosocial attributes, e.g., the other's intention and the degree of trust between target and observer (Tusche and Hutcherson, 2018).

The amygdala was the only region that was more strongly activated for the *Stranger* compared to the *Friend* condition. Others have found attenuated amygdala responses during threat regulation in the presence of a romantic partner versus a friend (Morriss et al., 2019), which supports the idea of decreasing amygdala responses with increasing closeness. The amygdala with its connections to brain networks involved in social cognition appears to be important for the encoding of social connectedness as well as regulating interpersonal distance (Bickart et al., 2014; Kennedy et al., 2009). In this context, it is important to note that although the *Stranger* condition was related to increased activity in the amygdala during the implementation phase, it was still behaviorally successful (demonstrated in reduced emotional state ratings compared to the *Look* condition). There are at least three possible interpretations for this observation. First, this could reflect that participants were less at ease as the picture of the stranger might represent a source of distress or distraction, which could explain why the effectiveness of emotion regulation was dampened rather than enhanced when compared to both regulating alone and being supported by the friend. This means that the stranger's support could have been partly helpful, and partly distracting. Second, the amygdala activation might reflect different aspects of trust. Ye (2018) distinguishes between generalized trust and assurance (Ye, 2018). While the friend might have evoked the latter (i.e. the sense of security that arises from a personal relationship), the stranger would only be helpful if it related to a general trust in people, which in turn might be weaker but distinctively reflected in the amygdala activation. In line with this idea, the amygdala has been shown to be implicated in the processing of trustworthiness in faces (Santos et al., 2016), Third, our findings might indicate the degree of difficulty with implementing the regulation strategy, and the amygdala response might indicate that this was more difficult during the *Stranger* condition than in the other two regulation conditions. Ultimately, follow-up studies are needed to fully understand this pattern of results.

Our MVPA findings of reappraisal-related regions revealed that social proximity was already encoded during the cuing phase in lateral PFC (bilaterally) and parietal regions, and SMA. Importantly, the amygdala was already amongst these regions and could have played a role in processing a threat response, social connectedness, or interpersonal distance. During the implementation phase, the left dlPFC maintained representations of social proximity. Interestingly, social proximity was not only represented in regions that are important for social cognition such as parietal regions and the amygdala (Bickart et al., 2014), but also in lateral PFC regions. It has been suggested that the PFC contributes to regulating emotional responses by representing the value of events in a highly contextualized fashion, i.e. it incorporates complex and abstract information about social context, task rules, self-image, and long-term goals (Cunningham and Zelazo, 2007; Dixon and Christoff, 2014; Ochsner and Gross, 2014). Thus, the representation of the source of social support in the lateral PFC might reflect an explicit appraisal of social context, which in turn might affect the subsequent implementation of the regulation strategy on a neuronal level and, as a consequence, regulatory success.

In addition, regions found to be implicated in interpersonal regulation such as the precuneus, left SFG and MTG also encoded social relevant information at an early stage. The precuneus further represented social proximity during the implementation phase. This set of brain regions might have supported mentalizing and processing social aspects such as affiliation and connectedness (Bickart et al., 2014; Jauniaux et al., 2019). In particular, the precuneus is suggested to play a crucial role in encoding information of the source of social support by first- versus third-person perspective taking, perceived agency, and social cognition (Cavanna and Trimble, 2006).

Taken together, our findings demonstrate that the enhanced ability to regulate negative emotions through the support of a close friend might be based on an interplay of different large-scale brain networks (e.g., emotion regulation, social cognition, and cognitive control), rather than the recruitment of a single brain region (Barrett and Satpute, 2013). Some parts of the cognitive control network based on lateral PFC regions were more activated for the presence of an external person but seemed to be indifferent to the source of the support. This suggests a role in compensating for increased processing demands related to understanding sentences and pictures, and working memory. The social cognition network might support empathic and mentalizing processes during interpersonal regulation to encode the social aspects of the provided reappraisals at large. Only some regions within this network explicitly encoded who provided the social support, either by increased (TPJ) or decreased (amygdala) activation differences, or through distinct patterns (e.g., precuneus). Reappraisal has been suggested to be implemented by the cognitive control network employing a top-down process which down-regulates the activity in the emotion network during successful regulation (Johnstone et al., 2007; Urry et al., 2006). Our results suggest that during interpersonal regulation, the social cognition network as well as regions supporting self-referential processing and emotional stress responses might contribute important information, which can facilitate (for friends) or interfere (for strangers) with regulation success. Future studies need to elucidate this interplay between networks during interpersonal emotion regulation, e.g., by implementing effective connectivity analysis and determine potential trait and situational moderators that influence regulation ability.

5. Limitations & outlook

Several limitations should be noted. First, it is likely that decoding accuracies in the cueing phase also reflect visual differences between conditions with respect to photos and sentences; however, the substantial spread of information through regions that are beyond the visual system, including brain areas strongly involved in self-referential processing and emotion regulation, suggests the presence of more abstract representations of social proximity that could have been integrated to influence the regulation process more directly. Our paradigm did not allow us to fully dissociate the processing of the visual information from its semantic meaning during the cueing phase.

There might be other consequences of showing different visual content during the cueing phase of the intra- and interpersonal regulation conditions. The presence of sentences or images could have impacted emotion regulation (and the neural processing in the following implementation phase) to some degree. We made sure that the implementation phase – which was analysed in our study – was visually identical between the regulation conditions (only the emotional image was presented), and that it was possible to estimate neural signals independent from the cueing phase by using appropriately jittered fixation periods separating them. Nevertheless, it remains a possibility that some advantage (or disadvantage) could be derived from seeing faces and/or sentences before entering the implementation phase. Related to this, it is important to note that in the interpersonal conditions, the reappraisal sentences were provided to the participants while these had to be self-generated in the intrapersonal condition. This means that the reinterpretation of the stimuli might have been less effortful in the interpersonal conditions. However, we did not observe an overall advantage of the interpersonal conditions in the behavioural patterns that would be congruent with this idea, as the intrapersonal condition (no faces, no sentences) was indeed less effective than the *Friend* condition but more effective than the *Stranger* condition (both of which had faces and sentences). This of course does not negate that due to the existing differences, intra- and interpersonal conditions would have differed qualitatively in the cognitive processes involved, which would necessarily to some extent engage different neural systems. For example, the intrapersonal condition required keeping in mind the abstract regulation goal followed by a translation of this goal into a verbal self-instruction. The same was not the case in the interpersonal conditions, which required participants to keep in mind an exact sentence that would be used during regulation. Future studies could address some of these shortcomings by introducing irrelevant pictures and sentences in the intrapersonal condition; however, these might then exert an unwanted distracting influence on emotion regulation and potentially introduce a new confound. Some other differences – i.e. the differences in memory load and content for inter- vs. intrapersonal regulation – are inherent to the processes under investigation and not avoidable (i.e. intrapersonal regulation simply rules out that regulatory sentences are provided; interpersonal regulation rules out that these are self-generated). These aspects, however, should be kept in mind when interpreting differences in neural patterns.

Second, during the implementation phase, participants were asked to down-regulate their emotions using reappraisal. However, we did not tightly control whether they always used the instructed sentences during the interpersonal regulation conditions, nor could we assess whether self-driven regulation in the intrapersonal regulation condition always involved reappraisal. Notably, participants did not report having used other strategies, but future experiments could probe compliance at multiple time points during the experiment. Third, in the current experiment, the *Look* condition was not completely matched with the interpersonal regulation conditions during the cueing phase. Thus, it would be of great interest to compare the *Friend* and *Stranger* condition to another baseline such as presenting the photo of the friend or stranger *without* the need for regulation, which would optimize the current *Look* condition.

Future studies could also further explore how levels of trust, in particular when ascribing competency in providing emotional support, might moderate the effectiveness of social support. A stranger, who is trusted because of high levels of perceived competency (e.g., a mental health professional), might have a much more positive influence on emotion regulation than the random stranger in our study.

6. Conclusion

In conclusion, our results suggest that social proximity represents an important factor for the effective implementation of social support in emotionally challenging situations that, in turn, is based upon the interplay of lateral prefrontal and subcortical networks that are important for cognitive control, integration of social information, self-referential processing, and the generation of emotional responses. The current results highlight the power of strong social connectedness that has the potential to boost our emotion regulation ability and thus to contribute to our social and emotional well-being (Sandstrom and Dunn, 2014).

Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Credit authorship contribution statement

Carmen Morawetz: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Stella Berboth:** Investigation, Formal analysis, Visualization, Writing - review & editing. **Stefan Bode:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing.

Data_statement

The data that support the findings of this study are available from the corresponding author, C.M., upon reasonable request.

Acknowledgments

This work was supported by the Deutsche Forschungsgemeinschaft Grant MO 2041/2–1 and Marie Skłodowska-Curie Action 795994 to C.M.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2021.117817.

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