The Social Regulation of Emotion and its Importance for Human Health

Katie Lancaster

Charlottesville, VA

M.A., University of Virginia, 2015

MSc., Radboud Universiteit Nijmegen, 2010

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ABSTRACT

Social support is critical to health. A recent estimate of the importance of social support's effects on health outcomes has demonstrated it is an equivalent or stronger predictor than cigarette smoking or physical inactivity[1]. Social support is thought to benefit health by buffering stress and reducing negative affect (e.g.,[2–5]), but the specific socio-biological mediators of this effect still need to be identified. I believe that it is the engagement of emotion regulation strategies that mediates the relationship between social support and susceptibility to disease. Individuals differ in their ability to use the support of a trusted other to downregulate negative affect. This process, known as the social regulation of emotion, is an understudied phenomenon, particularly insofar as it relates to health. My dissertation work is a highly multidisciplinary attempt to shed light on this issue. I present data from functional magnetic resonance imaging (fMRI), electroencephalography (EEG), psychophysiology, genetics, and behavioral experiments in order to examine individual differences in ability to socially regulate emotions and how this in turn impacts well-being.

ACKNOWLEDGMENTS

This research is fundamentally about the power of social support, and how it contributes to humans reaching their ultimate potential. For me personally, nothing can exemplify this better than the never-ending support I've received in the process of realizing this work.

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And I dedicate this work to Jake, without whom none of this would be possible, or have any meaning at all.

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INTRODUCTION

Although social support is one of the most important predictors of health outcomes that we can currently measure[1], there is little insight into the specific socio-biological processes that mediate its effects. Support is thought to attenuate negative emotions and buffer stress, but exactly *how* this process occurs, *for whom*, and *under which conditions* have yet to be established. Consequently, interventions designed to increase emotional support through peer groups have yielded underwhelming results: the evidence for these groups' effects on psychological adjustment is mixed[6–8], and most randomized controlled trial interventions targeting health outcomes show null or mixed results[9–14]. These interventions ignore pre-existing differences in people's coping styles and emotion regulation strategies, which I suggest are crucial to understanding how social support might benefit health.

I believe that the heart of this issue is the disconnect between the availability of social support, and one's ability to use this support to regulate their emotions. People differ in the extent to which they can make use of social support. A person who grew up in an unsupportive environment may have developed coping styles to compensate for this lack of support; later, when social support is available (through romantic relationships or in the context of interventions), this person may lack the implicit skills to effectively use it. Making use of social support to attenuate negative emotion is a recently identified affective regulation strategy called the social regulation of emotion. Coan and colleagues[15–17] have demonstrated using fMRI that the presence of a loved one attenuates the threat associated with an anxiety-provoking situation:

when participants are delivered electric shocks, simply holding hands with a loved one downregulates threat-related neural activity in regions including the vACC, dlPFC, caudate, PCC, postcentral and supramarginal gyrus. Coan has argued that social regulation is an efficient emotion regulation strategy since it distributes the effort across multiple people. Given its efficiency and the fact that social resources are often available, social regulation may be the default strategy that people use to regulate their emotions[18].

In the first chapter of this dissertation, I provide evidence that social regulation is health promotional, and further that one's ability to engage in social regulation mediates the association between available social support and health. Those who are better able to leverage the support of trusted others to buffer stress should have more positive health outcomes, both in physical and in mental health.

In the second chapter, I argue that one's ability to use social regulation depends on individual differences in attachment-related processes, including those that are firmly rooted in biology. Even when social support is available, some individuals may be unable to utilize this support to attenuate stress. Participants who had less supportive parental relationships during adolescence were less able to use a friend to help regulate their emotions[17]; similarly, participants with poorer quality marriages were less able to use their spouse to help regulate their emotions[15]. Importantly, participants in poor quality marriages who underwent a therapeutic treatment to strengthen attachment bonds showed significant gains in social regulation ability as a result[19]. Together this suggests that factors affecting the strength of attachment bonds – whether they reflect personality factors, or the dynamics of a specific relationship – influence the degree to which people can engage in social regulation. One potential contributor to the ability to form attachment bonds for the regulation of emotion is the human oxytocinergic system.

Oxytocin is implicated in both a myriad of social processes and in the attenuation of stress and anxiety. Prosocially, it increases trust[20], social perception[21] and social memory[22], affiliation[23], and improves attachment bonds[24]. Anxiolytically, it attenuates amygdala response to aversive stimuli[25,26], inhibits stress-induced cortisol release[27], and facilitates parasympathetic nervous system activity[28]. Genetic differences in the oxytocin system are associated with differences in the experience of emotion, including physiological stress responses[29], depression[30,31], and levels of positive affect[32]. Crucially, risk alleles of polymorphisms in the oxytocin receptor gene (*OXTR*) have been associated with insecure attachment[33,34]. In this work, I will investigate whether genetic variation of *OXTR* explains attachment-associated individual differences in social regulation ability.

The final chapter tests the boundary conditions of manipulating and measuring social regulation. Because this form of emotion regulation has not been the primary focus of scientific inquiry, there exist a number of theoretical and methodological questions that beg to be addressed. In particular, I examine the use of social regulation in the absence of social presence, and examine whether social regulation can be reliably elicited within a classic intrapersonal emotion regulation paradigm. Taken together, this work will improve our mechanistic understanding of the social regulation of emotion, an understudied phenomenon that has great potential translational impact.

CHAPTER 1: Social Regulation and Health

Emotion regulation and health. Regulating affective states has downstream impacts on mental and physical health. Most psychological disorders have an affective component and are characterized by emotion dysregulation[35]. Furthermore, individual differences in the use of emotion regulation predict cardiovascular disease[36,37] and other health outcomes[38,39]. It is thought that different forms of emotion regulation are more effective and thus more salutary than others[40,41]; in particular, it has been repeatedly established that regulation strategies which modify the appraisal of an emotionally evocative stimulus or situation (such as cognitive reappraisal) have greater health benefits than strategies which modify the expression of an emotion (such as expressive suppression)[36–39,42,43].

Social regulation and health. While research on the health benefits of emotion regulation has seen enormous growth in the past few decades, this body of research has concentrated almost exclusively on self-directed emotion regulation. Only recently has the social regulation of emotion begun to pique the interest of health and emotion researchers. While some have focused their interest on *extrinsic* social regulation (one's attempt to control the emotions of others)[44], the focus of this dissertation is *intrinsic* social regulation (one's use of close others to control their own emotions)[45]. Major contributions in this area have been made primarily by Coan and colleagues. In his seminal work, Coan demonstrated that people use others to regulate their negative emotions, and that this can be measured using functional neuroimaging[15]. Under the threat of electric shocks, holding the hand of a loved one is sufficient to attenuate subjective feelings of arousal and the concomitant neural threat response.

Much like self-directed emotion regulation strategies, it has been suggested that social regulation may enact its effects in a variety of ways: by modifying features of the situation, by changing the locus of attention, or by altering appraisals of the stimulus evoking the emotional response[46]. Importantly, Reeck and colleagues have argued that social regulation is goal-directed, and while people will often reflexively gravitate towards others under duress, they are generally conscious of their own emotional needs and aware of the effectiveness of the influence of others[46]. It has even been shown that people have explicit knowledge of how their various relationships fulfill different regulatory needs (for example, that their brother can cheer them up from sadness, but that their best friend can calm their anxiety), and that they solicit support from the appropriate person to fulfill each need[47].

It is abundantly clear that social relationships influence health through emotional processes. Mammals instinctively seek social contact under stressful conditions[48], and in rodents, forced social isolation during development is extraordinarily stressful and has lasting negative consequences for regulation of the hypothalamic-pituitary-adrenal axis[49,50]. In humans, similarly, social isolation is strongly associated with emotional dysregulation and predicts mortality[51,52]. Research on the social modulation of pain and the social buffering of stress has established that manipulating access to social resources in some form – often through the mere presence of a trusted other[53], receiving verbal support[54] or tactile stimulation from a loved one[55], or being shown images of one’s romantic partner[56,57] – can attenuate perceptions of pain[58] and diminish the physiological stress response[59]. Altogether this suggests that the social regulation of emotion might underlie the connection between health and access to social resources. Indeed, some initial evidence has linked one’s ability to socially regulate with perceptions of their own health[60]. The studies in Chapter 1 attempt to illustrate the health promotional effects of the social regulation of emotion.

Mediational hypothesis. Not everyone who has access to social resources can make use of them. Coan has identified several individual differences in one's ability to socially regulate emotions. First, he has shown that this is dependent on the quality of a participant's relationship with their partner: wives who were highly satisfied with their spousal relationships showed greater attenuation of neural threat when holding hands with their husbands vs. when they were alone[15]. Second, he has shown this ability is dependent on early relationships and experiences. Specifically, participants who had high levels of maternal support as an adolescent were able to use the support of their friend to downregulate threat activity in the insula, while participants with poor maternal support showed the opposite pattern: their threat activity was highest when receiving support from a friend.

Together these results imply that people differ in the extent to which they can make use of social support. Even if social support is available to a person (literally holding their hand!), they may not benefit from it. I argue that this is consequential for health, since one can receive health benefits from social support only to the extent that they can use it to regulate their emotions. It has been argued that social regulation may mediate the connection between social support and health[61,62]. This could, for instance, explain the noted discrepancies between *received* and *perceived* social support, such as when an individual indicates that they are the recipient of supportive behaviors by their family and community, but does not perceive themselves as being satisfactorily supported. Received and perceived support are only modestly correlated (r =.35 [63]), and perceived support has consistently shown stronger positive effects on health [64]; in fact, received support, or a large discrepancy between received and perceived support has been associated with negative outcomes such as increased mortality risk [65,66]. Thus, another goal of Chapter 1 is to elucidate the relationships between social support, health, and the social regulation of emotion; we will explicitly test the hypothesis that social regulation mediates the connection between social support and health.

STUDY 1

Study 1 was a pilot study to assess self-reported use of social emotion regulation and whether this predicted self-reported physical and mental health. Social regulation has primarily been measured using fMRI and has never before been measured via self-report: thus, one of our major goals in this study was to attempt to capture individual differences in social regulation using a simple self-report assessment. Conditional on its success, our main objective in this study was to test the idea that social regulation mediates the connection between social support and health.

Method

The first aim of this pilot study was to establish that social regulation could be assessed via self-report. To achieve this, we developed several emotion-eliciting scenarios and asked participants to imagine how they would feel if they found themselves in these situations (e.g. performing poorly on an exam), and to report how they would react in their wake (e.g., whether they would reach out to others, or prefer to be alone). Participants who consistently reported seeking out others in the face of negative emotions were presumed to be strong social regulators. We examined this metric in relationship to participants' perceived social support, and also to their self-reported mental and physical well-being. We then tested whether social regulation mediated the connection between social support and well-being.

Procedure. This study was administered in the fall semester of 2016 and took the form of an online questionnaire. Participants were 78 (43 male) University of Virginia undergraduate students, participating in exchange for research credit as a fulfillment of their course requirements. The mean sample age was 19.08 years (SD=1.30).

Materials. Participants were first presented with our social regulation assessment, and then completed the remaining instruments in random order. ***Social regulation of emotion assessment.*** This was composed of four different scenarios (e.g., performing poorly on an exam), after which a series of options were presented (e.g., calling a friend) and participants were asked to indicate how appealing each of these options were on a 7-point scale ranging from very unappealing to very appealing. Full text of the assessment scenarios and questionnaire items can be found in Appendix A. Items included options where participants might explicitly attempt to regulate emotions by discussing the issue (e.g., *texting your significant other*), or, conversely, regulating the emotion through distraction (e.g., *going to a movie with friends*). The questionnaire items reflecting explicit regulation and distraction were strongly correlated (all *r*s >.48) and thus were collapsed across. Three items from the questionnaire did not show strong relationships with other items, and were removed from the analyses: *posting about your feelings on social media; spending time alone where you are surrounded by people you don't know; making 1-on-1 plans where the issue will probably come up in conversation*. Further, items from each of the 4 scenarios were highly correlated (all *r*s >.41) and were averaged in order to form an index of participants' use of social regulation. Cronbach's alpha for the remaining questionnaire items was α=.94, indicating excellent internal consistency. **Additional scales**. To assess perceived social support, we administered the Brief Social Support Questionnaire (SSQ6[67]) which has participants indicate who they turn to for support, and how satisfied they are with the support that is provided. To assess self-reported health, we administered the Short-Form Health Survey (SF-36[68]) which provides an estimate of overall physical and mental health. We also administered the Experiences in Close Relationships-Revised (ECR-R[69]) in order to probe for individual differences in attachment security and how these might be related to social regulation. Further, after each scenario, we asked participants how upsetting they would find the imagined situation in order to confirm that the scenarios were sufficiently emotionally evocative.

Results

Manipulation check. On a 7-point scale, participants indicated that they would, on average, find the imagined scenarios upsetting. Scenario 1 (exam): M=5.01, SD=1.53, scenario 2 (lottery): M=3.54, SD=1.61, scenario 3 (model): M=4.92, SD=1.78, scenario 4 (textbook): M=4.44, SD=1.46. Interestingly, the only gender difference in the sample emerged here: females were significantly more distressed at the thought of performing poorly on an exam (scenario 1), $t(76)=2.73$, $p<.01$, and by the idea that their ex-partner is now dating a fashion model (scenario 3), $t(76)=2.28$, $p<.05$.

Relationship between social support and health. Using the SF-36, we investigated the impact of social factors on participants' general physical health and their mental health. In line with decades of previous research[1], participants' perceived social support was significantly associated with both general health, $r(76)=.31$, $p<.01$, and mental health, $r(76)=.42$, $p<.001$.

Relationship between social support and social regulation. Social support was positively associated with our index of social regulation, $r(72)=.27$, $p<.05$, confirming that participants with good social networks seek out the company of others in the face of negative emotions.

Relationship between social regulation and health. Social regulation was significantly correlated with general health, $r(72)=.30$, $p<.01$, but was only marginally correlated with mental health, $r(72)=.19$, $p=.10$.

Mediational relationship: Social support -> social regulation -> health. To investigate whether social regulation mediates the relationship between social support and health, we conducted a mediational analysis using a bias-corrected bootstrapping procedure [70] with 5000 samples. With this procedure, the test of the indirect effect is significant if the 95% confidence intervals do not contain zero. Indeed, we observed evidence of mediation, indirect effect = 2.04, 95% CI= [.15, 6.32], such that social regulation scores mediated the relationship between social support and general health.

Further individual differences. We suspected that individual differences in attachment might be associated with the variables of interest in our study. Strikingly, avoidant attached styles were robustly negatively correlated with nearly every index we assessed: social support, $r(75)= -.32$, $p=.005$, mental health, $r(75)= -.31$, $p=.006$, general health, $r(75)= -.31$, $p=.007$, and social regulation, $r(71)= -.25$, $p=.03$.

Discussion

For the first time, we were able to assess the social regulation of emotion using self-report. We showed that ones' quality of social support network predicted whether they would prefer to interact with others or be alone when experiencing negative emotions. This choice of emotional regulation strategy in turn predicted participants' physical and mental health, and mediates the relationship between social support and general health. We also made a few unanticipated, but interesting observations: there were no gender differences in social regulation, and people who are avoidantly attached seem to be extraordinarily vulnerable to poor health and well-being, being unable to leverage social regulation to mitigate negative emotions.

Unexpectedly, social regulation was more related to physical than mental health. Our original hypothesis was that the connection to physical health may operate directly through stress-related processes (thus, exerting an influence on physical health through mental health). However, the mental health component of the SF-36 is limited and was not designed to be used as a stand-alone measure, and thus future research employing a more comprehensive instrument (e.g. a perceived stress scale) might be needed to disentangle these effects. Relatedly, we would benefit from using indices of health and wellness which do not rely on self-report.

Another limiting factor concerns our social regulation assessment: unlike the handholding paradigm which can identify social regulation *success/ability*, our self-report measure can only identify social regulation *use* (e.g., how likely are you to reach out to others when experiencing negative emotions?). Whether this form of support-seeking behavior is actually correlated with social regulation success/ability remains to be seen. However, there is cause for optimism that people can accurately report on their use of emotion regulation: with other forms of emotion regulation, such as cognitive reappraisal, it has been shown that participants' self-reported use of regulation strategy is predictive of their actual use/ability, verified with fMRI[71]. Study 2 will address this limitation by investigating social regulation ability using fMRI.

STUDY 2

While social regulation ability (operationalized as a partner-facilitated attenuation of neural threat response) was been associated with different metrics of social support and relationship quality[15,17], this has never been used to predict objective health. As in Study 1, our goal here is to validate social regulation as a mediator between social support and health. However, in the current study we aim to use data from a longitudinal dataset in order to establish whether one's social regulation ability can *prospectively predict* objective health.

Participants in this experiment came from the Virginia Institute of Development in Adulthood (VIDA) study, which has followed a cohort throughout adolescence and into adulthood. A number of these participants completed the handholding fMRI[15] while in their mid-twenties. More recently, participants have undergone assessments of cardiometabolic health, including a number of biomarkers of early susceptibility to disease. In this study, we used the existing data to investigate how participants' ability to use social regulation predicts health outcomes, and whether this ability further mediates the relationship between social support and health.

Social regulation ability was estimated from threat-related neural activity from the handholding fMRI task. In this paradigm, subjects are scanned while being threatened with electric shocks; for part of the experiment, social support via handholding is provided by a trusted other (spouse, significant other, or close friend). In two comparison conditions, social support is provided from a stranger, or no support is given and participants face the electric shocks alone. The attenuation of threat-related neural activity from partner -> alone is indicative of one's ability to socially regulate their emotions.

The health assessments in this study include participants' perceptions of their own physical health, their body mass index, and a cardiovascular response to stress, estimated using high-frequency heart rate variability (HF-HRV). HF-HRV is computed using variance in heart beat intervals from ECG. High levels of HF-HRV have been associated with myriad positive health outcomes[72–74], and this measure is particularly useful for estimating health-risk in populations with low levels of illness and somatic complaints[75].

Method

Sample. The VIDA study has followed an initial sample of 172 demographically diverse participants from age 13 into their early thirties. Parents, peers, and romantic partners have been repeatedly interviewed at various points over time. Eighty-six of these participants (38 male) completed the handholding fMRI paradigm as originally described[15]. Twenty-six participants were accompanied by opposite-gender friends, and 60 participants were accompanied by opposite-gender romantic partners. Neuroimaging data were collected from participants over the span of several years, while participants were between the ages of 23-26 (mean age 24.06, SD=1.27). Participants were 61% Caucasian, 31% African American, and 8% Hispanic, Asian, or Other (including Mixed Race). In later waves, participants completed assessments of physical health and a blood draw for genotyping. Approximately 80% of the neuroimaging sample provided health assessment data, and 73% completed a blood draw for genotyping (which is discussed further in Chapter 2). Mean elapsed time between MRI and follow-up was 1439.83 days, SD=298.20.

Questionnaires. We examined participants' perceptions of social support within the assessment wave closest to the collection of neuroimaging data. We used both a measure of social support which indexes participants' perceived support across their entire network, the SSQ[76], and also a measure of the strength of relationship between the participant and their closest friend, the satisfaction scale of the Network of Relationships Inventory[77]. In this questionnaire, participants respond to items such as "How good is your relationship with this person?" and "How satisfied are you with your relationship with this person?" Participants' attachment security was assessed using the ECR-R[69], which was administered during the neuroimaging session.

Health assessment. Participants' subjective general health was assessed using the SF-36, as in Study 1. Additionally, body adiposity was estimated using body mass index (BMI), which was computed as participants' weight in kilograms divided by their squared height in meters. Although BMI is an imperfect estimate of adiposity as it can confound adiposity with musculature, nearly 20% of the sample were obese (BMI≥30) and 6% were morbidly obese (BMI≥40). BMI is a valid measure of adiposity within the obesity criterion as only .2% of people in this range are miscategorized[78].

Cardiovascular Stress Response. As part of the health assessment, participants completed a test of their cardiovascular stress response by undergoing a Trier Social Stress Test[79] while their psychophysiological data were measured. Participants were instructed to give a five minute speech in which they had to argue that they were the ideal candidate for their dream job; research assistants listened dispassionately and videotaped the speech. Psychophysiological data were recorded during a five minute resting baseline, during the five minute speech task, and during a five minute recovery period from the speech task.

Psychophysiology. Cardiovascular data were recorded using a Bionex impedance cardiograph from MindWare Technologies (Gahanna, OH). Six spot electrodes were placed across each participant's thorax to acquire electrocardiogram (ECG) and impedance cardiography data, according to prior recommendations[80,81]. Proprietary BioLab software was used for data acquisition and analysis. Participants' data were analyzed in one minute segments, with each segment visually inspected for artifacts and corrected when applicable. The physiological outcome variable is high frequency heart rate variability (HF-HRV), which provides an estimate of the unique contribution of the parasympathetic branch of the autonomic nervous system. HF-HRV is estimated from the ECG data. Using the HRV analysis module (Mindware Technologies), the interbeat interval series was estimated using the peak-to-peak distance between the ECG R-waves. This series was detrended and end-tapered, and a Fast Fourier transformation performed to calculate spectral power. This was then integrated over the high-frequency band of 0.12-0.40 Hz to obtain HF-HRV values for each measurement period.

Higher HF-HRV values reflect greater parasympathetic activity, which is a salutary biomarker. Additionally, we computed a measure of HF-HRV suppression (ΔHF-HRV), which is calculated as the difference between HF-HRV during the speech period and the mean HF-HRV of the baseline and recovery periods; this represents the *inhibition* of the parasympathetic nervous system during a period of acute stress, and has been associated with *negative* outcomes in health and well-being[82–84].

fMRI paradigm. The prototypical social regulation paradigm comprises three blocks of trials, one in which participants are alone in the scanner (ALONE), one in which participants are scanned while holding the hand of an opposite-gendered anonymous experimenter (STRANGER), and one in which participants are holding the hand of their partner (PARTNER). The order of these blocks are counterbalanced across conditions. In each block of trials, participants view visual cues presented on a screen, which is reflected onto participants' visual field using a mirror attached to the head coil. In each block of trials, participants view 12 Threat cues (red X on a black background) and 12 Safety cues (aquamarine 0 on a black background), in randomized order. Participants are instructed that threat cues represent approximately a 20% chance of electric shock (4mA) delivered to their ankle via a computer controlled device (E13-22, Coulbourn Instruments). Threat and safety cues are presented for 1s, followed by a fixation cross (anticipation cue) for 4 – 10s (jittered), followed by an end cue. During approximately two threat trials per block, a shock stimulus occurs at the same time as the end cue. Intertrial intervals are 4-10s (jittered). After each block, participants are asked to indicate their subjectively experienced valence and arousal using the self-assessment manikin[85], delivering their responses through a button box controlled via their dominant hand.

Figure 1. Time course of the handholding fMRI paradigm

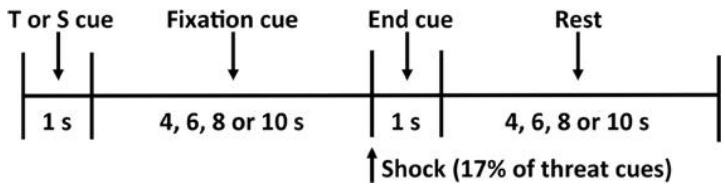


Image acquisition. Imaging data were acquired using a Siemens Magnetom Trio 3 Tesla MRI machine (Erlangen, Germany) using a 12-channel head coil. Functional T2*-weighted echo-planar imaging data were acquired during the handholding paradigm (repetition time = 2000 ms, echo time = 40 ms, resolution = 3 x 3 x 4.2 mm; flip angle = 90°, 28 slices, 216 functional volumes per block). Additionally, for each participant, a T1-weighted gradient-echo structural image was collected for anatomical reference (magnetization prepared rapid acquisition gradient-echo; repetition time = 1900 ms; echo time = 2.53 ms; field of view = 250 mm; resolution = 1 x 1 x 1 mm, flip angle = 9°, 176 total volumes).

fMRI Processing and Analysis. Imaging data processing and analysis were performed using FSL version 5.98 [FMRIB software[86]]. Images were motion corrected, grand mean scaled, spatially smoothed with a Gaussian kernel of 5 mm full width at half maximum, and highpass filtered (100 seconds) to remove low-frequency artifacts. Trials in which participants received a shock were removed from analysis to control for potential head movement.

Echo-planar imaging data were registered to each participant's T1-weighted anatomical reference image, which were then normalized into standard (Montreal Neurological Institute) space using a linear transformation. After preprocessing, the general linear model was fitted to the time-course of each voxel across the brain. Within each handholding condition, first-level contrasts of parameter estimates (COPEs) were computed for individual participants by convolving the period of "anticipation" from both threat and safety cue trials with a canonical hemodynamic response function. The threat-safety contrast was modeled across all three handholding conditions

Because of the nature of our hypotheses, no analyses were run at the third level. Instead, we extracted signal intensity values from each participant's first level COPE (threat-safety) for each individual handholding condition. Regions of interest were determined a priori by querying the literature and identifying brain areas that show a consistent effect of partner handholding: these regions show greater threat response when subjects are alone in the scanner (ALONE) vs. are holding the hand of their loved ones (PARTNER). These regions are summarized in Table 1, and include vACC, caudate, superior colliculus, PCC, postcentral gyrus, supramarginal gyrus, SFG, and SMC[15,17]. Masks for these regions were created using WFU Pick Atlas[87] by computing a 3 dimensional sphere around the peak voxel reported in the literature. To model the signal change for our contrast of interest, we subtracted the intensity values associated with the PARTNER condition from those in the ALONE condition, using the masks described in Table 1. Thus, greater values reflect the extent to which a person is able to downregulate their neural threat response in the presence of a partner, and this serves as our operationalization of social regulation ability. Because of the large number of discrete regions, in order to control for type 1 errors all analyses using fMRI data (unless otherwise specified) were conducted on the average of the difference scores associated with regions identified in Table 1.

Table 1. ROI coordinates drawn from prior research employing the handholding paradigm

Region	Coordinates	Diameter	Publication
Ventral anterior cingulate cortex	-12, 39, -1	8mm	Coan, Schaefer, & Davidson (2006)
Caudate	-8, 4, 2	8mm	Coan, Schaefer, & Davidson (2006)
Superior colliculus	3, -28, -2	6mm	Coan, Schaefer, & Davidson (2006)
Posterior cingulate cortex (1)	-9, -28, 38	8mm	Coan, Schaefer, & Davidson (2006)
Posterior cingulate cortex (2)	14, -33, 38	8mm	Coan, Schaefer, & Davidson (2006)
Postcentral gyrus	30, -50, 63	8mm	Coan, Schaefer, & Davidson (2006)
Supramarginal gyrus	-53, -29, 30	8mm	Coan, Schaefer, & Davidson (2006)
Superior frontal gyrus	-2, 23, 50	8mm	Beckes, Allen & Coan (2013)

Supplementary motor cortex	-6, 1, 56	8mm	Beckes, Allen & Coan (2013)

Legend. These regions were previously identified as showing greater neural threat response in ALONE vs. PARTNER conditions. Coordinates (x,y,z) are reported in Montreal Neurological Institute (MNI) space. Diameter denotes the size of the mask used to extract BOLD signal from this region.

Results

Associations between social regulation ability and health outcomes. A decrease in neural threat response between ALONE and PARTNER conditions within brain regions previously identified in the literature comprise our measure of social regulation ability. Here we see that – consistent with our results from Study 1 – social regulation ability positively predicts self-reported general health, as measured by the SF-36, r(66)=.23, p=.05.

Extending these results using objective measures of health, we see that social regulation ability negatively predicts BMI, r(68)=-.32, p=.007, such that better social regulators have significantly lower body adiposity. While social regulation was not associated with HF-HRV during the baseline, r(66)=.07, p=.60, speech, r(66)=.21, p=.09., or recovery periods, r(66)=-.01, p=.95, it is associated with the degree of suppression of HF-HRV from baseline/recovery to the speech task (ΔHF-HRV), which is indicative of an exaggerated stress response[88], r(66)=-.27, p=.03. Participants who have poor social regulation ability showed a greater suppression of HF-HRV during stress.

Social support. Unexpectedly, participants' social support ratings on the SSQ were not related to participants' social regulation ability, r(73)=-.07, p=.56. Further, SSQ was not related to either of the objective measures of health, or to participants' subjective health ratings (all ps>.2). By contrast, participants' relationship satisfaction with their friend (as measured by the

NRI) was significantly related to their general health ratings, r(57)=.30, p=.02, and to their body adiposity, r(54)=-.31, p=.02. Relationship satisfaction was significantly associated with social regulation ability, r(63)=.26, p=.03.

Mediation analyses. Social support measured by NRI did not predict HF-HRV suppression, r(46)=-.13, p=.36, and thus mediation will only be tested on the two remaining health measures. Mediation was tested using a bias-corrected bootstrapping procedure[70] with 5000 samples. With this procedure, the test of the indirect effect is significant if the 95% confidence intervals do not contain zero. The mediation testing the model of **social support -> social regulation -> BMI** was significant, indirect effect= -.21, SE=.17, 95% CI [-.66, -.03]. By contrast, the model social **support -> social regulation -> general health** was not significant, indirect effect= .41, SE=.36, 95% CI [-.03, 1.48]. Thus, this pattern of results partially supports the mediational hypothesis.

Attachment. Contrary to expectation, there were no relationships between avoidant attachment and all other variables tested in this study (all *p*s>.2).

Discussion

This study established that social regulation ability prospectively predicts physical health in a racially and economically diverse sample 3-4 years in the future. Measuring social regulation ability using an objective assessment of neural threat attenuation, we saw that better social regulators had better subjectively-rated health, lower BMI, and less suppression of parasympathetic nervous system activity during stress. Supporting the mediational hypothesis, we observed that social regulation ability mediated the relationship between social support and BMI.

These data support and extend the findings from Study 1: both our measures of social regulation – self-report and objective ability measured through fMRI– predict self-reported general health using the SF-36. Furthermore, the results of this study show that these effects are also apparent in objective indices of health.

STUDY 3

The purpose of the current work was to extend the findings of Study 2 by experimentally manipulating the presence of a supportive partner and examining how this interacts with individual differences to predict an objective health measure. Decades-old work on the social buffering of stress typically involved a paradigm in which participants underwent a stressful event in the presence vs. absence of a partner; results often demonstrated a main effect of condition on psychophysiology whereby participants in the partner condition would show a reduced physiological response to stress[53,54,89]. However, more recent work estimating physiology using more sophisticated methodologies (e.g., HF-HRV instead of heart rate) and looking at molecular-based individual differences often do not find a main effect of condition. Rather, the most potent effects are moderation by individual differences such as by genotype[90,91]. Furthermore, many studies – including the classic social buffering work – do not find condition-level differences in participants' subjective reports of stress[53,54,92]. For these reasons, it was unclear whether we would expect to find a main effect of social presence in addition to the individual differences that we expected. Thus, this study tested the relationship between social regulation and cardiovascular stress, compared to a control condition.

Method

Participants. Sixty-four participants from the University of Virginia research participant pool completed this study. When participants signed up for this study, they were assigned to one of two conditions: alone vs. partner[1]. Participants who were assigned to the partner condition were contacted and asked if they could bring a friend or romantic partner ("someone you trust and feel comfortable with") along to accompany them. Participants unable or unwilling to do so were awarded credit and dismissed from the study so as not to confound the results. Partners were paid $10 for their assistance, while participants received course credit. The data from four participants were discarded due to issues with the physiological data acquisition. Our final sample was 60 participants (24 male), mean age=19.02, SD=.95). Participants with partners knew them for an average of M=25.73 months (SD=32.59), and rated the closeness of their partner (0=not at all a close friend; 100=extremely close friend), as M=73.66, SD=20.04.

Procedure. Upon entering the lab, participants were told that they would have to give a five minute videotaped speech in which they had to argue that they were the ideal candidate for their dream job, a variant of the Trier Social Stress Test[79]. Additionally, their psychophysiology would be recorded using an impedance cardiograph. Participants were connected to the equipment using a set of disposable electrodes on their chests and backs, and given 5 minutes to prepare for their speeches. Preparation materials were taken away from participants while they performed their speech. Electrodes were removed from participants, they completed a series of questionnaires, and were dismissed. If participants were assigned to the social regulation condition, their partners were present during the speech preparation period and while they filled out the questionnaires, but were escorted into a separate room while participants gave their speeches.

(Social) regulation induction. Participants in both conditions were told: "This is a very stressful task for most people." *Alone condition*: "Try to suppress your emotions while you

[1] A third condition was collected to test a separate hypothesis that is irrelevant to the current work and is not discussed here.

perform this task. It should look to an outsider like you are calm, cool, collected, and not experiencing any emotion whatsoever." *Partner condition:* "You can use the presence of your partner for social support to help reduce negative emotions or anxiety about the task. They can provide emotional support but cannot provide instructions about what to say or help you with the content of the speech." *To the partners:* "Partners, try to be as supportive as you can. Remember that you can be a cheerleader, but you can't help your partner with the actual content of the speech."

Psychophysiology. Psychophysiological data were recorded during the speech preparation period and the speech task using the same equipment and a similar method to Study 2. Unfortunately, differences in the study design prevent us from using equivalent outcome variables. In Study 2, participants were assessed using a resting baseline, the speech task, and a resting recovery period. Physiology from the speech preparation period was not recorded in Study 2, and the current study lacked the resting baseline and recovery periods. Thus, in lieu of computing HF-HRV suppression as we did in Study 2 (which reflected the change in HF-HRV between the rest periods and the stressful period), our outcome measure was variability of HF-HRV within the preparation and speech periods.

Questionnaires. Participants were given a series of questionnaires to help interpret the effects observed in this study, and also to validate and extend findings from the work previously described. **Manipulation checks**: participants were asked to describe how stressful they found the speech task, how well they thought they performed, and how motivated they were to perform well. Participants in the social regulation condition were additionally asked how satisfied they were with the support provided by their partner, and how effective it was in reducing their negative emotions. Both participants and partners were asked to gauge the closeness of their relationships. **Social support.** Participants were asked to indicate how supported they felt across their entire social network. Pilot testing established that this one-item questionnaire was highly correlated with the SSQ, r(75)=.53, p<.001. **Attachment.** The ECR-R was used to characterize participants' attachment security. Given the results from Study 1, we are particularly interested in avoidantly attached participants. Unfortunately, time constraints prevented us from administering the social regulation assessment developed in Study 1.

Results

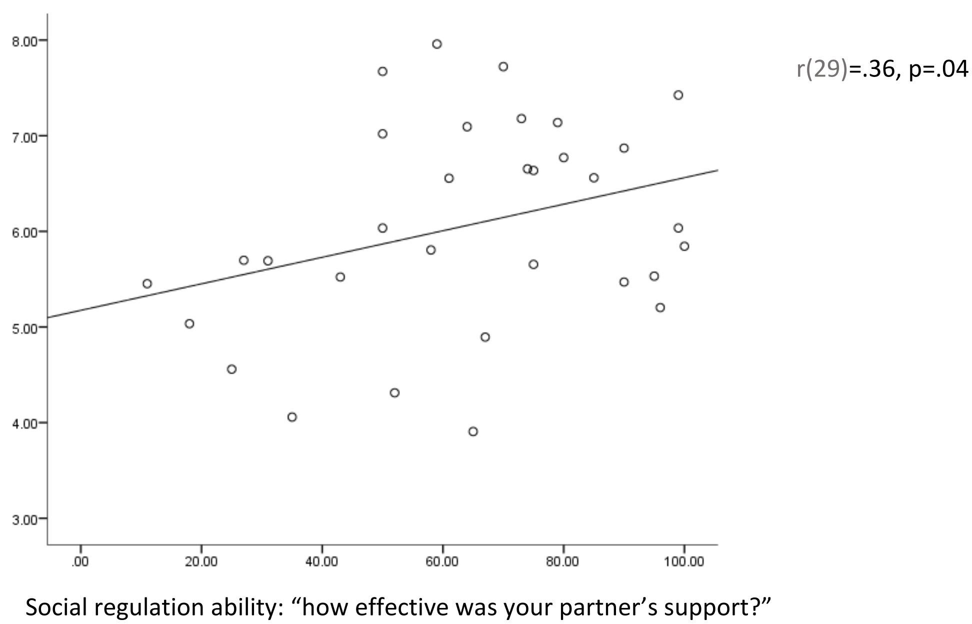
Condition. There were no main effects of condition on any outcome variable: perceived stress, t(54)=.19, p=.85, perceived performance, t(54)=-1.57, p=.12, motivation, t(49)=-1.55, p=.13, HF-HRV during the preparation period, t(57)=-.80, p=.42, and HF-HRV during the speech period, t(57)=1.10, p=.28.

HF-HRV. Mean HF-HRV was M=5.95 ms^2, SD=1.11, for the preparation period and M=6.07 ms^2, SD=1.10 for the speech period. There was no change in HF-HRV from preparation to speech, t(58)=1.06, p=.29, and values were correlated at r(57)=.69, p<.001. Contrary to expectation, neither value was associated with subjective stress, r(54)=-.11, p=.40 for the preparation period, r(54)=-.05, p=.74 for the speech period.

Social support. Across both conditions, social support was positively associated with HF-HRV during the preparation period, r(56)=.28, p=.03, such that participants with high levels of social support showed high levels of parasympathetic nervous system activity during stress. However, this relationship only held for the speech preparation period, and not the speech task itself: social support was not associated with HF-HRV during the speech task, r(54)=.12, p=.41. Further, social support was not associated with perceived stress, r(51)=-.13, p=.35, perceived performance, r(52)=.19, p=.15, or motivation, r(47)=.12, p=.40.

Social regulation. Within the partner condition, participants were asked to indicate how effective their partner was at reducing the stress associated with giving an unprepared speech. Participants' effectiveness rating was a significant predictor of HF-HRV during the speech preparation period, r(29)=.36, p=.04; participants who felt that their partners were successful in socially regulating their emotions showed greater parasympathetic nervous system activity while preparing for their speech. This relationship is plotted in Figure 2. Partner effectiveness was not related to HF-HRV during the speech period itself, r(29)=.10, p=.60, suggesting this effect was specific to speech preparation. Intimacy of relationship was significantly related to social regulation ability: the closer that participants rated their relationship with the partner, the more effective they reported it was in helping regulate their emotions, r(26)=.39, p=.04.

Figure 2. Association between social regulation and HF-HRV



Mediational relationship: social support -> social regulation -> HF-HRV. Having established that both social support and social regulation predict parasympathetic activity during stress, we explored the relationship between these predictor variables. As expected, social support and social regulation were strongly correlated, r(27)=.58, p=.001. Given the interrelationships between all three variables, we explored the hypothesized mediational model using a bias-corrected bootstrapping procedure[70] with 5000 samples. With this procedure, the test of the indirect effect is significant if the 95% confidence intervals do not contain zero. The mediation was analysis was not significant, indirect effect = .008, 95% CI= [-.01, .01]. In this case, social support had a stronger influence on HF-HRV than social regulation and this pattern of results did not support the mediational hypothesis.

Attachment. Avoidant attachment was negatively correlated with social support, r(54)=-.38, p=.004, but was not associated with social regulation in this study, r(29)=-.02, p=.91. Similarly, it was not associated with HF-HRV during preparation, r(57)=.12, p=.36, or speech period, r(57)=.04, p=.75. It was marginally associated with perceived stress, r(54)=.23, p=.09, and was significantly negatively correlated with perceived performance, r(54)=-.32, p=.02, and motivation, r(49)=-.30, p=.03.

Discussion

In this experiment, self-reported social regulation was associated with increased parasympathetic nervous system activity during stress (increased HF-HRV). This result complements the finding from Study 2 that better social regulators have less suppression of HF-HRV: while our HRV measures aren't directly comparable due to differences in study design (i.e., the lack of resting baseline made it impossible to compute HF-HRV suppression in the current study), the direction and interpretation of the results are similar. Both studies show results a pattern of salutary cardiovascular response in participants who are better social regulators.

Unexpectedly, social regulation was associated with HF-HRV only during the speech preparation period and not the speech task itself. This is notable because the partners were present *only* during the preparation period, and were asked to step outside the room while participants delivered their speeches (to minimize distraction and self-presentation concerns). This may reflect a context-specific nature of social regulation, suggesting that partners must be physically present for social regulation to occur; conversely, this effect might have occurred simply because of the abrupt removal of participants' source of support. Study 6 will address this issue in further detail in Chapter 3.

Interestingly, we failed to observe any differences between our two conditions (alone vs. partner), which suggests that the presence of social support is not always beneficial to participants. Instead, the utility of social support seems to be contingent on individual differences in peoples' ability to use this presence to socially regulate their emotions. Accordingly, we saw that participants who have strong social networks and who brought a very close friend along to the experiment were better able to socially regulate their emotions, and this was reflected in a boost in parasympathetic nervous system activity while their partners were helping them prepare for a stressful speech.

CHAPTER 2: Individual Differences

We have established there are individual differences in the social regulation of emotion: In Study 1, people differed to the extent to which they indicated turning to others in times of distress. In Study 2, people differed in the extent to which they could use the presence of a trusted other to attenuate their threat response. And finally, in Study 3, simply having access to a supportive partner was not sufficient to attenuate a physiological stress response – this attenuation was dependent on people's perceptions of the social support being provided. These findings complement and extend the work of Coan and colleagues who have identified that social regulation ability depends on individual differences such as relationship quality[15,16,19,93]. However, relationship quality is strongly contextually determined, and we are more interested in examining individual differences that reflect personality constructs which facilitate or inhibit people's ability to socially regulate their emotions.

Attachment. One individual difference that we identified in Study 1 is avoidant attachment. The concept of attachment is inextricably linked to the quality of social relationships, as it reflects a person's comfort and security in relationships. There are two broad dimensions of attachment: anxious and avoidant[94]. Anxiously attached people report concerns over the stability of their relationships, and endorse fears of abandonment. Avoidantly attached people report difficulty depending on and becoming emotionally vulnerable around others, and prefer to maintain psychological distance[69]. By contrast, securely attached individuals are low in both anxious and avoidant attachment. Attachment in adulthood is thought to extend from early experiences and bonds with caregivers[95], although the measured stability of attachment security throughout the life course is quite modest[96].

In terms of attachment's relevance to social emotion regulation, there are striking differences in how securely and insecurely attached individuals perceive and use social support: avoidantly attached individuals in particular are much less likely to report having and seeking-out social support than both the anxiously and securely attached[97–99]. In one study, avoidantly attached participants facing an acute stressor solicited less support from their romantic partners; furthermore, partners who themselves were avoidantly attached were less likely to spontaneously offer social support[100]. Even when social support is experimentally manipulated and participants have equal access to high quality support, avoidantly attached individuals were unable to benefit from this support to alleviate negative emotions[101]. These findings strongly point toward avoidant attachment styles being incompatible to the social regulation of emotion. This, in turn might explain why insecurely attached individuals have more reactive stress physiology[102], and poorer mental[103] and physical health[104,105].

Biological predisposition. Another stable individual difference in the use of emotion regulation strategies may be biological predisposition. Genetics are a driving force behind our dispositions and behaviors, influencing our social relationships and our experiences of emotion[106]. Much of the research on genetic contributions to social behavior has investigated the neuropeptide oxytocin. Oxytocin is both a social and a stress-buffering hormone. Stimulated through positive social interactions and touch, oxytocin downregulates HPA-axis activity[107], improves parasympathetic control of the ANS[108], and decreases amygdala responses to threatening stimuli[25]. In fact, it has been suggested that the mechanism through which oxytocin promotes social bonding is its anxiolytic properties[109], and it has been shown that reducing anxiety via oxytocin administration facilitates an automatic approach response[110]. Risk alleles of genetic polymorphisms on *OXTR* are associated with increased physiological responses to stress [29], decreased positive affect[32], depressive symptomology[30], and reduced hypothalamic volume[111].

Because the oxytocinergic system is dually involved in social bonding and stress-buffering, it is likely particularly relevant for emotion regulation strategies that are, by nature, social. Two prior studies provide evidence supporting the idea that oxytocin may influence social emotion regulation: in one study, when participants in an oxytocin administration study were asked to perform a Trier Social Stress Test, those whose best friends provided social support and who received oxytocin (versus placebo) were less anxious, and had the lowest levels of cortisol secretion of all groups[112]. In a second study, social support interacted with *OXTR* genotype to predict stress: when social support was available, those with an *OXTR* risk allele had higher levels of cortisol than those without the risk allele. By contrast, there was no difference between genotypes when support was unavailable[90].

Oxytocin and attachment. Oxytocin is also thought to interact directly with attachment processes. In both animals and humans, oxytocin released in parturition and lactation contributes to the formation of maternal-offspring bonds[113,114]. In human adults, oxytocin levels are positively associated with relationship quality in married couples[115], and can be increased through intimate contact between spouses[116]. Importantly, oxytocin has been found to be positively associated with secure attachment[117].

While little is known about oxytocin profiles in avoidantly attached participants, administering synthetic oxytocin selectively increased trust and cooperation in participants who were highly avoidantly attached[118]. This suggests that participants high in attachment avoidance may have a dysregulated oxytocinergic system which contributes to social difficulties (and perhaps also downstream vulnerability to disease); this will be tested in the current research.

STUDY 4

The purpose of Study 4 was to investigate the relationship between social regulation and variability in the oxytocin system. To test this, we examined a common polymorphism on the third intron of *OXTR*, rs2254298. In this polymorphism, an A allele replaces the ancestral G allele. Allele-specific effects of this polymorphism have been implicated in social and emotional processes: attachment[33,119], affective disorders[34], amygdala reactivity to socially salient information[120], and risk for autism[121,122]. However, there is no consensus on which allele can be considered the risk allele for dysregulation of these social/emotional processes: some studies have implicated the A allele as risk factor[119,121,123], while others have implicated the G allele[34,122,124]. One reason for the conflicting results is a difference in allele frequencies by race: whereas in Caucasian participants, the A allele is rare (occurring in ~20% of the population), in East Asian and (Black) African participants, the A allele is much more common (occurring in ~50% of the populations)[125]. Thus, the risk allele can be thought of as race-contingent: for instance, Chen and colleagues showed that in non-Caucasian infants, the A allele-carriers were much more likely to be securely attached to their primary caregiver; this effect was reversed in Caucasian infants such that the A allele was a risk for *in*secure attachment (although this latter effect was not significant due to low power)[33]. Because of the interactions with race, care was taken to analyze results separately for race.

Further, because these effects associated with rs22542988 (and polymorphism-specific effects in general) have shown some inconsistencies, replication of these effects is critical to their interpretation. The current study is unique in that it is comprised of two independent samples who completed identical measures: a discovery sample and a replication sample. The first sample is a racially diverse, but majority Caucasian sample drawn from the VIDA study described in Study 2. The second sample is a smaller cohort of Caucasian males drawn from the Charlottesville community. All participants completed the handholding neuroimaging paradigm as the measure of social regulation ability.

We hypothesize that there will be genotype-specific differences in participants' ability to socially regulate their emotions. We will also test for relationships between genotype and attachment.

Discovery Sample

Participants. The participants in this sample came from the VIDA neuroimaging sample described in Study 2. Beginning in 2013, blood samples for genetic analysis were taken from participants at the time of the health assessment. Usable genetic data was acquired for 59 participants (24 male), 63% of this sample was Caucasian, 31% African American, and 6% Hispanic, Asian, or Other (including Mixed Race). Average age at scan time was M=23.85, SD=1.30.

Method

Social regulation. Participants' social regulation ability was computed using handholding neuroimaging data, identically to the procedure described in Study 2. Briefly, our estimate of social regulation ability represents the decrease in neural threat response from the ALONE condition to the PARTNER (handholding) condition. Twenty-two participants in this sample were accompanied by an opposite-gendered friend, and 37 by their romantic partner (16 dating, 19 cohabitating, and 2 married).

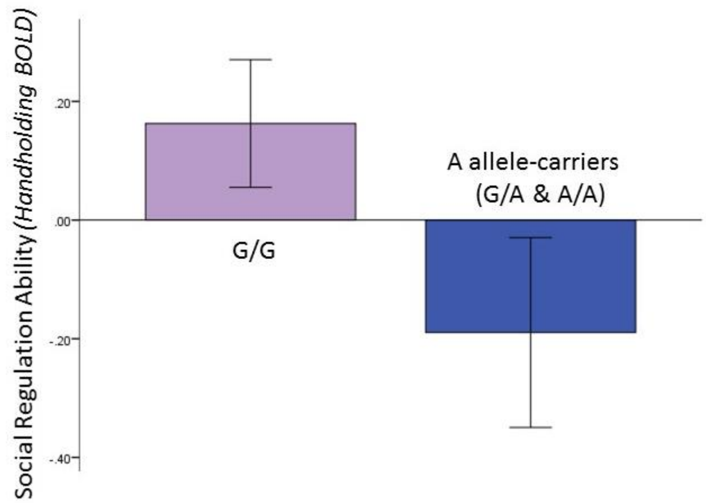
Genotyping procedure. Eight milliliters of whole blood were collected from each participant into mononuclear cell separation tubes (Vacutainer sodium citrate CPT, BD Biosciences, Franklin Lanes, NJ). The tubes were spun at 1800 relative centrifugal force for 30 minutes, according to product protocol. The Gentra Puregene Blood Kit (Qiagen, Valencia, CA) was then used to lyse mononuclear cells and extract DNA. Extracted DNA was stored at -20°C. PCR amplification was conducted using Pyromark PCR (Qiagen, Valencia, CA), with 10 ng/uL of DNA as a template, and .2uM/uL primers (5′-GAAGAAGCCCCGCAAACTG-3′) and (5′-biotin-AGTGCCCCTTTCAGGAAACC-3′). Samples were amplified using a C1000 Thermal Cycler (Biorad, Hercules, CA) with the following conditions: 95°C for 15 minutes {denaturation], followed by 45 cycles of 93°C x 30s; 56°C x 30s; 72°C x 30s [annealing], followed by 72Cx10 minutes [synthesis], held at 4°C with heated lid. PCR amplification of the region containing rs2254298 was confirmed by running gel electrophoresis.

Results

Genotyping. The allelic distribution of our sample was 3 A homozygotes (A/A), 16 G/A heterozygotes, and 40 G homozygotes (G/G). The data are in Hardy-Weinberg equilibrium, x^2 = 0.66, p>.05. Because G homozygotes are more frequent in Caucasian samples, we combined the A homozygotes and the heterozygotes into a group (A allele-carriers) to compare against G homozygotes.

Social regulation. An independent samples t-test comparing social regulation ability for G homozygotes vs. A allele-carriers showed that G homozygotes were (marginally) significantly better social regulators, t(57)=1.84, p=.07, $M_{G/G}$=.16 $SD_{G/G}$=.68, $M_{A/A/G}$=-.19, $SD_{A/A/G}$=.70. Restricting the sample to the Caucasian participants only (to control for differences in allele frequencies across race), this difference was magnified, t(35)=2.07, p=.05.

Figure 3. Social regulation differs by genotype



Further individual differences. Because of the previously identified connections between rs2254298 and attachment, we tested whether attachment styles differed by genotype in this sample. Results of an independent samples t-test showed that A allele-carriers are more likely to be avoidantly attached than G homozygotes, t(55)=2.25, p=.03, $M_{G/G}$=2.29 $SD_{G/G}$=.95, $M_{A/A/G}$=2.92, $SD_{A/A/G}$=1.03. As in the analysis above, this effect is magnified when excluding non-Caucasian participants from the analyses, t(35)=2.45, p=.02. This pattern of results is interesting as it demonstrates that A allele-carriers are more likely to be avoidantly attached, and also to be poor social regulators: in Study 1, we showed that avoidantly attached people tend to be poor social regulators. Testing this connection in this sample, the association between avoidant attachment and social regulation ability was not significant, r(55)=-.11, p=.43.

Replication Sample

Participants. Twenty-three male subjects completed this experiment in the company of their wives. Couples were recruited through flyers and advertisements distributed around Charlottesville and the University of Virginia. Couples were paid $200 for their participation in this study. All participants were Caucasian, mean age=26.52, SD=3.60.

Method

Participants in this sample underwent the exact neuroimaging paradigm as the VIDA participants (using the identical MRI scanner, imaging paradigm, and analysis pipeline). Additionally, genotyping was conducted using identical procedures: the blood samples from both cohorts of participants were analyzed in the same batch.

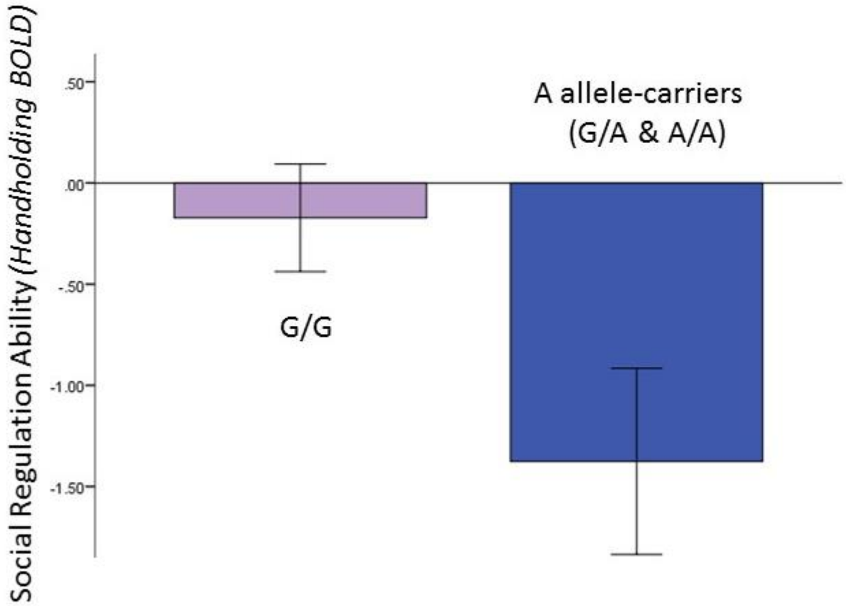
Results

Genotyping. The allelic distribution of our sample was 2 A homozygotes (A/A), 4 G/A heterozygotes, and 17 G homozygotes (G/G). The data are in Hardy-Weinberg equilibrium, x^2 = 3.58, p>.05. Because G homozygotes are more frequent in Caucasian samples, we combined the A homozygotes and the heterozygotes into a group (A allele-carriers) to compare against G homozygotes.

Social regulation. An independent samples t-test comparing social regulation ability for G homozygotes vs. A allele-carriers showed no significant difference, t(21)=1.29, p=.21. Because our measure of social regulation ability is derived from the average BOLD signal across distinct brain regions, we conducted follow-up tests to examine genetic differences for each of the contributing brain regions. The overall MANOVA test was marginally significant, F(1,21)=2.52, p=.06, and individual univariate tests identified the supplementary motor cortex (centroid coordinate x=-6, y=1, z=56) as a region that differed significantly by genotype, t(21)=2.23, p=.03. Conceptually replicating the results from the discovery sample, we observed that G homozygotes were significantly better social regulators than A allele-carriers, $M_{G/G}$=-.17 $SD_{G/G}$=.1.10, $M_{A/A/G}$=-1.38, $SD_{A/A/G}$=1.13. This difference is illustrated in Figure 4.

To determine whether this brain region-specific pattern was also present in the discovery sample, we reconducted our original analyses using supplementary motor cortex as our singular region of interest. While the genotype difference was not apparent in the full, racially diverse sample, t(57)=.99, p=.33, the difference was marginally significant when restricting the analyses to the Caucasian sample, t(35)=1.97 p=.05, $M_{G/G}$=.38 $SD_{G/G}$=.1.12, $M_{A/A/G}$=-.38, $SD_{A/A/G}$=1.04.

Figure 4. Social regulation differs by genotype (replication)



Participants in this sample did not complete a measure of attachment security, and thus we are unable to replicate those results from the discovery sample.

Discussion

In this study, we found that a common polymorphism on *OXTR* was associated with differences in social regulation ability measured using fMRI: in particular, we found that participants who were A allele-carriers were more likely to be better social regulators than G homozygotes. We also found that A allele-carriers were more likely to be avoidantly attached than G homozygotes. While social regulation and attachment were not directly associated in this sample, we have previously shown that avoidantly attached individuals tend to be poorer social regulators (Study 1). Additional analyses linking social regulation and attachment are demonstrated in the supplementary analysis section which follows. Together these results illustrate a novel, yet theoretically supported three-way relationship between oxytocin, attachment, and the social regulation of emotion.

Our sample sizes in this study were small - particularly when restricting analyses to the Caucasian sample – which resulted in some marginally significant, and regionally-specific effects. However, this study is the first of which we are aware to replicate genotype-specific effects of rs2254298 using two independent samples. Because of the prior inconsistent results in identifying a risk allele, this replication has remarkable utility for increasing our confidence and ease of interpretation of these results.

Supplementary Analyses of Attachment

While not their main theoretical focus, the subsequent Studies 5 and 6 included measures of attachment (the ECR-R) and social regulation (the self-report assessment from Study 1). Given that Study 1 found a negative association between avoidant attachment and social regulation, $r(71) = -.25$, $p = .03$, which was not replicated in the handholding fMRI sample, we report the correlations from these additional samples here. Consistent with Study 1, social regulation was inversely associated with avoidant attachment in Study 5, $r(35) = -.48$, $p = .004$, and in Study 6, $r(127) = -.35$, $p < .001$.

CHAPTER 3: Boundary Conditions

In the social sciences, boundary conditions represent constraints on a theory which qualify its generalizability across contexts[126,127]. A theory addresses the "what, how, and why" questions concerning natural phenomena, while boundary conditions help establish the pragmatics of "who, when, and where"[126]. Boundary conditions help constrain a research program by discovering the limits of how the theory can be implemented in experimentation.

Measurement. One boundary we have attempted to address in this work is delineating how social regulation can be assessed. We have seen in Study 1 that we can measure social regulation using self-report, where previously this has been done primarily using fMRI. This is significant because the social regulation of emotion is likely understudied due to the expense and difficulty of using fMRI. Certainly, the ability to flexibly operationalize a concept such as social regulation determines the diversity of the forms of experimentation in which it can appear[2].

Study 5 will investigate whether social regulation can be measured within a classic emotion regulation paradigm which has formed the majority of the work within the cognitive neurosciences. This paradigm involves participants viewing an affective stimulus, and then engaging in a regulatory strategy (typically, expressive suppression or cognitive reappraisal) in order to modify the initial affective response[128,129]. A recent meta-analysis reported that this was the most commonly used paradigm within emotion regulation research in cognitive neuroscience, having been used in both fMRI and EEG research[130]. Study 5 used this paradigm to measure event-related potentials (ERP), which are time-locked electrophysiological signals recorded from the scalp. ERP experiments are less expensive and better temporal resolution than fMRI; however, they require many repeated trials to acquire clean data, as the signal-to-noise ratio in

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[2] Anecdotally, confirming that regulation could be measured via self-report was the impetus for continuing this line of research.

ERP is very small[131]. We designed Study 5 to test the suitability of the ERP version of the common paradigm to assess social regulation.

Proximity of Support. Another question that we explored was related to the *social* component of social emotion regulation. The existing work in social regulation manipulates the presence of another person to regulate emotions: participants either interact with or maintain physical contact with others as the mechanism of regulation[15,132]. Because people do not always have access to their social support network, we were curious whether social regulation could be induced via mental imagery – that is, by having participants simply imagine the presence of a supportive other. Research investigating the social modulation of pain supports the idea that physical proximity may not be a necessary condition; several studies have shown that simply viewing images of loved ones is sufficient to increase neural reward response[56,133] and to reduce the subjective experience of pain[56,57]. Study 6 will test whether mental imagery is sufficient in inducing social emotion regulation.

STUDY 5

This study was designed to compare electrocortical response to aversive stimuli while participants are alone or are in the presence of a partner. Using scalp-recorded event-related potentials (ERP), we will examine the effect of social regulation on the Late Positive Potential (LPP). This positive-going deflection which arises between 200-300ms after stimulus onset is typically detected over centro-parietal electrodes, and is thought to reflect attention toward arousing or salient stimuli[134,135]. Greater amplitudes of this component have been associated with increased autonomic response and subjective reports of increased affective arousal[134]. Importantly, LPP can be modulated by different emotion regulation strategies such as cognitive reappraisal and expressive suppression[135].

If the presence of a trusted partner is sufficient in downregulating an affective response to negative stimuli, we would expect to see this reflected as a difference in LPP. To test this, we modified a classic LPP paradigm to compare one's neural affective response when participants were alone vs. when they were in the presence of friend. This study was conducted in collaboration with my undergraduate thesis student, Rachel Dick.

Method

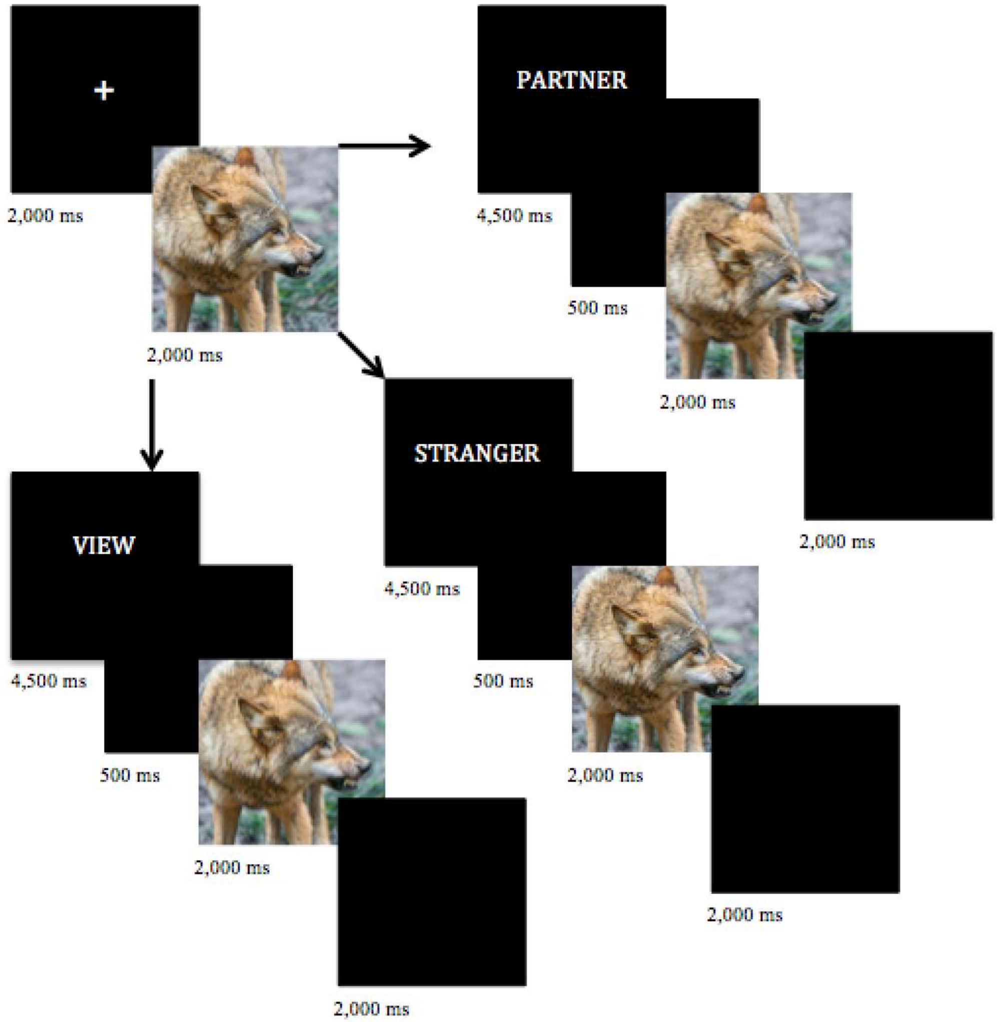
Subjects. Forty-seven participants from the University of Virginia research participant pool completed this study. Participants were recruited in a similar fashion to Study 3: they first signed up to participate in the study and then were contacted by a research assistant and asked to bring a partner along with them to the experiment. If participants could not produce a partner, they were granted credit but not invited to participate. Participants received course credit, and their partners received $15. Ten participants were dropped from the analysis due to movement artifacts (artifacts in >50% of trials in any block), and 2 participants were excluded for ERP values >2 SD from the mean, leaving 35 participants (12 male), mean age =18.79, SD=1.17. Participants knew their partners for an average of M=29.52 months (SD=45.07), and rated the closeness of their partner (0=not at all a close friend; 100=extremely close friend), as M=70.73, SD=20.34.

Procedure. In this within-subjects study, participants completed 3 blocks of trials in randomized order, differing only in the regulatory context: View, social regulation + partner & social regulation + stranger[3]. We included the presence of a stranger in our design as a control since a partner could attenuate LPP simply through the distraction of another's presence (rather than true social regulation). Our ERP paradigm (see Figure 5) was adapted from seminal work on

[3] One additional block of 40 trials investigated participants' cognitive reappraisal ability. These data were acquired to address a separate hypothesis and are not discussed here.

the electrophysiology of emotion regulation[135], and requires participants to first view a stimulus (a negative and highly arousing photograph) for 1 second, receive regulatory instructions for 4.5 seconds, and then view the same stimulus again for 2 seconds while regulating their emotions. Each block of trials is followed by a brief rest period. In the View block, participants simply attend to the stimulus. In the two social regulation conditions, participants are instructed to view the stimuli; however, seated next to them and also viewing the stimuli is either their partner (social regulation + partner condition) or a confederate (social regulation + stranger condition). For these blocks, it is explained that their partner/the confederate are present to mitigate the stress associated with viewing the negative images; they are instructed not to communicate while the participant is viewing the stimuli, but to use the other person's presence as a source of comfort. Partners/confederates are seated beside but slightly behind the participant, out of their peripheral field of view to minimize distraction. Stimuli comprise 120 negative, high arousal images from the OASIS database[136], which are distributed across the 3 blocks of trials. Before beginning the study, the experimenter explains the paradigm in detail and leads participants through a guided practice session using a set of images which do not appear in the experiment, similar to the procedure reported in prior work[135]. To reduce artifacts due to eyeblinks, participants are instructed to avoid blinking while the images are being presented on the screen.

Figure 5. Experimental design and time course of stimulus presentation of Study 5



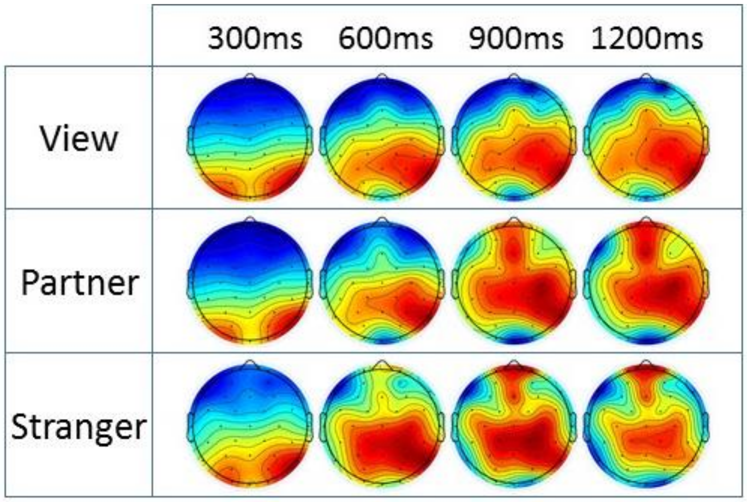
Questionnaires. Immediately following each block of trials, participants reported on their experience using visual analog scales ranging from 0-100. Participants were queried: "How negative/distressing did you find the images during this set of trials?" [not at all negative=0, extremely negative=100], and "How much of your attention did you allocate towards the task?" [not much attention=0, my full attention=100]. **Regulatory strategy**. We administered the Emotion Regulation Questionnaire[39] and the social emotion regulation assessment from Study 1 in order to assess participants' self-reported use of emotion regulation strategies. **Social support.** Participants were asked to indicate how supported they feel across their entire social network.

Attachment. The ECR-R was used to characterize participants' attachment security, with particular attention to avoidantly attached participants. **Health.** The Beck Depression Inventory[137] was used to assess mental health.

Electrophysiological data collection and analysis. We collected EEG/ERP data from our participants using a BioSemi Active two system with 32 active Ag/Ag-Cl electrodes in a standard 10-20 configuration, referenced online to the left mastoid. Electrooculogram (EOG) was recorded from the left eye: an electrode placed lateral to the external canthi was used to detect horizontal eye movements, while an electrode placed below the eye was used to detect eyeblinks and vertical eye movements. EEG data were processed using the EEGLAB[138] and ERPLAB[139] toolboxes in Matlab. Data were re-referenced offline to the average of the left and right mastoids. EEG was sequentially high- and low-pass filter at 0.1 and 30Hz using a Butterworth impulse response function, 24 dB/oct roll-off, 60Hz notch). Data event codes were shifted 50ms in time to account for the delay in stimulus presentation in the LCD computer monitor (quantified using oscilloscope). An epoch comprising 200ms before and 2000ms after stimulus onset was extracted for each participant, and baseline corrected using the 200ms pre-stimulus period. Artifactual trials were identified as those with an amplitude change exceeding 100 μV between data points, or within a moving 200ms window, and were discarded from analysis. A remaining mean of 33.2 trials per condition were combined to create a single averaged waveform for each condition.

Quantifying LPP. While prior work has focused primarily on a combination of electrodes surrounding PZ, the electrode with the highest mean amplitude across time and condition was P8 (right parietal). This electrode also showed sensitivity to emotional modulation (i.e., a difference between conditions) of similar magnitude to midline parietoccipital electrodes, and thus our LPP was computed as an average signal across Pz, Oz, P3, P4, PO3, PO4, and P8, reported in μV.

Figure 6. Scalp topography of electrical activity across time and condition



In these analyses, we concentrated on a time window spanning 300ms-1500ms, as prior work has shown the LPP can be manipulated through suppression and distraction as early as 250-300ms after stimulus onset[140–142]. Figure 6 demonstrates the scalp topography of the signal in each condition over time. Since it appears that the scalp topography begins to diverge between conditions around 1000ms, we analyzed LPP waveforms averaged across both a 300-1000ms window and the full 300-1500ms window. While the results of both sets of analyses were similar in direction and magnitude, the results of the 300-1000ms window are presented here, unless otherwise specified.

Results

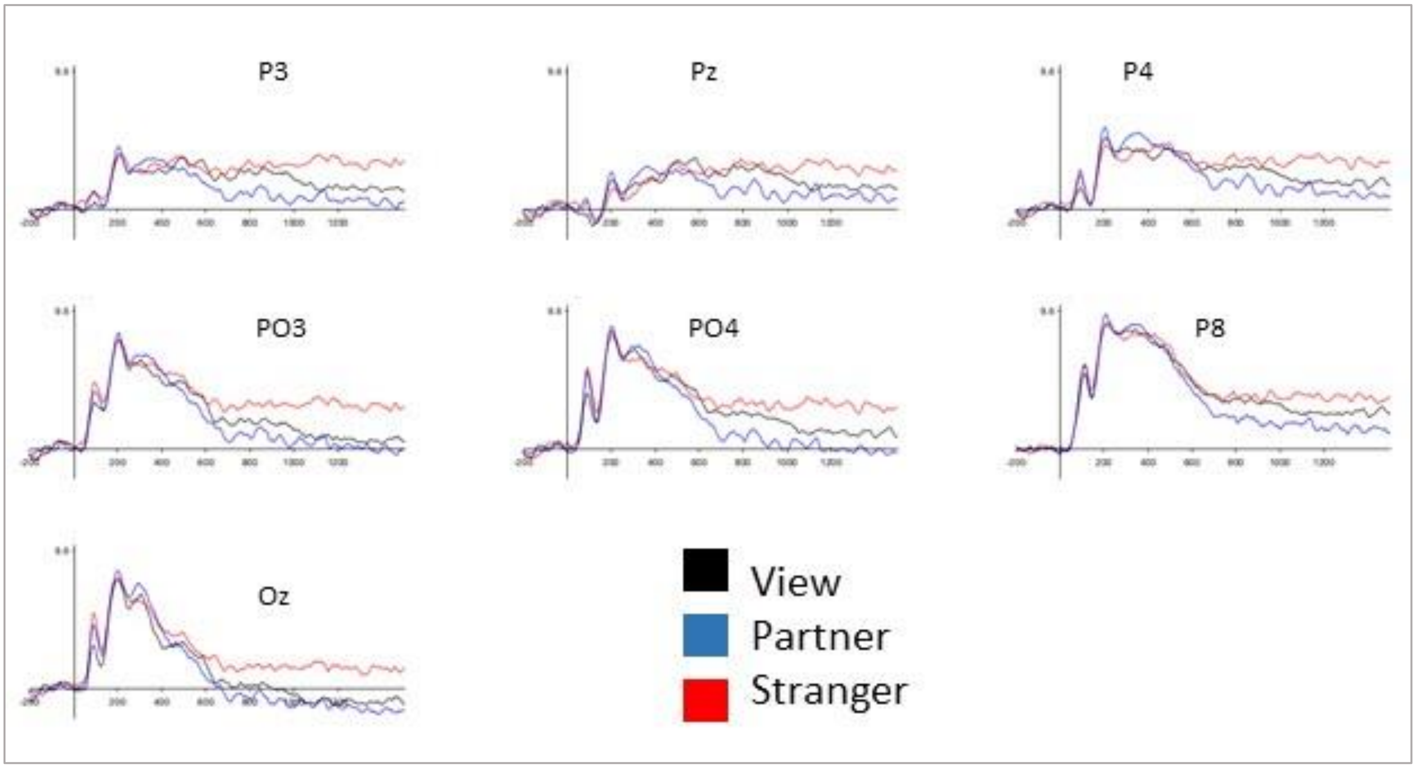
Main effect of condition. In light of our past findings, we were agnostic about whether to expect a main effect of condition on arousal, or whether to expect only moderation by individual differences. Prior work has shown that inducing an explicit cognitive reappraisal strategy consistently elicits a dampened LPP within this paradigm[135]. However, our manipulation in this study (instructing participants to use the support of the other person) was exponentially more subtle. Furthermore, our primary question concerns individual differences.

Across all participants, we did not see a significant difference in participants' self-reported negative arousal to the images by task condition, $F(2,33)=1.70$, $p=.20$, $M_{view}=50.33$, $SD_{view}=22.41$, $M_{stranger}=45.18$, $SD_{stranger}=21.00$, and $M_{partner}=47.63$, $SD_{partner}=23.81$, nor did we see a difference in participants' reported attention by task condition, $F(2,33)=1.55$ $p=.22$, $M_{view}=62.59$, $SD_{view}=20.79$, $M_{stranger}=60.79$, $SD_{stranger}=21.82$, and $M_{partner}=66.33$, $SD_{partner}=17.94$.

Similarly, we did not find a significant difference in LPP by task condition. The stimulus-locked grand-averaged waveform for all contributing electrodes can be seen in Figure 7. Looking across the entire 300-1500ms time-window, there was no significant difference of condition, $F(2,33)=.467$, $p=.49$, $M_{view}=2.25$, $SD_{view}=2.71$, $M_{stranger}=2.36$, $SD_{stranger}=2.84$. However, the waveform between conditions can be seen to be diverging around 600ms, and across all contributing electrodes there is a consistent pattern where the partner condition has the lowest amplitudes while the stranger condition has the highest amplitudes. While we did not find a significant difference between conditions by looking across the entire time-series, we also tested the time period between 1400-1500ms as this was the greatest observed difference between conditions. The repeated measures ANOVA was marginally significant, $F(2,33)=3.66$, $p=.07$, such that there was a trend-level difference between the stranger condition and the partner condition[4] $M_{partner}=1.69$, $SD_{partner}=3.16$, $M_{stranger}=2.79$, $SD_{stranger}=3.53$.

[4] A difference between partner and stranger isn't immediately interpretable as our hypotheses are directed towards the difference between partner & view.

Figure 7. Condition-specific waveforms for each contributing electrode



Individual differences. Because we did not detect main effects of condition, we turned our attention to moderation by individual differences to examine whether any of our predictor variables would explain a difference in LPP amplitude between conditions. Since we are most interested in the difference between partner and view conditions (and, to a lesser degree, stranger and view), we looked at the association between our explanatory variables and the difference scores for view-partner and view-stranger. An attenuation in LPP in the partner condition relative to the view condition would be evidence of social regulation.

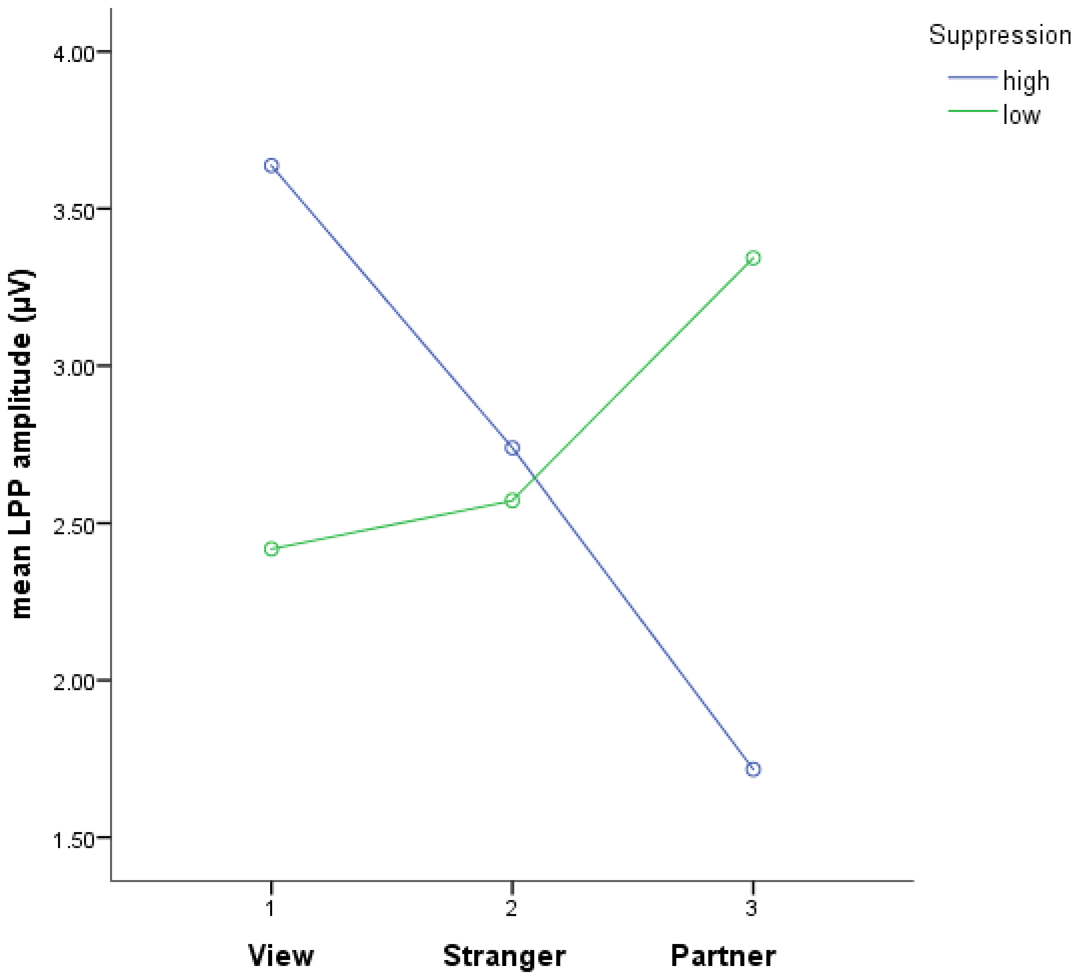
Partner closeness and self-reported social regulation. We tested whether relationship closeness or self-reported social regulation predicted a difference in LPP from view-partner. Contrary to expectation, we did not find an association with either variable, $r(33)=.04$, $p=.84$, $r(33)=-.25$, $p=.15$, respectively. This suggests that participants in our sample were not more likely to engage in social regulation in this paradigm if they are in the presence of a highly trusted other, nor if they are particularly frequent users of social regulation. While the relationship between self-reported social regulation and LPP is not statistically significant, it is consistently in the opposite direction than expected across all contributing electrodes (*r*s range from -.21 to -.36), such that self-reported social regulators have an *increased* LPP in the partner vs. the view conditions. Self-reported social regulation was not associated with an attenuation of self-reported arousal from view-partner, r(33)=.10, p=.58.

Suppression. Further, completely contrary to expectation, the variable that most strongly predicts an attenuation in LPP from view-partner is participants' self-reported expressive suppression. That is, if participants indicate that they typically use suppression to control their emotions, they are more likely to attenuate their emotional responses when instructed to use the support of their partner, r(33)=.55, p=.001 (and, to a lesser extent, the stranger r(33)=.33, p=.06). This relationship can also be described by looking at the mean differences between task conditions, as a function of high or low suppression. Means are plotted in Table 2. To formally test this, a mixed-effects ANOVA was run with condition as a within-subjects factor and suppression (median split) as a between-subjects factor. While there were no main effects of suppression or condition, the interaction was significant, F(1,33)=6.38, p=.02. Figure 8 shows the disordinal interaction of suppression ability by task condition. Simple effects tests using Fisher's LSD revealed that participants in the high suppression group showed a significant difference in LPP between the view and partner conditions, mean difference =1.92, p=.02, 95% CI=[.28,3.57]. No other simple effects contrasts were significant. Additionally, in contrast to LPP difference scores, expressive suppression was not associated with a change in self-reported arousal from view-partner, r(33)=-.26, p=.13.

Table 2. Descriptive statistics for average LPP waveforms from 300-1000ms by suppression

	View	Stranger	Partner	View-Stranger	View-Partner
Low Suppression	M= 2.41 SD= 4.87	M= 2.57 SD= 2.65	M= 3.34 SD= 2.68	M= -.83 SD= 4.01	M= -.93 SD= 3.83
High Suppression	M= 3.64 SD= 2.49	M= 2.75 SD= 2.32	M= 1.72 SD= 2.98	M= .04 SD= 1.86	M= 1.92 SD= 2.71

Figure 8. Interaction between suppression and condition on LPP amplitudes



***Relationship between suppression and other variables*.** As seen in Table 3, suppression was robustly inversely correlated with self-reported social regulation, suggesting that participants who typically socially regulate do not use expressive suppression and vice versa. Furthermore, avoidant attachment was positively related to suppression, and negatively related to social regulation. Finally, we looked at the relationship between expressive suppression and depression scores, and found a positive relationship such that suppressors report higher levels of depression, r(33)=.35, p=.04. Self-reported social regulators showed the opposite pattern, r(33)=-.48, p=.004.

Table 3. Correlation matrix between predictor and outcome variables

	Expressive Suppression	Avoidant Attachment	Social reg. frequency	LPP: view-partner	LPP: view-stranger
Expressive Suppression					
Avoidant Attachment	**r(33)=.56, p=.001**				
Self-report Social reg.	**r(33)=-.47, p=.004**	**r(33)=.-40, p=.02**			
LPP: view-partner	**r(33)=.55, p=.001**	r(33)=.32, p=.06	r(33)=-.25, p=.15		
LPP: view-stranger	r(33)=.33, p=.06	r(33)=.22, p=.19	r(33)=-.19, p=.29	**r(33)=.50, p=.002**	

Interim Discussion

In this experiment, we had predicted that people who report frequently socially regulating their emotions would benefit from the presence of a trusted partner. In contrast, these participants' LPP was slightly elevated in the presence of their partner, suggesting an *increased* affective response. Further, we observed that only participants who were high in expressive suppression were successful in "socially regulating" their LPP response to emotional stimuli (i.e., attenuating the LPP in the presence of their partner); this is counterintuitive since suppressors tend to be avoidantly attached and should be unlikely to leverage the support of others. Indeed this is supported by the strong negative correlation between suppression and self-reported use of social regulation.

What could account for these paradoxical results? The most obvious possibility is that suppressors are – in fact – suppressing. When instructed to regulate their emotions using their partner's support, they simply inhibited their emotional response. Unfortunately it is impossible to tease apart participants' use of strategy as we only asked participants about their *general* use of suppression, and did not inquire about their use of suppression *in this experiment*. To address these remaining questions, we choose to conduct a follow-up study which is described in the next section.

STUDY 5.b.

We tested whether participants' general use of suppression was associated with their actual, stated use of suppression within the ERP experiment by having participants reflect on their experiences during the study. Furthermore, we took this opportunity to attempt to explain our null findings with regards to self-reported social regulators: we questioned whether these participants may have been unable to attenuate their emotions in the presence of their partner because their partner was also exposed to the aversive images. We reasoned that this could have been distressing for participants, and that their concern for their partner could have overridden any natural social regulation process that otherwise would have occurred.

Method

Approximately 6 weeks after completion of the ERP study, we sent a follow-up questionnaire via e-mail to the participants whose data were not discarded due to artifacts/outliers (n=35), offering $5 compensation via Amazon e-gift card for completion of a brief online survey. Participants were given 3 reminders to complete the study before we terminated data collection.

Questions. We asked participants a short series of questions about their experiences in the study and their use of emotion regulation strategies, using visual analog scales ranging from 0-100. Questions included: "*I didn't know how to 'make use of my partner's support', so I just suppressed an emotional response to the images as best I could*", "*I was concerned about my partner's reaction to viewing the negative images*", and "*I found the images more threatening* *when my partner was next to me versus when I was alone*". We also asked participants to complete the Empathic Concern subscale from the Interpersonal Reactivity Index[143]. We also asked participants to reflect on aspects of the experimental design which may have contributed to the pattern of results we obtained: "The instructions I received during the task were confusing or didn't make sense to me", "I found the experimental conditions too inauthentic to be able to use social support to regulate my emotions", and "*The experiment wasn't stressful to the point where I felt I needed my partner's support*."

Results

Nineteen of the original 35 participants completed the follow-up survey. While the sample of respondents was very limited in size, they were fortunately representative of the total population of ERP study participants: those who chose to participate in the follow-up were no different than the non-responders on all variables reported in the original study (all *t*s were <1.4). Thus our sample is safe from selection effects.

Suppression. Our primary motivation for administering this survey was to determine whether participants who reported using expressive suppression in general were also employing that strategy within the ERP paradigm. Participants' endorsement of the question "*I didn't know how to 'make use of my partner's support', so I just suppressed an emotional response to the images as best I could*" was positively associated with participants' suppression scores, $r(17)=.45$, $p=.05$ and also to the LPP attenuation from view-partner, $r(17)=.45$, $p=.05$, but not the LPP attenuation from view-stranger, $r(17)=.03$, $p=.92$.

Partner concern. Our secondary question in this survey was whether frequent social regulators in this study were distressed or concerned with their partners' own experiences, which prevented them from benefitting from their partners' support. We did not find support for this hypothesis. Self-reported social regulation was not associated with endorsement of the item "*I was concerned about my partner's reaction to viewing the negative images*", r(12)=.-23, p=.43, nor "*I found the images more threatening when my partner was next to me versus when I was alone*", r(10)=-14, p=.67. It was also not associated with empathic concern, r(17)=-.22, p=.37.

Experimental validity. Finally, we asked participants to reflect on how stressful and authentic the experimental conditions were, and also how understandable the experimental instructions were in order to assess the experiment's validity. While participants indicated that the instructions weren't confusing [100=very confusing], M=12.69 SD=15.14, and that the experiment wasn't overly inauthentic [100=very much so], M=59.69 SD=23.29, participants strongly endorsed the item "*The experiment wasn't stressful to the point where I felt I needed my partner's support"* [100=very true], M=85.47, SD=18.68. Social regulators were more likely to report that the experiment wasn't stressful, r(15)=.49, p=.04, and also (marginally significantly) more likely to find the experimental conditions inauthentic , r(15)=.42, p=.09.

Discussion

This ERP experiment was designed to test whether social regulation could be elicited and measured using a canonical emotional regulation paradigm. While we did observe that some participants could attenuate their LPP in the presence of a trusted partner, follow-up analyses suggested that this attenuation was being driven primarily by expressive suppression. This is a common strategy amongst participants who are poor social regulators, which contributed to a pattern of results which were in the opposite direction than expected. While suppressors were able to attenuate their neural affective responses, it should be noted that this is not necessarily a salutary outcome: consistent with a large body of work showing that expressive suppression can be maladaptive[144], expressive suppression in our sample was positively associated with depression scores. This suggests that LPP to aversive stimuli may not represent the component of the stress response that is most relevant to mental and physical health, since suppressors can reflexively modulate it while social regulators (who are healthier) do not.

In this experiment, self-reported social regulators were unable to benefit from the support of their partner. While we were able to rule out participants' concern for their partners as an explanation for these null results, it is not immediately clear why self-identified social regulators were unable to engage in social regulation in this paradigm. Our follow-up study provided some clues: social regulators were more likely to report that the experiment wasn't particularly stressful, and further, that they found the experimental conditions were too inauthentic to engage in social regulation. It is possible that the length of the experiment - which lasted approximately 45 minutes after participants were consented and capped – contributed to participants' apathy. Anecdotally, we noted that participants reported feelings of exhaustion at the completion of the experiment, and several of the participants whose data were excluded due to artifacts were struggling to stay awake. Because ERP experiments necessitate a large number of trials in order to cleanly estimate electrical activity at the scalp level, they are not well-suited to measure acute emotional responses. It is thus possible that social regulation of emotion is most pertinent and efficacious in situations where a stressor is intense and immediate rather than mild and sustained, the latter of which is optimal for ERP. Thus, the overall pattern of results from this experiment suggest a boundary for social regulation research: this paradigm is not suitable for eliciting and measuring social regulation in its current form. Given the sheer amount of emotion regulation research which employs this paradigm, this is a significant observation.

STUDY 6

A second boundary condition that we explored was the immediacy of social support resources. This experiment tested whether the physical presence of a social supportive partner is a prerequisite for people to experience social emotion regulation. To accomplish this, we assigned participants to imagine the presence of another person immediately before facing an acute stressor. Participants were assigned to imagine the presence of someone unreliable, or to imagine the presence of their mother – a relationship that is generally positive, but within which we expected considerable variability. We hypothesized that participants who imagined the presence of an emotionally supportive other would show reduced affect and persist longer under the stressor.

Method

Subjects. Participants were 137 students who were recruited through the University of Virginia participant pool and completed the study as part of their course credit requirement. Seven participants were excluded from the analyses: six for failing to follow directions and one participant was not able to complete the cold pressor task due to a blood circulation disorder. The remaining participants were 130 students (46 male), mean age=18.99, SD=1.15.

Procedure. Participants came into the lab and were consented and told that they were participating in a study on pain and visual imagery. They were instructed to engage in a visualization task: depending on which of three conditions they were assigned to, participants were either asked to either imagine a) their mother, b) an untrustworthy other, or c) their typical morning routine. After completing the visualization, participants were asked to perform a cold pressor test in which they placed their non-dominant arm in ice water for as long as they could tolerate. Participants then completed several questionnaires and were debriefed.

Visual Imagery Task. After completing a consent form, participants were seated in front of a computer, and were administered the following instructions:

Mother/Untrustworthy other conditions: *"We would like you to imagine* ***your mother/a person in your life who you can't rely on. This could be a person who has let you down in the past, or someone that you just don't have a close and trusting relationship with. You would never read out to this person in a time of need.*** *Imagine that* **she was/they were** *here with you right now. Try to think about what* **she/they** *might say or do. What would* **she/they** *think about this experiment? Would* **she/they** *encourage you? Why or why not? How do you think* **her/their** *presence might make you feel overall?"*

Control condition: *"we would like you to imagine your morning routine on a typical day. What time do you usually wake up? What activities do you tend to start the day with? Do you eat breakfast? Do you drink coffee? Do you follow the same routine every day, or does it tend to be quite variable?"*

All conditions: *We'd like you to visualize this as vividly as possible for 2 minutes. You can close your eyes briefly if you need to. When the timer runs out, you will have about 4 minutes to write about and describe your visualization."*

The experimenter confirmed with the participants that they understood the instructions, and in the case of the untrustworthy other, that they were able to think of an appropriate person before completing the visualization. Participants performed the visualization task for 2 minutes and then typed up a summary of their visualization for approximately 4 minutes.

Cold Pressor. Participants were seated at a table facing a wall with bucket containing ice water which was maintained at a consistent temperature of 1-3 degrees Celsius. This task reliably induces arousal and a consistent HPA-axis response, with a stereotyped cortisol response[145].

Participants were instructed to place their non-dominant hand into the ice water with their palm resting face down on the bottom of the bucket, in order to consistently submerge the arm to the mid-forearm. They were instructed to keep their arm in the ice water for as long as they could bear it, and were asked to signal the experimenter (who has seated with their back facing the participant) when they had to remove their hand from the water. Persistence time was recorded by the experimenter and is our main dependent variable in this study. At the conclusion of the cold pressor task, participants were supplied a towel and then were asked to fill out several questionnaires about their subjective experiences during the task, as well as their attitudes and temperament.

Questionnaires. Immediately following the cold pressor task, participants reported on their experience using visual analog scales ranging from 0-100. Participants were queried: "How negative or positive is your current mood?" [negative=0, positive=100], "How stressful did you find the ice water task?" [not at all=0, very much so=100], "How painful did you find the ice water task?", [not at all=0, very much so=100]. They were also asked to report how cold they believed the water was [in degrees Fahrenheit][5] and how long they estimated their ice water persistence [in seconds]. In the mother/untrustworthy other condition, participants were asked to report how emotionally supportive they considered the person they visualized. Participants completed the ECR-R, the social emotion regulation assessment, and also a visual analog scale asking "how supported do you feel across your entire social network?" [0=not at all, 100=very much so].

Results

[5] Estimates of the water temperature were dropped from analysis as several participants indicated values lower than 32F; it was unclear what percentage of participants though liquid water could be colder than 32F, and what percentage simply confused Fahrenheit and Celsius. This rendered the estimates unintelligible and could not be used.

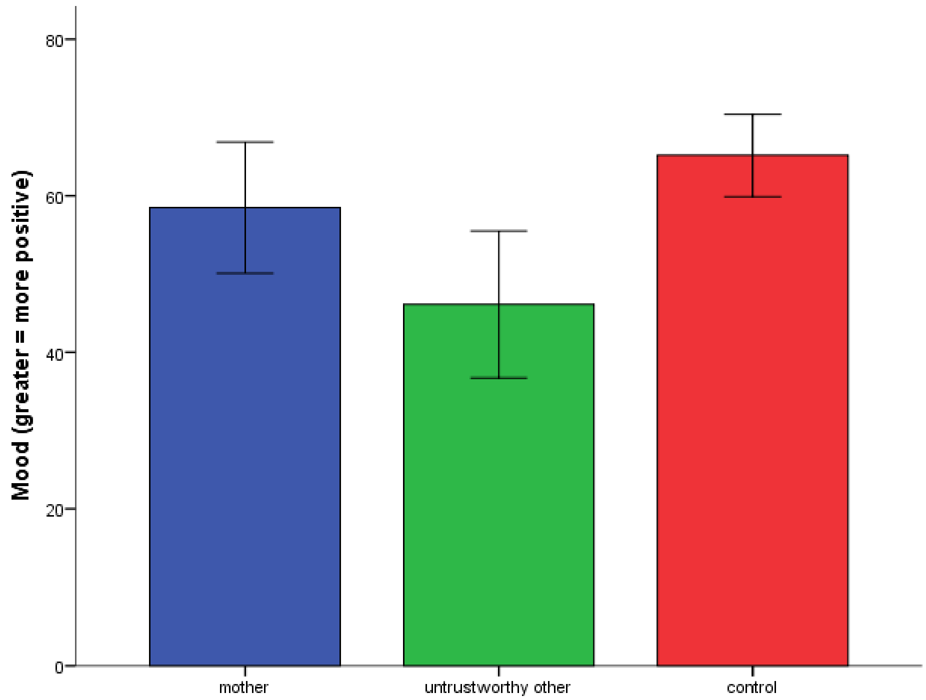
Gender differences. Males found the cold pressor task less stressful and less painful than females participants, t(106)=2.87, p=.005, and t(116)=2.20, p=.03, respectively. There were no significant gender differences on any other variable measured in this study, including persistence time, t(128)=1.03, p=.31, and won't be discussed further.

Main effect of condition. Consistent with the results of Study 3 where we did not find differences in stress level in the presence/absence of a partner, there was no difference in ice water persistence times after visualizing a trusted/untrustworthy/no other person, F(2,127)=1.30, p=.28. Similarly, there were no differences between condition in participants' estimated ice water persistence time, or stress levels (all *F*s <1).

As expected, participants rated the emotional support of their visualization target as higher if it was their mother, M_{mother}=77.86, SD_{mother}=27.32, than if it was an untrustworthy other, M_{other}=15.35, SD_{other}=3.20, t(57.56)=11.29, p<.001.

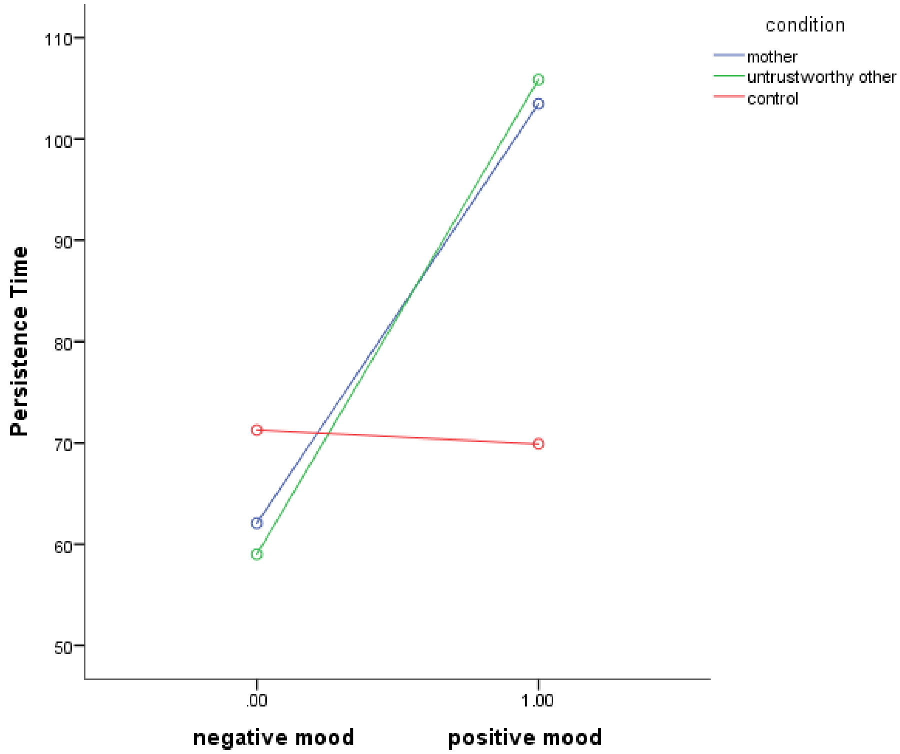
A main effect of condition on mood was observed F(2,105)=7.04, p=.001. Post-hoc tests revealed that participants in the untrustworthy other condition reported feeling significantly more negatively than participants in the control condition (mean difference=19.04, p=.001) and the mother condition (mean difference=12.36, p=.03). Participants' mood scores did not differ between the mother and control conditions (mean difference=6.68, p=.19). Mood scores by condition are illustrated in Figure 9. Participants' positive mood was negatively correlated with how stressful they perceived the cold pressor task, r(93)=-.36, p<.001.

Figure 9. Mean self-reported mood by condition



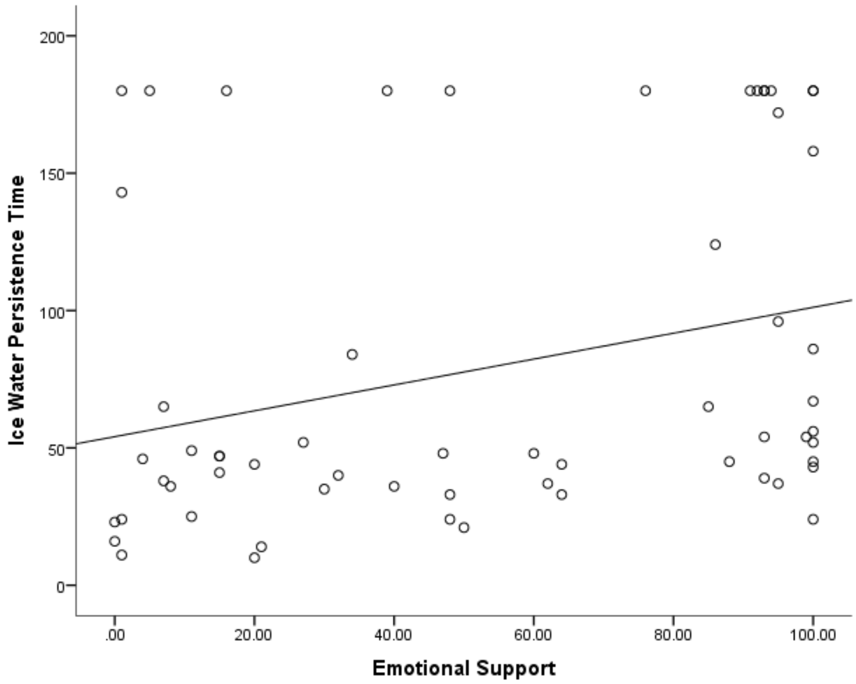
Relationship between persistence time and mood: Participants' persistence time and their mood were positively correlated across conditions, meaning that participants with more positive moods were able to keep their hands submerged longer, r(114)=.26, p=.006. However, there was also a marginally significant interaction between mood and condition, F(2,102)=2.92, p=.06. Follow-up analyses show that mood and persistence time are only associated within the two social visualization conditions: mother condition, r(28)=.48, p=.007, untrustworthy other condition, r(27)=.48, p=.008, whereas this strong correlation was absent in the control condition, r(47)=-.03, p=.84.This interaction is illustrated in Figure 10.

Figure 10. Interaction between condition and mood on persistence time



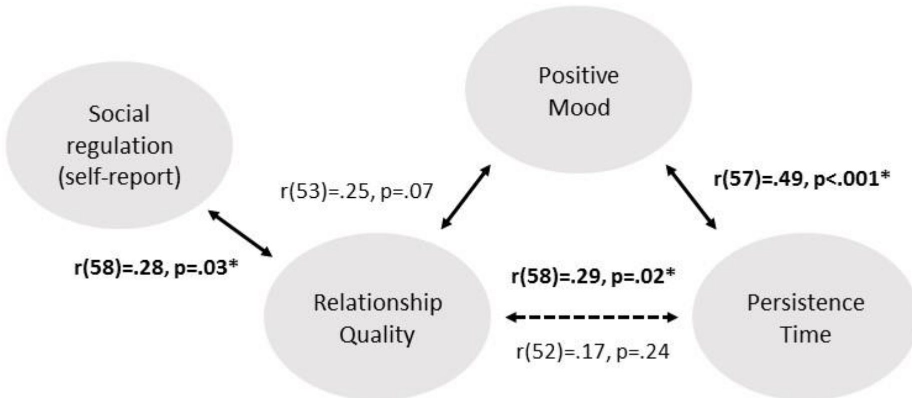
Relationship between persistence time and relationship quality. Across the two social visualization conditions, there was a significant relationship between persistence time and participants' ratings of how emotionally supportive was the person they visualized, r(58)=.29, p=.02; this relationship is illustrated in Figure 11. This relationship was particularly apparent within the condition where participants first visualized their mothers, r(35)=.48, p=.003, and showed a similar but non-significant pattern in the untrustworthy other condition, r(21)=.21, p=.34. The interaction between relationship quality and condition was not significant, F(2, 56)=.07, p=.79.

Figure 11. Supportive relationships predict persistence time



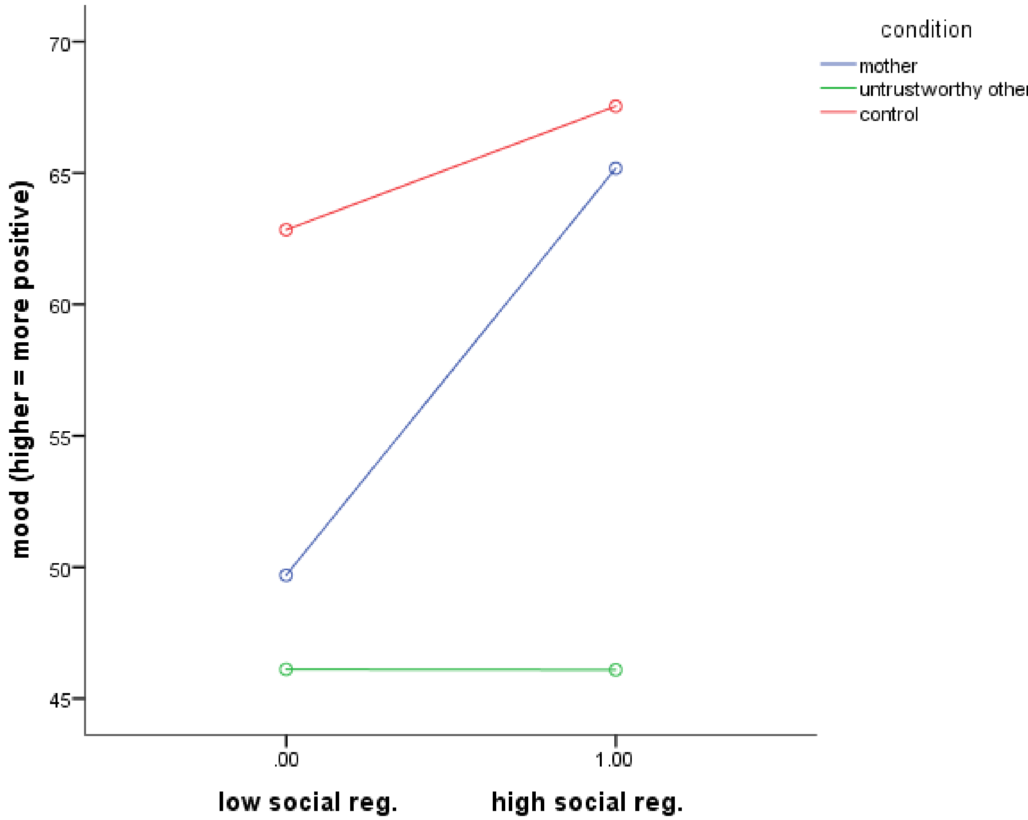
Relationship between mood, relationship quality, and time. Participants' moods were marginally associated with their emotional support ratings of their visualized other, r(53)=.25, p=.07. Because of the inter-relationships between variables, we tested whether a change in mood could account for the association between relationship quality and ice water persistence time. We conducted a mediational analysis using a bias-corrected bootstrapping procedure [70] with 5000 samples. With this procedure, the test of the indirect effect is significant if the 95% confidence intervals do not contain zero. As illustrated in Figure 12, we observed evidence of mediation, indirect effect =.18, SE=.10, 95% CI= [.02, .44], demonstrating that mood mediated the relationship between emotional support and persistence time across the two conditions.

Figure 12. Model of social regulation processes within a cold pressor task



Social regulation scores. We also looked at the relationship between participants' self-reported social regulation and other variables in this study. Participants' use of social regulation was associated with emotional support, demonstrating that social regulators had better quality relationships (even when asked to imagine an untrustworthy other), r(58)=.28, p=.03. Self-reported social regulation did not directly predict persistence time, r(127)=.02, p=.83 or mood, r(106)=.11, p=.23. However, social regulation's effects on mood were qualified by a marginally significant interaction with condition, F(2,102)=2.72, p=.07, which is illustrated in Figure 13. This interaction revealed that participants' self-reported social regulation scores positively predicted mood in the mother condition, r(28)=.41, p=.03, but not in the untrustworthy other r(27)=.02, p=.94, or control condition, r(47)=-.12, p=.43.

Figure 13. Interaction between social regulation and condition on mood



Discussion

In this study, we demonstrated that imagining the presence of another person can impact participants' ability to regulate their emotions and to persist through pain, but this effect is completely dependent on pre-existing individual differences. We have established that imagining someone with whom one has an emotionally supportive relationship will boost participants' persistence times, and we have identified that the mediating mechanism is participants' mood. These results are significant in demonstrating that social regulation can occur even when the supportive person is not physically present; this highlights the utility of social regulation across situations and its relevance in many different contexts.

This study is also notable for being the first in this series of studies to show an effect directly on participants' moods. While in other studies we have asked participants to report retrospectively on their stress levels or the valence of the stimuli/situation – typically some variation of "how negative/stressful did you find this task?" – this experiment also had participants report on their current moods. While participants' mood and stress ratings were related in the current study, stress was not modulated by condition or individual differences in the same way that mood was. This discrepancy may be a result of the influence of cognition on emotion: it is possible that making retrospective judgments about the stress associated with a situation requires greater reliance on meta-cognition and memory processes which skew participants' judgments. By contrast, current mood judgments could be less susceptible to bias from beliefs and memory distortions.

Interestingly, mood was unrelated to persistence time within the control condition. It is possible that in this condition, emotion regulation wasn't as salient or as explicitly identified as a mechanism through which to persist longer in the task. One possible factor which could account for this difference was the wording of the visualization induction. In both of the social visualization conditions, participants were asked to describe how the imagined presence of the other person affected their emotional state: in fact, the very last sentence of the induction asked "*How do you think [your mother's/the untrustworthy other's] presence might make you feel overall?"* In contrast, the control condition induction did not have participants perseverate on their emotions, but instead had participants list banal aspects of their morning routine. Thus, the control condition differed from the other conditions both in social content and – inadvertently – in emotional content. In the future, a control condition which conforms closer to the other conditions would be useful in better explaining these effects.

Participants' self-reported use of social regulation showed interesting effects within this experiment. It predicted the quality of participants' social relationships across conditions, and was also positively related to mood exclusively within the mother condition. This latter relationship is notable because the mother condition can be assumed to be the situation most ecologically similar to how social regulation might naturally occur: when faced with a stressor, people solicit support from those with whom they have supportive relationships. We also observed in this experiment that relationship quality was a stronger predictor of mood and persistence time than participants' self-reported social regulation. This result may be an artifact of our study design in which we restricted who participants could imagine; it is possible that if we allowed participants to imagine the most supportive influence in the life, that participants' reported use of social regulation might have been directly related to their actual ability to socially regulate in this paradigm (resulting in higher moods and longer persistence times). Despite the lack of direct relationship, participants' self-reported social regulation use does contribute indirectly, and the results of this experiment are consistent with our previous research.

CONCLUSION

Six studies contribute to our knowledge of how we use others to regulate our emotions. We have seen that individual differences in the use of social regulation predict both subjective and objective health-related outcomes (Studies 1, 2 & 3), and that in some cases, the use of social regulation mediates the relationship between social support and health (Studies 1 & 2). We have also seen that the social regulation of emotion is highly dependent on individual differences: we have replicated the finding that relationship quality predicts a person's ability to benefit from a supportive other (Studies 3 and 6), have shown that avoidant attachment is an impediment to this ability (Studies 1, 4, 5, 6), and further that this attachment-related vulnerability may stem from genetic differences in the oxytocin system (Study 4). We have also attempted to stretch this research across multiple different paradigms to examine its boundaries. This led to the finding in Study 6 that social regulation can be induced even in the absence of social presence. We also attempted to induce social regulation as measured by electrocortical responses in Study 5, but were unsuccessful in doing so. This failure in and of itself was interesting as it suggests that social regulation may be more relevant for acute stressors of a larger magnitude, rather than the prolonged periods of mild stress that are more readily measured using ERP.

The Importance of Individual Differences

Across several studies (3, 5 & 6), we manipulated participants' access to social resources via the presence or absence of a partner, and yet we observed no main effect of condition where the mere presence of partner was sufficient in attenuating negative emotions. Instead, where we found our effects was in moderation by individual differences. While some classic work on the social-buffering of stress finds main effects for social presence, this is inconsistent across samples[146]. Some of the more robust findings of social presence in the buffering of stress come from comparative studies of laboratory animals[147]; unlike animals, humans may experience social evaluative threat in stressful situations where another person is present. This was beautifully illustrated in a study where women performed an anxiety-inducing mental arithmetic task with no audience, in the presence of a friend, or in the presence of their dog. Compared with having no audience, one's canine companion reduced the autonomic activity associated with performing mental arithmetic. By contrast, the presence of a human companion only served to hamper performance and magnify one's stress response, given that they were now vulnerable to social evaluation[148].

Another reason we did not find a main effect of condition may be our lack of selection effects. Researchers will often pre-select participant dyads with extremely high quality relationships, diminishing the likelihood of moderation by individual differences[15]. By contrast, our dyads varied wildly in their level of familiarity and closeness: a large number had known each other for mere months, while others had been best friends for over a decade. Furthermore, the mother manipulation from Study 6 showed a fair amount of variability in ratings of emotional support, which facilitates the emergence of individual differences like those we observed across multiple studies.

Attachment. Based on our understanding of how people with avoidant attachment styles relate to others, it was perhaps not surprising that attachment was found to be an important predictor of people's ability to socially regulate their emotions. Also consistent with past research linking oxytocin to attachment processes, we found that genetic differences in the oxytocinergic system are important contributors to attachment styles. We saw that oxytocin also impacts social regulation directly. While we did not find a direct relationship between attachment and social regulation ability as measured by the handholding fMRI task in Studies 2 and 4, we have found this relationship using our self-report measure in Studies 1, 5, and 6. While it could be inferred from these data that attachment may only predict people's perceptions of social regulation use and not their actual measured ability, a recent neuroimaging study casts doubt on this assumption: Xie and colleagues[132] used a social regulation paradigm where a therapist interacted participants while they viewed aversive images inside an MRI scanner. They found that participants' attachment security positively predicted their social regulation ability. While they did not differentiate between insecure attachment styles, which prevents us from knowing whether anxious or avoidant attachment was more deleterious to social regulation, two additional studies examining the social modulation of pain shed light on this issue. It was found that highly avoidantly attached individuals showed increased levels of pain[149] and increased neural response (consistent with increased pain[150]) in the presence of another person, compared to when they were alone. These data point toward avoidantly attached individuals eschewing the social regulation of emotion. Based on the findings from our ERP study, and consistent with past work[39], it seems that avoidantly attached individuals instead use expressive suppression to regulate their emotional responses. Furthermore, both avoidant attachment and expressive suppression were inversely related to self-reported social regulation, which suggests that not only are they not using social regulation, they are choosing suppression instead of social regulation – this was supported by our follow-up survey in which these participants endorsed the item "*I didn't know how to 'make use of my partner's support', so I just suppressed an emotional response to the images as best I could*." The use of suppression in the avoidantly attached may help to explain their patterns of poor mental and physical health, observed here and consistently in the literature[151]. These findings converge to illustrate how vulnerable and warranting of further study are the avoidantly attached.

Limitations and Future Directions

Positive emotions. The spectrum of emotion is broad. And while both positive and negative affect contribute individually to health and well-being[152,153], our investigations are limited to negative emotions underlying the experience of stress. The experimental paradigms that we have used in this work are not designed to assess positive emotions, nor can they be easily modified to do so. However, there exists an entire field of research on the social transmission of positive emotions, which is known as capitalization[154]. When a person discloses a positive event (such as a job promotion) with a close other, they will “capitalize” or benefit from the other’s reaction insofar that it is positive: a positive reaction will upregulate their own positive emotions. Thus, capitalization can be thought of as a form of emotion regulation specifically concerning positive emotions. Much like the research described herein, capitalization is associated with social support[155], closeness of relationships[156], and health and well-being[156,157]. Importantly, capitalization is also affected by attachment process; avoidantly attached individuals are less likely to respond positively to their disclosing partners, and also to underestimate the positivity of their partner when they themselves are disclosing, thus hindering the process of capitalization[158,159]. Given these parallels, it is likely that capitalization and the social regulation of positive emotions are conceptually similar, if not identical. While capitalization processes are outside of the scope of the current work, in the future it would be theoretically beneficial to better define the relationship between these concepts.

Culture. Another theoretical issue that begs consideration is culture. Much of the current research and the supporting literature has been conducted on WEIRD samples (Western, Educated, and from Industrialized, Rich, and Democratic countries) yet psychological processes are often profoundly affected by one’s cultural milieu. For instance, it has been well-documented that East-Asians interface differently with social support than Westerners: they solicit social support to a lesser degree[160,161], and are less likely to emotionally benefit from support that is provided[162], likely due to concerns about burdening the support provider[163]. Cultural differences exist also in the expression[164] and regulation of emotion[165]. These factors may also interact to differentially influence health: while expressive suppression is deleterious to health in Westerners, in East-Asians it may be salubrious[166]. Thus, until additional work addressing cultural differences in social regulation is conducted, we caution the overgeneralization of our results to other (in particular East-Asian) cultures.

Significance

One final consideration of this body of work is its broader utility. In addition to the theoretical contributions of the work, I believe that our main health-relevant finding – that social regulation is health promotional and may explain the connection between social support and health – has major translational potential. This seems especially promising in light of recent research by Johnson and colleagues[19] who demonstrated that social regulation ability could be improved through intervention. In this study, participants in romantic relationships of varying qualities were assessed for social regulation ability using the handholding fMRI paradigm. Then, couples were led through a therapeutic intervention (a form of partnered therapy focused on strengthening attachment bonds between the couples), and were assessed again via fMRI. They found that the effectiveness of their intervention was dependent on individual differences: participants who were securely attached to their partners showed a significant effect of social regulation at Time 1, and their results did not change at Time 2. However, participants who were insecurely attached to their partners at Time 1 did not show social regulation; in fact, their neural threat response was higher when holding the hand of their romantic partner. After the therapeutic intervention, which significantly improved their romantic attachment, these participants showed a dramatic reversal in social regulation ability and now showed a major attenuation of threat while holding the hand of their partner. These encouraging results constitute the first evidence that social regulation ability can be ameliorated, and thus represent a potential mechanism for improving health. Developing interventions which target poor social regulators would be a fruitful first step in translating this research to enhance human health and well-being.

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APPENDIX A

Social Emotion Regulation Assessment from Study 1

The four scenarios included, 1. “Imagine that you heard you did poorly on an important exam that you had put a lot of time and effort into studying for. This hits you pretty hard and you are fairly upset.”; 2.” Think of someone you know and actively dislike because they are selfish or immoral person. Now imagine finding out that this person has just won an incredible amount of money through the lottery and is bragging about it over social media. This upsets you greatly.”; 3. “Imagine that you have just heard that an ex- (boyfriend/girlfriend, or someone that you had a crush on) is now dating a fashion model. They are obviously very attractive, and seem to have a successful and interesting jet-setting lifestyle. This hurts your ego and makes you feel crummy about yourself.”; and 4. “Imagine you realized that you left a very expensive textbook behind in a classroom, and it was missing when you returned for it. It was not turned into the lost and found or the campus police, and you have to come to terms with the fact that it's gone forever. You are greatly upset because you will have to figure out a way to replace it or to do without.”

The original analysis of these data compared participants’ preferences for social vs. non-social strategies (as described in my dissertation proposal). However, the results were similar; thus, for parsimony’s sake, only the questions probing participants’ attitudes for social strategies were included as the metric of social regulation.

How appealing do any of these options sound?

	Not very appealing	.	.	.	.	.	Very appealing
Calling/Texting/Emailing a close friend	○	○	○	○	○	○	○
Calling/Texting/Emailing one of your parents	○	○	○	○	○	○	○
Calling/Texting/Emailing your significant other (if applicable)	○	○	○	○	○	○	○
Posting about your feelings on social media	○	○	○	○	○	○	○
Making 1-on-1 plans with a friend where the issue will probably come up in conversation	○	○	○	○	○	○	○
Going to a casual get-together with friends	○	○	○	○	○	○	○
Going to a movie with friends	○	○	○	○	○	○	○
Going to a party/bar/club with friends	○	○	○	○	○	○	○
Spending time alone, distracting yourself from your feelings (watching TV, working out, etc)	○	○	○	○	○	○	○
Spending time alone, thinking about the issue, or trying to deal with your feelings	○	○	○	○	○	○	○
Spending time alone, where you are surrounded by people you don't know (e.g. coffee shop, cinema, public park)	○	○	○	○	○	○	○