# A Functional Magnetic Resonance Imaging Study of Cognitive Emotion Regulation in Relation to Individual Differences in Self-Esteem

by

Freda Zoë Swan

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| **Supervisor** | Dr Nynke Groenewold, Dep. of Psychiatry and Mental Health, University of Cape Town |
| **Co-Supervisors** | Dr Anne Uhlmann, Dep. of Child and Adolescent Psychiatry and Psychotherapy, Technische Universitaet Dresden |
| | Prof. Dan Stein, Dep. of Psychiatry and Mental Health, University of Cape Town |

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## Declaration

I, **Freda Swan**, hereby declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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## Abstract

### Objectives

Self-esteem may affect the processing and regulation of emotion. However, it is unclear whether differences in self-esteem are associated with changes in initial emotional appraisal or engagement of emotion regulation. I investigated whether individual differences in self-esteem predicted brain responses to negative emotional stimuli: 1) when they were viewed without intentional regulation; and 2) during downregulation using cognitive reappraisal. Thirdly, I investigated whether self-esteem predicted reappraisal success.

### Method

Twenty-nine healthy adults (age $M$=47, $SD$=15; 16 female) performed a cognitive reappraisal emotion regulation task during fMRI scanning. Participants viewed and subsequently reappraised or attended to negative and neutral images. Trait self-esteem (Rosenberg Self-Esteem Scale) was included as a predictor in a whole-brain multiple regression analysis. Analyses were thresholded at $p$<.005, $k$>20, p<.05 family-wise error (FWE)-corrected at cluster-level. The anterior cingulate cortex (ACC; BA32) and the dorsal prefrontal cortex (PFC; BA6) were a priori regions of interest (ROI), since both have previously been reported in fMRI studies of self-esteem and cognitive reappraisal. A post-hoc ROI analysis tested the correspondence of self-esteem-related ACC activation with findings from a meta-analysis of emotion regulation. Ratings of negative emotional intensity following reappraisal trials were subtracted from ratings following attend-negative trials to index reappraisal success.

### Results

Self-esteem was associated with potentiated ACC ROI activation during viewing of negative, compared to neutral, images (MNI $x, y, z$ = -6, 17, 38, $k$=43, $p_{unc}$=.001 at peak, $p_{\text{FWE}}$=.368 at cluster-level). For reappraisal compared to attended negative images, self-esteem was

positively associated with activation in the left posterior insula (MNI *x, y, z* = -30, -10, 17, $k$=30, $p_{unc}$<.001 at peak, $p_{\mathrm{FWE}}$=.959 at cluster-level) and negatively associated with activation in the mid cingulate cortex (MNI *x, y, z* = 3, -34, 35, $k$=50, $p_{unc}$=.001 at peak, $p_{\mathrm{FWE}}$=.805 at cluster-level). However, only the post-hoc ACC ROI analysis was significant after multiple comparison correction (MNI *x, y, z* = -6, 23, 38, $k$=22, $p_{unc}$=.001 at peak, $p_{\mathrm{FWE}}$=.021 at cluster-level). For reappraisal, self-esteem was not related to activation in the ACC or dorsal PFC ROIs. Trait self-esteem did not correlate with reappraisal success, $r$ =.16, $p$ =.208.

**Conclusion**

Trait self-esteem may affect recruitment of the ACC during initial emotional appraisal. This may reflect successful automatic emotion regulation for high self-esteem, consistent with the demonstrated spatial overlap with a meta-analytic emotion regulation cluster. While self-esteem may affect brain responsivity during cognitive reappraisal, the observed trends must be interpreted carefully, since the findings do not survive correction for multiple comparisons, and emotional outcomes of applying reappraisal do not differ as a function of self-esteem. Taken together, these findings suggest that high trait self-esteem may be advantageous for rapid automatic emotion regulation, but not deliberate cognitive reappraisal.

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| | |
|---|---|
| ACC | Anterior cingulate cortex |
| BA | Brodmann Area |
| BDI-II | Beck Depression Inventory-II |
| BOLD | Blood-oxygenation-level-dependent |
| dACC | dorsal anterior cingulate cortex |
| DIP | Depression in the Picture |
| dlPFC | Dorsolateral prefrontal cortex |
| dmPFC | Dorsomedial prefrontal cortex |
| DSM | Diagnostic and Statistical Manual of Mental Disorders |
| fMRI | Functional magnetic resonance imaging |
| FOV | Field of view |
| FWE | Family-wise error |
| FWHM | Full-width half-maximum |
| IAPS | International Affective Picture System |
| IFG | Inferior frontal gyrus |
| *k* | Cluster size |
| mini-SCAN | Mini Schedules for Clinical Assessment in Neuropsychiatry |
| MNI | Montreal Neurological Institute |
| MRI | Magnetic resonance imaging |
| MTG | Middle temporal gyrus |
| PANAS | Positive and Negative Affect Schedule |
| PFC | Prefrontal cortex |
| ROI | Region of interest |
| RSES | Rosenberg Self-Esteem Scale |
| SMA | Supplementary motor area |
| SPM12 | Statistical Parametric Mapping 12 |
| TE | Echo time |
| TR | Repetition time |
| vlPFC | Ventrolateral prefrontal cortex |

A functional magnetic resonance imaging (fMRI) study of cognitive emotion regulation in relation to individual differences in self-esteem

## Introduction

Psychological health entails positive self-regard and adaptive emotional responses that are context-appropriate in order to facilitate effectively managing the demands of social life. Part of what this entails is the ability to regulate one's emotions. Emotion regulation is the conscious or unconscious modulation of emotions in order to alter their features, such as type, intensity, valence, or duration (Etkin, Büchel, & Gross, 2015; Gross, 2015; Morawetz, Bode, Derntl, & Heekeren, 2017; Ochsner, Silvers, & Buhle, 2012). Also entailed in psychological well-being is a healthy level of self-esteem; that is, an affective sense of self-worth (Blascovich & Tomaka, 1991). In contrast to a picture of health, disruptions in emotion processing, regulation, and self-esteem, feature in many psychiatric disorders and contribute to the burden of disease and disability around the world, and potentially also contribute to a range of social problems. In 2017, mental disorders one of the leading cause of disability globally (Institute for Health Metrics and Evaluation, 2017; S. L. James et al., 2018)

Much research has focused on the negative consequences of low self-esteem and painted high self-esteem as an innately positive attribute. Low self-esteem is a primary feature affective disorders such as anxiety (Farmer & Kashdan, 2013) and depression (Orth & Robins, 2013) and may increase the risk of developing depression later in life (Sowislo & Orth, 2013). Low self-esteem also accompanies a range of other disorders from developmental coordination disorder to body dysmorphic disorder and anorexia nervosa (American Psychiatric Association, 2013). However, inflated self-esteem or delusions of grandiosity are characteristic of psychiatric illness, such as in bipolar and related disorders (American Psychiatric Association, 2013). Nevertheless, the inflated levels of self-esteem associated with psychiatric morbidity are not equivalent to healthy high self-esteem. Pathologically high self-esteem can be distinguished from healthy self-esteem as it is ungrounded in an individual's actual skills or experience, and thus represents a departure from reality (American Psychiatric Association, 2013). In this sense, pathologically inflated self-esteem may not be considered "true" high self-esteem.

Notably, self-esteem is associated with an individual's ability to function in a social context. Self-esteem and social relationships have a strong reciprocal relationship (Harris & Orth, 2019) and an individual's perceived failure to perform to a societally expected standard, or social ostracism by peers, may contribute to low self-esteem. For example, low self-esteem frequently accompanies enuresis (repeated urination in inappropriate places, such as in bed or into clothing), and depression, which often results in failure to function "as normal" (American Psychiatric Association, 2013). Beyond mental illness, low self-esteem is associated with social and behavioural problems, such as delinquency, aggression (Donnellan, Trzesniewski, Robins, Moffitt, & Caspi, 2005; Garofalo, Holden, Zeigler-Hill, & Velotti, 2016) and increased risk-taking behaviour in adolescents (Wild, Flisher, Bhana, & Lombard, 2004). In contrast, high self-esteem is associated with academic success amongst students (Richardson, Abraham, & Bond, 2012) and is associated with better quality of life even in the face of chronic physical illness (Mikula et al., 2016; Platten, Newman, & Quayle, 2013). These findings underscore the close-knit relationship between self-esteem and social functioning – including the effect of an individual's perceived social standing on his or her self-esteem.

Expressing and responding to emotions (of both oneself and others) is a core part of many social interactions. Understandably, then, self-esteem is associated with individuals' characteristic patterns of affective experience. Individuals with low self-esteem tend to experience more intense, prolonged, negative emotions (Benetti & Kambouropoulos, 2006; Houben, Van Den Noortgate, & Kuppens, 2015; Kuppens & Verduyn, 2015; Liu, Wang, Zhou,

& Li, 2014). While individuals with lower levels of self-esteem experience drops in state self-esteem in response to negative feedback, individuals with high trait self-esteem are not subject to the same reduction in self-esteem (Hoefler, Athenstaedt, Corcoran, Ebner, & Ischebeck, 2015). How individuals respond to emotional threats such as negative feedback on an intelligence test, or negative social feedback may differ as a factor of trait self-esteem, and may also have an impact on state self-esteem, and this is reflected at the level of the brain, as observed in functional neuroimaging research (Eisenberger, Inagaki, Muscatell, Byrne Haltom, & Leary, 2011; Hoefler et al., 2015). Self-esteem may therefore influence how an individual copes in response to negative emotional challenges in daily life, and one way in which it does so may be through emotion regulation (Garofalo et al., 2016; Shafir, Guarino, Lee, & Sheppes, 2016; Wood, Heimpel, Manwell, & Whittington, 2009).

Emotion regulation encompasses any conscious or non-conscious attempt to modulate emotional experience (Etkin et al., 2015). The process through which emotions arise has been conceptualised as an attention-appraisal-response cycle in which attention is captured by a salient feature of the environment, which is subsequently appraised, generating an emotional response (Gross, 1998b, 2015). Each step in the cycle provides an opportunity to regulate emotion generation. However, whilst there are many possible emotion regulation strategies, one of the most effective is cognitive reappraisal (Buhle et al., 2014; Morawetz et al., 2017; Webb, Miles, & Sheeran, 2012). This strategy involves revisiting the appraisal stage and reinterpreting the meaning of an emotion evoking stimulus in such a way as to alter its emotional impact. Variation in emotional outcomes associated with individual differences in self-esteem may reflect differences in initial emotional reactivity, or subsequent emotion regulation. These differences may be associated with different patterns of neural recruitment. However, to the best of my knowledge, this has not been directly examined in a neuroimaging study to-date.

With the advance in technology of non-invasive in-vivo neuroimaging techniques such as fMRI, pursuing this line of research is more do-able than ever before. In contrast to bygone decades in which neuroscience relied primarily on lesion studies for mapping brain function to anatomy, fMRI can be used to visualise differences in how the brain functions during a certain task even when the behaviour occurs in a healthy individual. Taken together with behavioural indicators of links between self-esteem, emotion processing, and emotion regulation, previous fMRI studies illustrating differences in brain responsivity to negative socio-emotional cues pave the way for the current research. In this dissertation, I examine the neural correlates of self-esteem during emotion processing and emotion regulation in healthy individuals.

This dissertation is constituted by four subsequent chapters. First, in the following chapter, I review relevant existing literature on emotional appraisal, emotion regulation, and self-esteem, including their functional neural correlates. I suggest that appraisal taking is core to the process of emotion generation. Drawing on both psychological theory and neurobiological models, I outline some of the dominant perspectives in the field of emotion regulation, and then focus on the cognitive reappraisal emotion regulation technique. For self-esteem, I discuss both state- and trait-perspectives on self-esteem, and review the available fMRI literature on self-esteem with a focus on emotional reactivity. I conclude by summarising key findings and outlining the objectives and hypotheses of the current work.

Second, I discuss the methods used in the current study. Notably, the current study is a secondary data analysis of behavioural and functional neuroimaging data originally collected in the Netherlands. I summarise characteristics of the participants, and recruitment and study procedures. For those unfamiliar with fMRI, I include an information box on understanding what aspect of physiology is being measured in task-fMRI research, and how the resultant data is typically analysed. In addition to an overview of the behavioural measures that were used, I provide information on how neuroimaging data were acquired, and the particular fMRI emotion regulation task employed. After outlining my fMRI and behavioural data analyses, I proceed to the third chapter, in which I present the results of my analyses. Supporting the text report of my results, I supply tables with additional detail (such as cluster co-ordinates) and a figure to assist in visualising a key finding.

In the final chapter, I discuss my results and situate my findings in the context of the literature I reviewed. I discuss self-esteem in healthy individuals in relation to neural correlates of emotional appraisal and emotion regulation (cognitive reappraisal), and in relation to behavioural findings for negative emotional reactivity. I also discuss how the fMRI emotion regulation task-related finding correspond to previous emotion regulation studies and meta-analyses, noting similarities and possible explanations for differences I observe. This leads me into my discussion of the strengths and weaknesses of the current study, and recommendations for future research.

# 1. Literature Review

## 1.1 Emotional appraisal

### *1.1.1 A working definition of emotion*

Emotions comprise a large part of our subjective experiences on a day-to-day basis (barring certain illness or injury). Sometimes the emotions are pleasant – like happiness or excitement – yet at other times we experience unpleasant or painful emotions, like anger or sadness. Despite our intimate familiarity with the subjective experience of emotions, and numerous attempts to define it (Adolphs, 2010; Cabanac, 2002; Damasio, 1998; Ekman, 1992; W. James, 1884), there is no consensus within the scientific literature on an exact definition of emotion. While some have proposed that our subjective experience of emotion is constituted by our perception of our physiological responses to stimuli (Damasio, 1996, 1998; W. James, 1884), others have proposed that emotions are a set of discrete phenomena that can be studied cross-species through observable behaviour, such as facial expressions (Ekman, 1992). In the face of the plethora of possible approaches to defining emotion, insight can be gleaned by posing a further question: what is the function of emotion? An answer is suggested by looking at situations in which emotions arise. In particular, emotions arise in response to situations that are relevant to an individual's goals (Frijda, 1988; Smith & Lazarus, 1990). From an evolutionary perspective, the most basic goal is survival. Emotions serve this goal by guiding an individual's responses to the environment. Situations that are relevant to survival or other, more complex goals can be internal (e.g. a thought about giving a public presentation) or external (e.g. being approached by a menacing stranger). In the face of a goal-relevant situation, the felt subjective experience of an emotion is accompanied by associated behavioural tendencies, such as the urge to cry or smile, and cognitive and physiological changes (e.g. Mauss, Levenson, Mccarter, Wilhelm, & Gross, 2005; Scherer & Moors, 2019). Physiological changes include autonomic responses such as raised heart rate and changes in skin conductivity

(Craig, 2002; Mauss et al., 2005) while cognitive responses typically include an evaluation of the stimulus, such as whether it presents a threat or whether it furthers or impedes an individual's goals (e.g. receiving a teaching award may increase the chances of a promotion) (Moors, 2017; Scherer & Moors, 2019). Cognitive responses may consist of both rapid non-conscious processes and explicit conscious thought content (Dolcos et al., 2011; Scherer, 2009). The observation of the multiple changes that occur in the body and mind in response to emotion-evoking stimuli have given rise to the so-called "componential" account of emotion (Moors, 2017), that explores salient features of emotion, such as its intensity, valence, and duration.

A componential account of emotion allows us to unite what may appear as disparate branches within research on emotion. Within emotional appraisal theory (of the type championed by Frijda, Scherer, Lazarus, Moors etc), adopting a componential approach to emotion can account for changes in physiology, cognition, and behaviour that accompany the subjective experience of emotion. Simply put, each of the components that constitute emotional experience are set in motion by an emotionally evocative stimulus, and are united to form emotion via a rapid, automatic appraisal (Moors, 2013). Some characteristics of a situation that may be important to its emotional outcome, and thus constitute appraisal criteria, include novelty, goal congruence, agency, theory of mind, social norms, exteroceptive sensation, episodic memory and imaginary future events, and self-related information (Brosch & Sander, 2013; Dixon, Thiruchselvam, Todd, & Christoff, 2017; Sander, Grandjean, & Scherer, 2018). In the context of emotion, appraisal is a process by which an input (emotional stimulus) is evaluated against appraisal criteria, which results in an output (emotion) (Moors, 2010, 2013). The type of emotion produced is determined by the values assigned to relevant appraisal criteria. Consider being cornered in a dark alleyway by a stranger with a weapon drawn. This situation might be evaluated as novel, goal-incongruent, out of one's control (low agency), and involves the perception that another individual wishes one harm (theory of mind). As a result, it is likely to produce a negative emotion such as fear. Although the bulk of the representation of appraisal values is non-conscious, it is their partial reflection into conscious awareness that gives rise to the subjective feeling of an emotion (Scherer, 2009).

Evidently, while emotional appraisal is a core element of emotion generation, it is part of an on-going interactive process between an individual and his or her environment. This is notion is captured in the "modal model" of emotion generation (Barrett, Ochsner, & Gross, 2007; Gross, 1998b, 2014, 2015), in which emotional appraisal occurs as a step in a situation-attention-appraisal-response cycle. In other words, emotional appraisal can only occur after information about an individual's situation (external and internal) has been gathered and filtered through attention. After emotional appraisal of the incoming information has occurred, an emotional response is generated. The emotional response then feeds back into the individual's situation, and the process repeats with the influx of information about the changed situation.

Emotion should also be distinguished from similar feeling states: mood and affect. In line with previous work (e.g. Etkin et al., 2015; Gross, 2015) I view emotions as a type of affect. Affect, and by extension emotion, entails a rapid, binary value judgement of "this is good for me" or "this is bad for me" (Scherer, 1984 as cited in Gross, 2015). At the simplest level, this "judgement" is encapsulated by the hedonic valence of the emotion i.e. whether it is pleasant or unpleasant. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013, p.817) affect is analogous to "fluctuating changes in emotional 'weather'", in contrast to mood which is a "pervasive and sustained emotional 'climate'". To summarise, emotions carry information about whether a stimulus advances or inhibits an individual's goals (including basic survival), and this encapsulates the "valence" component of emotion. However, valence is but one component of emotion. In contrast to mood, emotions may be shorter in duration and occur in response to specific goal-relevant environmental triggers, be they internal or external.

### *1.1.2 Neural systems of emotional appraisal*

Traditional accounts of the neural bases of emotion ascribe this function to the "limbic system" – a network of brain regions including the cingulate and parahippocampal gyri, hippocampal formation, amygdala, septal area and hypothalamus (Nakano, 1998; Papez, 1937; Rajmohan & Mohandas, 2007; Sadock & Sadock, 2000). However, controversy surrounds the limbic system: there is still contemporary debate regarding which regions should be included in the limbic system, and whether all of the original limbic regions are neural substrates of emotion per se, or in fact primarily serve other functions. For example, the hippocampus is now known to play an important role in memory and recent work (Rolls, 2013, 2017) suggests separable limbic *systems* involved in emotion and memory, co-activated only insofar as both processes are engaged – for example, in an emotional episodic memory.

While early studies relied on brain lesions to reveal functions associated with anatomical regions, advances in technology now support functional neuroimaging methods that allow non-invasive exploration of function-anatomy correspondence in vivo. Modern accounts of emotion generative brain regions – based on composites/summaries of years of fMRI research in the form of meta-analyses – continue to highlight the amygdala, and less consistently, the portions of the cingulate cortex (Etkin et al., 2015; Ochsner et al., 2012; Phillips, Ladouceur, & Drevets, 2008). Other regions consistently highlighted include the insula and ventral striatum. Within the modern framework, the amygdala and the ventral striatum encode the affective value of a stimulus, which is then integrated with input from other brain regions in the ventromedial portion of the prefrontal cortex (PFC) to determine a contextually appropriate response to the stimulus (Ochsner et al., 2012). This framework suggests that emotion processing in the brain concurs with componential emotional appraisal theory: different aspects of incoming perceptual information are processed individually and then integrated to produce an emotional response.

Appraisal is core to the emotion generation process. Unsurprisingly many regions described above form part of a network of brain regions responsible for emotional appraisal taking. This appraisal network drives synchronised change within other emotion-related brain networks linked to emotional response (e.g. expression, action tendency, feeling, autonomic reaction)(Sander et al., 2018). Regions within the appraisal network form several sub-networks encapsulating different appraisal criteria (Brosch & Sander, 2013). Some characteristics of a situation that may be important to its emotional outcome, and thus constitute appraisal criteria, include novelty, goal congruence, agency, theory of mind, social norms, exteroceptive sensation, episodic memory and imaginary future events, and self-related information (Brosch & Sander, 2013; Dixon et al., 2017; Sander et al., 2018). The following is a broad mapping of these appraisal criteria onto their neural substrates: novelty is linked to medial temporal regions; concern relevance with amygdala; goal congruence with anterior cingulate cortex (ACC) and dorsolateral PFC (dlPFC; Brosch & Sander, 2013), regions also suggested to process viscero-motor and viscero-sensory signals, actions, and emotional states and regulatory strategies (Dixon et al., 2017); agency with tempero-parietal junction, precuneus, dorsomedial PFC (dmPFC), pre-supplementary motor area (pre-SMA), insula, and motor-specific regions; the dmPFC also contributes to theory of mind: understanding the mental states of others – as an appraisal input (Dixon et al., 2017). Social norms are represented by superior temporal pole, the medial PFC, the amygdala, the dorsal striatum, and the dlPFC (Brosch & Sander, 2013) and lateral orbitofrontal regions are linked to exteroceptive sensation; medial orbitofrontal cortex to episodic memory and imagined future events; and finally, the rostromedial PFC to self-related information (Dixon et al., 2017). It has been suggested that the primary role of the PFC in emotion is appraisal-taking and that different subregions of the PFC specialise in processing different inputs like exteroceptive perception, interoception, and representing the mental states of others (Dixon et al., 2017). Evidently, multiple regions across the brain, both cortical and subcortical, are involved in emotional appraisal.

## 1.2 Emotion regulation

### *1.2.1 Emotion regulation: An introduction*

Emotion regulation encompasses any conscious or non-conscious attempt to modulate emotion, including the type, intensity, or duration of emotional experience (Etkin et al., 2015; Gross, 2015; Morawetz et al., 2017; Ochsner et al., 2012). Above and beyond alerting us to situations that pose immediate physical danger, emotions can guide social responses – and this too is important for survival, given the social nature of human beings. Adaptiveness of an emotion depends on the context: if appropriate within a particular context, then it is adaptive, else it can be maladaptive and bear costs such as social acceptance, ability to achieve goals, survive and so forth (Gross & Jazaieri, 2014). The ability to regulate the intensity, frequency, duration, and type of emotion one experiences is an important part of ensuring that one’s emotional experiences support one’s goals in a given situation rather than hindering them. Unfortunately, examples of emotions that are too intense in a given situation, or of the inappropriate type or duration, are only too frequent, and are central to many psychiatric illnesses (American Psychiatric Association, 2013).

There are numerous ways in which the regulation of emotion may be attempted. One way of differentiating emotion regulation strategies relies on the fact that there are multiple points during the generation of emotion at which an attempt to regulate emotion can be made. Recalling the modal model of emotion generation, intervention at any step in the situation-attention-appraisal-response cycle may result in a different emotional outcome, and thus represents an opportunity for emotion regulation (Gross, 1998b, 2014, 2015). For example, emotion regulatory choices can be made via choosing one situation over another (situation selection), by choosing to attend to one feature of the situation over others (attentional deployment), by reframing the emotional meaning of the feature attended to (cognitive change), or by attempting to alter the emotional response once it has been generated (response modulation). Grounded as it is in the emotion generation process, this emotion regulation classification system is termed the process model of emotion regulation (Gross, 1998b, 1998a). Conceptualising attention, appraisals, and responses as possible targets for emotion regulation is consistent with other classifications of emotion regulation strategies (e.g. Koole, 2009). Within these categories, three of the most commonly studied emotion regulation strategies are distraction (e.g. directing one's attention away from an unpleasant task), cognitive reappraisal (adjusting one's appraisal of a situation such that its emotional meaning is altered), and suppression (e.g. controlling bodily expression of emotion such as frowning) (Morawetz et al., 2017; Webb et al., 2012). These theoretical models of emotion regulation inform and are informed by developments in the field of affective neuroscience.

### *1.2.2 Dominant neurobiological models of emotion regulation*

As the field of neuroscience and its research methods (e.g. neuroimaging) have advanced, interaction between psychological and neuroscientific perspectives has enhanced our understanding of emotion regulation. In particular, there has been significant interest in the cognitive control of emotion in recent decades (e.g. Etkin et al., 2015; Mcrae, Jacobs, Ray, John, & Gross, 2012; Ochsner & Gross, 2005). Broadly, it has been hypothesised that cognitive regulation of emotion would parallel cognitive control over other processes such as attention and memory in terms of its neural mechanisms. This hypothesis has largely been supported (Ochsner, Bunge, Gross, & Gabrieli, 2002). Prominent meta-analyses and reviews of emotion regulation (e.g. Etkin et al., 2015; Morawetz et al., 2017; Ochsner et al., 2012; Phillips et al., 2008) have consistently highlighted activation in the dorsal PFC (lateral and medial) and dorsal

ACC regions of the prefrontal/cingulate control systems during emotion regulation in contrast to control conditions. Activation in the above-mentioned cognitive control regions has a modulatory effect on the more posterior, ventral, and subcortical regions involved in generating emotional experience, such as the amygdala, insula, and ventral striatum (Etkin et al., 2015; Ochsner et al., 2012; Phillips et al., 2008). On some accounts, ventral regions of the PFC, such as the orbito-frontal cortex, mediate dorsal PFC activation in response to bottom-up emotional reactivity (Phillips et al., 2008). While the ACC is no doubt implicated in conscious emotion regulation strategies that rely on cognitive control, it has also been implicated in involuntary, automatic emotion regulation (Phillips et al., 2008).

Although there are significant commonalities across neurobiological models of emotion regulation, not all models agree on which brain regions are involved in the regulation of emotion, and what the role of each region is. For example, while the dorsal ACC (dACC) has been assigned a primary emotion regulatory role (Ochsner et al., 2012) - whether that regulation is conscious or non-conscious (Phillips et al., 2008) - others have located the dACC amongst regions underlying emotional reactivity (Etkin et al., 2015). In support of their grouping, Etkin et al. (2015) refer to work on conditioned fear responses, in which the dACC is active alongside other emotion generative regions. In the emotional appraisal literature, the ACC has been linked to appraisals of goal-congruence: specifically whether a given situation takes the individual closer to or further from their active goal (Brosch & Sander, 2013). It is also involved in monitoring actions and their associated costs in a particular context with relevance to an individual's active goal (Brosch & Sander, 2013; Dixon et al., 2017). Therefore, while the outcome of these appraisals may feed into the outcome of the emotion generation process (e.g. fear), the dACC may play a similar role during emotion regulation. For example, it may monitor the costs of emotion regulatory actions, and whether an individual's attempts to regulate their emotions are succeeding or must be adjusted. This is consistent with Ochsner et al.'s (2012) interpretation of the ACC's role in emotion regulation. It is therefore possible that the dACC contributes to both emotion generation and regulation through its role in appraisals of goal-relevance and the cost of action.

Further nuances regarding the neural substrates of emotion regulation become evident when different emotion regulatory goals and strategies are compared. For example, the modulatory effect of the PFC on emotion generative regions has been shown to vary, depending on whether the goal of regulation is to upregulate (i.e. increase) or downregulate (i.e. decrease) emotion. Regardless of the valence of the targeted emotion, up-regulation of emotion appears to be associated with increased activation in emotion generative regions such as the ventral striatum, in addition to prefrontal regions (e.g. inferior frontal gyrus [IFG]), while down-regulation of emotion seems to be associated with stronger involvement of regions involved in cognitive control, such as the dlPFC (Morawetz et al., 2017). This suggests that although both up- and downregulation may draw on an individual's cognitive resources, downregulating emotion may draw more strongly on cognitive control processes to dampen bottom-up emotional arousal.

Different emotion regulation categories may rely on overlapping but distinct neural networks. There is some evidence for a core subset of regions, including left IFG/ventrolateral PFC (vlPFC), the left pre-supplementary motor area, and the insula, bilaterally, that are recruited across a variety of emotion regulation strategies (Morawetz et al., 2017). These regions may support psychological functions that are common across strategies, such as inner speech generation, semantic meaning processing, representation of bodily states, and preparation for appropriate behavioural responses (Morawetz et al., 2017). This conclusion is drawn from a conjunction analysis of meta-analytic contrasts cognitive reappraisal>control and other strategies>control. Morawetz et al. (2017) performed sub-analyses for other emotion regulation strategies, which included studies using either attention-focused or response-focused techniques such as distraction and suppression respectively. Attention-focused strategies recruited the anterior insula and the left pre-SMA which have been associated with interoception (Craig, 2002) and control of attention (Cieslik, Mueller, Eickhoff, Langner, & Eickhoff, 2015; Trautwein, Singer, & Kanske, 2016) and volitional action (Nachev, Kennard, & Husain, 2008) respectively. Response-focused strategies recruited the right inferior parietal lobule which is involved in perception of emotional body language (Engelen, de Graaf, Sack, & de Gelder, 2015) and the left IFG/vlPFC, associated with inhibition of responses to emotional cues (Schulz et al., 2009). However, when other emotion regulation strategies are broken down into their constituent emotion regulation categories, it seems that attention-focused strategies and response-focused strategies do not have regions in common with each other, yet each have something in common with cognitive reappraisal. This is interesting in the context of the process model of emotion regulation, since reappraisal would fall between attention-focused and response-focused strategies on a timeline. This could suggest that emotion regulation at different points in the process model of emotion regulation may recruit similar regions to temporal neighbours. Cognitive reappraisal is a prime example of an appraisal or knowledge-related strategy, the final category of emotion regulation techniques (Gross, 1998b; Koole, 2009; Morawetz et al., 2017; Ochsner et al., 2012), and will be discussed in depth below.

### *1.2.3 The emotion regulation technique "cognitive reappraisal"*

One of the most effective conscious emotion regulation strategies for downregulating negative emotion is cognitive reappraisal (Webb et al., 2012). This strategy involves a reinterpretation of the meaning of an emotion-evoking stimulus in such a way as to alter its emotional impact. Cognitive reappraisal is an emotion regulation technique that operates through *cognitive change* and takes place at the appraisal stage of Gross' (Gross, 1998b, 1998a) process model. Central to the idea of cognitive reappraisal as an emotion regulation technique is the idea that there is an initial emotional appraisal that occurs, since cognitive *reappraisal* is voluntarily repeating the appraisal process in a top-down manner. Cognitively engaging with any of the variables that contribute to initial emotional appraisal taking (e.g. agency or theory of mind) and changing its assigned value would result in a shift in the subsequent emotional response.

Cognitive reappraisal is perhaps the most well studied emotion regulation technique in the neuroimaging literature to-date. This has made it possible for several meta-analyses to examine its functional neural underpinnings (Buhle et al., 2014; Frank et al., 2014; Kohn et al., 2014; Messina, Bianco, Sambin, & Viviani, 2015; Morawetz et al., 2017). The patterns of neural activation observed for reappraisal also seem to be robust in relation to emotional stimuli used (Morawetz, Bode, Baudewig, Jacobs, & Heekeren, 2016; Morawetz et al., 2017). In healthy adults, reappraisal, compared to a control condition, activates regions across the frontal, temporal and parietal lobes. Frontal regions include bilaterally: the superior frontal gyrus / dlPFC, IFG/vlPFC, supplementary motor area (SMA) and pre-SMA (Frank et al., 2014; Kohn et al., 2014; Messina et al., 2015; Morawetz et al., 2017). Medial frontal regions, including the dmPFC and ACC, are also engaged (Buhle et al., 2014; Frank et al., 2014; Messina et al., 2015; Morawetz et al., 2017). Activation in the temporal lobe is left-lateralised and includes the superior and middle temporal gyri. Parietal regions include the angular gyri (Buhle et al., 2014; Frank et al., 2014; Kohn et al., 2014; Morawetz et al., 2017), and supramarginal gyri, bilaterally (Buhle et al., 2014; Morawetz et al., 2017).

As is evident from these meta-analytic findings, many of the regions involved in reappraisal are also part of the fronto-parietal cognitive control network or have been classified as semantic processing regions in the temporal cortex (Binder, Desai, Graves, & Conant, 2009; Patterson, Nestor, & Rogers, 2007). This has led some to propose that reappraisal is the top-down modulation of emotion generative regions by using cognitive control to alter semantic representations (Buhle et al., 2014; Morawetz et al., 2016). Within the cognitive control network, activation observed in the dlPFC may represent modulation of selective attention and working memory for manipulation of appraisals, vlPFC may be involved in selecting appropriate meanings for stimuli and inhibiting others, and the dmPFC may engage self-reflective processes, inference about the mental states of others and self-generated retrieval of relevant semantic information (Binder et al., 2009; Buhle et al., 2014; Molenberghs, Johnson, Henry, & Mattingley, 2016). Furthermore, activation in temporal regions of the semantic processing network may represent manipulation of semantic information in order to alter the appraisal or meaning if the emotion evoking stimulus (Buhle et al., 2014). Although findings are largely consistent across these meta-analyses, a more nuanced view on the neural underpinnings of cognitive reappraisal is possible by looking at factors that contribute to heterogeneity in findings.

Sub-strategies of reappraisal may constitute one source of heterogeneity. Although reappraisal as a whole reliably activates cognitive control and semantic regions, sub-strategies of reappraisal may have distinct neural profiles (Dörfel et al., 2014; Messina et al., 2015) and affect the emotional outcome of employing the strategy (Webb et al., 2012). A recent meta-analysis showed that sub-strategies of reappraisal rely differentially on semantic versus executive control regions located in temporal and frontal regions respectively (Messina et al., 2015). The sub-strategies in question were reappraisal via reinterpretation (i.e. reinterpreting the emotion-evoking situation), and reappraisal via perspective-taking, which involves distancing oneself from the emotion-evoking situation (e.g. viewing it as though one were a neutral on-looker) (Webb et al., 2012). While reappraisal via reinterpretation recruited both executive control regions and semantic processing regions, reappraisal via perspective-taking relied only on semantic regions (Messina et al., 2015). These findings suggest that the meaning we attach to emotional stimuli (i.e. their semantic associations) in a particular context may be central to using cognitive reappraisal to manipulate emotional outcomes. One area of life that may regularly evoke emotions is one's sense of social acceptance or rejection. How socio-emotional challenges are navigated may have implications for psychological well-being and one's sense of self-worth or self-esteem.

## 1.3 Self-esteem

### *1.3.1. Self-esteem: A brief introduction of the concept*

Self-esteem, or "the overall affective evaluation of one's own worth" (Blascovich & Tomaka, 1991, p.115), is fundamental to psychological well-being. It emerges as a function of the discrepancy between one's perception of oneself (or how one thinks one is perceived by others) and the standards one has set for oneself, which may be derived from others' implicit or explicit expectations of one (Higgins, 1987; Shavelson, Hubner, & Stanton, 1976). The smaller the discrepancy, the higher one's self-esteem (Higgins, 1987). Previous research has linked self-esteem to measures of psychological (mal)adjustment, such as life satisfaction, quality of life, and psychological distress across both clinical and non-clinical populations (e.g. Liu et al., 2014; Platten et al., 2013).

Historically, self-esteem has been viewed as an individual's own personal evaluation of his or her worth, the degree to which he or she possesses characteristics that are important to him or her (W. James, 1983). Notions of self-esteem that follow this school of thought are often referred to as "*intra*personal" theories of self-esteem. In contrast, other theorists, such as MacDonald, Saltzman, and Leary (2003), argue that such intrapersonal theories of self-esteem overlook the important role that the perceived values of others play in determining an individual's level of self-esteem. In other words, these theorists view self-esteem as *inter*personal. However, regardless of the source of an individual's desired or valued self (be it intra- or interpersonal), both intra- and interpersonal theories of self-esteem hold the discrepancy between the current, actual self, and the desired or valued version of the self as a fundamental to the process that gives rise to self-esteem. Indeed, MacDonald et al. (2003) found that the degree to which an individual believes that a particular trait, such as competence or physical attractiveness, is valued by his or her peers interacts with the degree that he or she reports possessing that trait to produce his or her self-esteem. Higgins (1987) argues that both one's own ideal self, and the self that reflects other's expectations of us, are important factors in influencing how we feel about ourselves. Therefore, both sources of an individual's standards for him or herself are relevant for exploring the sequalae of a discrepancy between the actual self versus the preferred self.

Interpersonal or social theories of self-esteem such as the "sociometer" theory propose that connection with others is key to survival for social species like humans, so perception of self as accepted and valued by others in one's community is an important indicator of one's chances of survival (Leary, Tambor, Terdal, & Downs, 1995). On this view, "state" self-esteem, or one's moment-to-moment sense of self-worth in a given context, acts as an immediate feedback loop to motivate behaviours that increase one's chances of acceptance in one's community (Leary et al., 1995). To this end, some have even gone as far as to suggest that "self-esteem" is not *self*-esteem at all, but rather "*social*-esteem" (Eisenberger et al., 2011, p. 3448). However, other researchers have viewed self-esteem as stable, personality-like trait.

A number of studies have examined self-esteem across the lifespan (for reviews, see Orth, Robins, & Orth, 2019; Robins & Trzesniewski, 2005). Findings from recent meta-analysis of longitudinal studies suggest that mean-level changes in self-esteem follow a typical developmental pattern across the lifespan, and that this pattern is unaffected by demographic variables such as gender, nationality, and ethnicity (Orth, Erol, & Luciano, 2018). In general, self-esteem appears to increase from childhood until approximately age 70, and then begin to decrease, although increases are interspersed with periods of stability in early adolescence and between ages 60-70 (Orth et al., 2018). Interestingly, self-esteem stability appears to follow a similar pattern. While self-esteem stability begins low in childhood, it increases in stability during adolescence and stabilises in adulthood before decreasing in old age (Kuster & Orth, 2013; Trzesniewski, Donnellan, & Robins, 2003). However, the overall rank-order correlations for self-esteem (Kuster & Orth, 2013; Trzesniewski et al., 2003) suggest stability on par with other personality measures, such as the Big Five (Specht, Egloff, & Schmukle, 2011). In other words, individuals tend to maintain their "rank" in comparison to their peers, such that an individual with high self-esteem in adolescence is likely to have high self-esteem compared to peers in old age. Thus, it seems that self-esteem can, indeed, be viewed as a personality-like trait.

At a trait-level, self-esteem may emerge as the cumulative result of past appraisals of one's self-worth based on perceived social evaluations (Cole, Jacquez, & Maschman, 2001; Gruenenfelder-Steiger, Harris, & Fend, 2016; Leary et al., 1995; Will, Rutledge, Moutoussis, & Dolan, 2017). This process could be understood by adopting a Bayesian-type neurobiological perspective (Moutoussis, Fearon, El-Deredy, Dolan, & Friston, 2014; Will et al., 2017). Put simply, individuals' (social) interactions with the world produce new evidence that affects the probability that their current beliefs about themselves are true. In support of this notion, Will et al. (2017) found that state self-esteem was impacted not only by the valence of the social evaluation received, but also by whether the evaluation was consistent with the participants' expectations – in other words, whether the new evidence supported their prior predictive model. Will et al. (2017) also found that the biggest decrease in state self-esteem occurred when participants expected positive feedback but received negative feedback, while another study found an association for lower self-esteem with negative emotions for unexpected negative feedback (van Schie, Chiu, Rombouts, Heiser, & Elzinga, 2018). One explanation for the greatest change in self-esteem occurring for unexpected negative feedback rather than any negative feedback is that the aim of brain-based Bayesian inference is to achieve predictability (Moutoussis et al., 2014). In other words, trait self-esteem may be the internal model that is the result of many instances of state self-esteem. This research suggests one possible pathway for the relationship between state and trait self-esteem, and highlights the importance of an individual's expectations in determining how the same objective event (receiving social feedback) may produce different emotional responses in different individuals.

### *1.3.2 Self-esteem in relation to emotional reactivity and its neural correlates*

Self-esteem has a significant effect on an individual's ability to enjoy life and cope adaptively when faced with challenges. Interestingly, self-esteem is predicted by one's natural tendency towards different patterns of emotional experience. Lower self-esteem is reported by individuals high in negative affect (Benetti & Kambouropoulos, 2006; Liu et al., 2014) and also by individuals high in emotional reactivity, as indexed by larger deviations from a personal baseline and the prolonged experience of a given affective state (Kuppens & Verduyn, 2015). It has been suggested that the relationship between emotional reactivity and self-esteem is most pronounced for negative affect (Houben et al., 2015). In other words, low self-esteem may be particularly associated with an inability to shift one's more intense and prolonged negative emotional experiences. There is indeed some evidence to suggest that self-esteem predicts emotion (dys)regulation (Garofalo et al., 2016; Wood et al., 2009).

An alternative suggestion is that poor emotion regulation capacity may lead to lower levels of self-esteem by rendering individuals less able to dismiss emotions arising from negative emotional challenges or social feedback. However, referring back to the modal model of emotion generation, an individual's beliefs about his or her self-worth may act as a filter for incoming stimuli at the level of appraisal. This is in line with previously cited work by Will et al. (2017) and van Schie et al. (2018). If an individual's self-worth is low, he or she may be more likely to interpret negative feedback as true or being personally directed at him or her.

Consistent with this suggestion, self-esteem may also affect whether an individual chooses to engage an emotion regulatory strategy and regulation strategy selection (Heimpel, Wood, Arshall, & Brown, 2002; Shafir et al., 2016; Wood et al., 2009). Specifically, individuals with low self-esteem may choose not to regulate their negative emotions, feeling that in some way, they “deserve” it (Heimpel et al., 2002; Wood et al., 2009). Therefore, while the ability to regulate emotion successfully may play some role in the degree to which one takes to heart negative social feedback (and as a result, one’s self-esteem), one’s self-esteem influences how one engages with the emotions that arise and whether or not one attempts to regulate them.

Several neuroimaging studies have investigated individual differences in self-esteem in association with reactivity to negative emotional cues or challenges. Two common paradigms used in fMRI literature on emotion and self-esteem are social rejection/exclusion paradigms (e.g. Eisenberger et al., 2011; Kashdan et al., 2014; Onoda et al., 2010; Somerville, Kelley, & Heatherton, 2010; van Schie et al., 2018; Will et al., 2017) and self-/other-referential processing paradigms (e.g. Frewen, Lundberg, Brimson-Théberge, & Théberge, 2013; Hoefler et al., 2015; Yang, Dedovic, Chen, & Zhang, 2012). A limited number of studies have combined self-/other-referential and social feedback paradigms (e.g. Jiang et al., 2018; Yang, Xu, Chen, Shi, & Han, 2016). These paradigms allow exploration of self-esteem through social evaluation by others and through self-evaluation respectively. Findings from studies on social rejection indicate that increased activation in the ACC (particularly the dorsal area; BA32 and BA24) in response to social rejection or exclusion is associated with decreases in moment-to-moment self-esteem (i.e. state self-esteem) (Eisenberger et al., 2011; Kashdan et al., 2014) and with exacerbated social pain for individuals with lower trait self-esteem (Onoda et al., 2010). This suggests that the ACC may be an important region for monitoring one’s social standing (through acceptance/rejection) and its affective consequences (social pain).

In addition to findings highlighting dorsal regions of the ACC, one study found that individuals with low self-esteem showed increased activation in ventral ACC regions (in the ventral part of BA32), and in the medial PFC in response to receiving positive versus negative social evaluative feedback (Somerville et al., 2010). However, such potentiated activation in the vACC and medial PFC in response to positive feedback was not observed for individuals with high self-esteem. Other studies also support an association between self-esteem and medial prefrontal regions. For example, poorer self-regard has been linked to increased activation in the ventral ACC and the ventromedial PFC during negative self-referential processing in contrast to negative other-referential processing (Frewen et al., 2013). During social exclusion, activation in the left premotor cortex (BA6) was potentiated for individuals with low trait self-esteem (compared to high trait self-esteem; Onoda et al., 2010). This is of interest, since endorsement of others' evaluations of one's goal-related/agentic traits is associated with activation in the supplementary motor area extending into the dACC (BA6 and BA32; Jiang et al., 2018). Therefore, for individuals with low trait self-esteem, increased activation in dorsal prefrontal regions (captured in BA6) might indicate greater endorsement of others' perceptions of themselves. In response to positive social feedback, endorsing others' positive opinions of one may be a mechanism to repair low self-esteem. In the context of social rejection, increased activation in dorsal prefrontal regions may reflect endorsement of a others' negative perceptions of oneself, inferred from experiencing social rejection.

Activation in the right premotor area and bilateral SMA (BA6) has also been positively correlated with state self-esteem in response to social feedback (Eisenberger et al., 2011). In this case, activation in BA6 may be tracking moment-to-moment changes in self-esteem. Self-esteem has also been linked to activation in the dlPFC. For example, trait self-esteem was negatively correlated with activation in the dlPFC (BA8 and BA9) during self-evaluation of one's goal-related/agentic traits (Jiang et al., 2018). Low self-esteem individuals were more self-critical, and self-criticism has been linked to activation in the dlPFC (Jiang et al., 2018; Longe et al., 2010). Given the known association of the dlPFC with emotion regulation (e.g. Etkin et al., 2015; Morawetz et al., 2017; Ochsner et al., 2012), this could suggest that people with low self-esteem expend greater effort to regulate negative emotions arising from self-critical thinking during self-evaluation of traits relating to personal agency (e.g. intelligence; Jiang et al., 2018). One study of particular interest examined attentional control capacity as a moderator of the neural correlates of low self-esteem (Gyurak et al., 2012). Individuals with low self-esteem and high attentional control reported less arousal and more acceptance appraisals in response to rejecting cues compared to low attentional control counterparts. This could be indicative of higher reappraisal capacity. Interestingly, the buffered negative emotional responses observed by Gyurak et al. (2012) were associated with increased activation in the rostral ACC in individuals with low self-esteem.

Neural correlates of self-esteem have also been studied in the context of self-/other-referential processing, with a focus on how self-esteem relates to self-evaluation. Some findings in this stream of literature concur with the negative correlation of self-esteem and activation in the dACC observed in social feedback paradigms. For example, when individuals evaluated items from the Cooper-Smith self-esteem inventory in relation to themselves (compared to others), higher activation in the dACC was associated with lower levels of trait self-esteem (Yang et al., 2012). However, other studies point toward a more complicated relationship between dACC activation and self-esteem when processing information about the self. For example, dACC activation during negative self-referential processing was attenuated following “self-threat”, in which participants were given  experimentally determined negative feedback on a challenging cognitive task (Hoefler et al., 2015). However, this attenuation of dACC activation was less pronounced for individuals with higher self-esteem. Informing interpretation of this finding, dACC activation also correlated with response latencies, which the authors take to reflect the accessibility of information about the self. Individuals with higher self-esteem responded faster during positive self-referential processing and slower during negative self-referential processing following self-threat. In other words, individuals with higher self-esteem may have accessed positive information about themselves more easily following self-threat, with the inverse true for negative information about themselves. Furthermore, unlike individuals with lower self-esteem, individuals with higher self-esteem did not experience a drop in state self-esteem following the task. Thus, in this case, it seems that dACC activation during self-referential processing after self-threat might represent a protective mechanism for preserving high self-esteem.

In the absence of self-threat, the relationship between reaction time and self-esteem during negative self-referential processing is reversed: individuals with lower self-esteem take longer to process negative information about themselves than individuals who regard themselves less negatively (Frewen & Lundberg, 2012; Frewen et al., 2013). However, in this case, taking a longer time to process this information is theorised to indicate processing the negative information about themselves more deeply, especially since it is accompanied by experienced higher negative affect during the task (Frewen & Lundberg, 2012). In support of this interpretation, individuals who experienced greater negative affect during negative self-referential processing compared to negative other-referential processing showed increased activation in the right amygdala, a region that is critically important for appraisal (Frewen et al., 2013). A possible interpretation for these divergent findings regarding reaction time could be that self-esteem orients an individual towards information consistent with his or her self-image. While individuals with high self-esteem view themselves positively and orient toward positive self-information, individuals with low self- esteem view themselves negatively and struggle to disengage from negative self-information.

While lower levels of self-esteem appear to paint a picture of vulnerability to negative emotional experience and greater reactivity to negative social evaluation, higher levels of self-esteem may be associated with a positivity bias. High self-esteem is linked to inflated positive emotions (or decreased negative emotion). and may bias cognitive judgements related to preserving self-esteem. For example, individuals with high self-esteem appear to overestimate the amount of positive social feedback they receive, whilst individuals with lower self-esteem can accurately estimate the proportion of positive to negative social feedback they receive (Somerville et al., 2010). Furthermore, high self-esteem has been associated with more positive affect during positive self-referential processing, and less negative affect during self-referential processing  overall (Frewen & Lundberg, 2012; Frewen et al., 2013). This suggests that higher self-esteem may not only be a buffer against negative emotion, but may also increase positive emotion, and may do so by subjectively enhancing the positive aspects of a given situation.

Of relevance to the current investigation, self-esteem and the ability to regulate emotion may be linked. From the preceding review of the literature it is evident that self-esteem and emotion regulation –  cognitive reappraisal in particular (Buhle et al., 2014; Etkin et al., 2015; Morawetz et al., 2017; Ochsner et al., 2012) –  have neural correlates in the ACC and dorsal regions of the PFC. It is also clear that self-esteem involves a regulatory process (Gyurak et al., 2012; Hoefler et al., 2015; Kashdan et al., 2014; Somerville et al., 2010), especially in the context of challenges to self-esteem, such as negative social feedback or rejection, or negative self-referential processing. However, it is not yet clear whether the activation differences observed as a function of self-esteem in the context of social rejection and negative self-referential processing relate to initial appraisal processes or to regulatory re-appraisal.

**1.4 Study objectives and hypotheses**

To summarise, self-esteem may impact emotional reactivity to negative emotional cues and, subsequently, the ability to regulate emotional responses. However, the neural correlates of these processes remain to be fully elucidated. Activation in cortical midline structures including the ACC (BA32) and dorsal regions of the PFC (BA6), appear to be associated with self-esteem irrespective of whether an individual is undergoing social evaluation by others, or is evaluating him- or herself. However, the negative emotional stimuli used in the literature examining the neural correlates of self-esteem to date are limited: it is not clear whether the findings from these studies can be extended to more general negative emotional challenges that are not directly related to the self or to one's social acceptance. To the best of my knowledge, trait self-esteem has not been examined as a predictor for brain responsivity during cognitive reappraisal of negative emotional cues to date. The aim of this study is therefore to extend the literature on the neural correlates of self-esteem by investigating whether individual differences in self-esteem predict brain responsivity to negative emotional stimuli, 1) when the stimuli are attended to without an intentional effort to regulate the emotions they evoke, and 2) when a conscious attempt is made to diminish negative emotional experiences using the cognitive reappraisal technique.

Based on the findings reviewed above, the following were hypothesized: 1) potentiated ACC activation may reflect increased emotional reactivity, given the literature noting potentiated ACC activation associated with social pain and increased reactivity to social rejection for individuals with low self-esteem, therefore individuals with higher levels of self-esteem will show reduced ACC (BA32) activation during the appraisal phase of exposure to a negative emotional stimulus (i.e. self-esteem will be negatively associated with ACC activation during emotional appraisal); 2) given that individuals with higher self-esteem appear to engage emotion regulatory regions (including the ACC) following exposure to self-threat, higher levels of self-esteem will be associated with increased activation in the ACC (BA32) during cognitive reappraisal; 3) trait self-esteem is negatively associated with engagement of dorsal prefrontal regions (BA6) during emotion regulation, since more regulation may be more effortful for individuals with lower self-esteem; 4) higher self-esteem individuals will be more successful at regulating their emotions using cognitive reappraisal than individuals with lower levels of self-esteem.

# 2. Method

## 2.1 Study characteristics

Data for the current study were drawn from a larger study, “Depression in the Picture” (DIP), conducted in the Netherlands (Meurs et al., 2016). Structural and functional magnetic resonance imaging (MRI/fMRI), and behavioural data for the DIP study were collected between 2012 and 2014. The present investigation comprised the healthy participants included in the DIP study ($n$ = 32). Patients with chronic kidney disease and patients with depression were included in the overarching DIP study, but not in the present secondary data analysis.

## 2.2 Sample characteristics

Prior to participation, potential participants were screened for the following exclusion criteria, using self-report with verification in medical records where appropriate: MRI incompatibility and the presence of chronic kidney disease, cardio- or cerebrovascular disease, and psychiatric diagnoses (past or present) as established in a clinical interview (see Study procedures). The exception was nicotine dependence, which was allowed. Participants were also excluded if they scored 10 or above on the Beck Depression Inventory-II (BDI-II) at screening, which is below the threshold for “mild” depression (BDI-II score > 13; Beck, Steer, & Brown, 1996 as cited in Beck, Steer, Ball, & Ranieri, 1996). Adequate comprehension of the Dutch language was a participation requirement.

After data collection was complete, three participants were excluded from analysis due to concerns about data validity: two participants indicated that they did not fully comprehend instructions for the emotion regulation task, and one participant showed atypical task performance. The latter participant consistently selected the minimum rating value for negative emotional intensity regardless of emotion regulation task condition (neutral or negative). This suggests that the task did not elicit significant negative emotion for this participant or that the participant did not understand the task instructions. Since a core element of the current study was participants' responses to negative emotion, the response pattern of this participant warranted their exclusion from the analysis. This left a final sample of 29 healthy adult participants for analysis. Although it was not possible to conduct a prospective fMRI power analysis (given that the present work is based on pre-existing data), the sample size of the current study is on par with typical fMRI samples (Poldrack et al., 2017; Szucs & Ioannidis, 2017) and exceeds the minimum recommendation of 20 participants for single-group fMRI research[1] (Simmons, Nelson, & Simonsohn, 2011). Of the final sample for analysis, 16 were female. The mean age of participants was 46.66 years (*SD* = 15.04) and the majority of participants (*n* = 18) were highly educated (higher professional education, university, or university of applied science), while only one participant had a low education level (pre-vocational education).

### 2.3 Ethics statement

The DIP study received ethical approval from the ethics board of the University Medical Centre Groningen (ethics number: METc 2012.008) and was conducted in accord with the Helsinki Declaration (World Medical Association, 2008) and international Good Clinical Practice guidelines (International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use, 2002). The secondary data analysis as described in this dissertation was approved by the University of Cape Town Faculty of Health Sciences Human Research Ethics Committee (HREC reference: 369/2017).

### 2.4 Study procedures

The study procedure consisted of a telephonic screening and two study sessions. Potential participants' eligibility for the study, including MRI safety and lack of psychiatric

[1] In recent years, fMRI sample size has come under scrutiny – see Strengths and limitations of the present study.

history, was initially assessed during the telephonic screening and later verified during the first study session. At the start of the first session, participants provided written informed consent after the investigator had explained the study procedures. Thereafter participants underwent semi-structured clinical interviews based on the mini Schedules for Clinical Assessment in Neuropsychiatry (mini-SCAN) which is a shortened version of the Schedules for Clinical Assessment in Neuropsychiatry (SCAN; Nienhuis, van de Willige, Rijnders, de Jonge, & Wiersma, 2010). Both instruments use diagnostic criteria as per the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994).

The second study session occurred approximately ten days after the first session and several questionnaires, including the Rosenberg Self-Esteem Scale (RSES; Rosenberg, 1965), were completed between the two study sessions. During the second session, participants underwent MRI scanning, and completed the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) and the BDI-II. The BDI-II was completed twice during the course of the study: once during screening, and once following scan acquisition.

**Understanding functional magnetic resonance imaging (fMRI)**

**Blood oxygenation level dependent (BOLD) signal**

Functional magnetic resonance imaging (fMRI) is a non-invasive in-vivo imaging technique that can be used to measure neural activation across time. It is commonly used to measure neural activation during cognitive, emotional, or sensorimotor tasks (i.e. task fMRI). One of the most common fMRI methods is blood-oxygenation-level-dependent (BOLD) fMRI. Blood flow typically increases near actively firing neurons to meet an increased demand for glucose and oxygen. Interestingly, however, the regional increase in oxygenated blood flow is greater than the increase in oxygen demand of the active neurons. The end-result is a surplus of oxygenated haemoglobin in venous blood vessels. These regional increases can be quantified using the different magnetic properties of oxygenated and deoxygenated haemoglobin. This quantification is known as BOLD signal, which is used to produce a visual representation of brain activation in fMRI scans.

**Haemodynamic response function**

The characteristic pattern of change in cerebral blood flow in response to neural activation is known as the *haemodynamic response*. It is important to note, however, that the BOLD signal does not perfectly approximate neural activity. Neuronal firing that prompts a haemodynamic response may last only milliseconds, yet the resultant changes to cerebral blood flow occur over a number of seconds. After reaching its peak approximately 4-6 seconds after onset, the haemodynamic response only returns to baseline after 15 – 20 seconds. This temporal offset from the neuronal response to a stimulus is important to factor into analysis of fMRI datasets acquired using the BOLD contrast technique.

**Analysis of fMRI data: Contrasts**

A common misconception regarding task fMRI amongst lay people is that a temporal sequence of images can be interpreted immediately. However, in reality, analysis of task fMRI data is only possible when task conditions are contrasted with one another. This is because at any given moment the brain is performing multiple functions. In order to determine which brain activation corresponds to a particular function, it must be isolated from the other functions occurring alongside it. As a result, fMRI research typically includes a control condition in which participants perform a similar, but not identical, activity to the experimental condition of interest. For example, researchers investigating brain activation associated with reading might ask their participants to look at pictures of squiggly lines as a control condition; squiggly lines may have a similar appearance to letters, but they lack the linguistic and phonetic associations of letters. In other words, contrasting an experimental condition (e.g. reading) to a control condition (e.g. viewing of squiggly lines) controls for what the two conditions have in common (visual processing) and isolates what distinguishes one from the other (phonetic and linguistic associations unique to reading).

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## 2.5 Measures

### *2.5.1 Scan acquisition*

Scanning was completed in a 3-Tesla MRI scanner, with a SENSE 32-channel head coil (Philips Intera, Best, NL, USA). Anatomical images were acquired using a three-dimensional gradient-echo T1-weighted sequence (170 slices; TR = 9 ms; TE = 3.51 ms; flip angle = 8 degrees; FOV [anterior-posterior, foot-head, right-left] = 232 x 170 x 256 mm; voxel size = 1 x 1 x 1 mm; scan duration = 4.18 min). T2*-weighted echo-planar images were acquired during the emotion regulation task (37 slices; TR = 2000 ms; TE = 20 ms; flip angle = 70; FOV [anterior-posterior, foot-head, right-left] = 224 x 129.5 x 224 mm; voxel size = 3.5 x 3.5 x 3.5 mm; scan duration = 19.67 min). All anatomical scans were previously evaluated for clinically relevant abnormalities by an experienced neuroradiologist, and no new abnormalities were detected in the present study.

#### *2.5.2 Emotion regulation task*

During scanning, participants completed an emotion regulation task similar to the one reported in Modinos, Ormel, and Aleman (2010) and Ochsner et al. (2002). The task involved viewing images with neutral and negative emotional content (View Neutral and View Negative conditions) and responding to them by following on-screen instructions to either attend to them or engage in cognitive reappraisal to lessen the negative emotional impact of the picture. The attend instruction was paired with both neutral and negative images (Attend Neutral and Attend Negative conditions), while the reappraise instruction was paired only with negative images (Reappraise condition). To ensure that participants adequately understood how to follow the "reappraise" instruction, they received brief training in cognitive reappraisal before scanning commenced. During post-scan debriefing, participants also rated whether they were able to reappraise the stimuli during scanning and how difficult they found the task. Ratings were completed using a five-point Likert-type format from 1 (*disagree*) to 5 (*agree*).

Participants were guided through the task using E-Prime version 2 (Psychology Software tools Inc.). The stimulus set contained negatively ($n$ = 42) and neutrally ($n$ = 21) valenced images drawn from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) and each picture was presented only once. The negative images depicted complex scenes of emotionally perturbing stimuli, such as burn victims, traffic accidents and people crying. The images presented in the attend negative and reappraise negative conditions were matched for arousal and valence ratings as described in Van der Meer et al. (2014).

The course of each trial is depicted in Figure 1. Each trial started with viewing (View) a negatively or neutrally valenced image for 2s, allowing for an emotional response to develop. The view condition was then followed by on-screen instructions, presented below the image, to either reappraise (solely for negative stimuli) or attend to (for negative or neutral stimuli) the emotions evoked by the image for 4s (Regulate). After the image disappeared from the screen, a blank screen was presented for 2s, allowing the emotions evoked to linger (Linger). Participants were then given 3s to provide an emotional intensity rating ranging from 1 (not at all negative) to 4 (very negative; Rating). Finally, the word "relax" was displayed on the screen for 4s (Relax), allowing participants to rest before the next trial commenced.

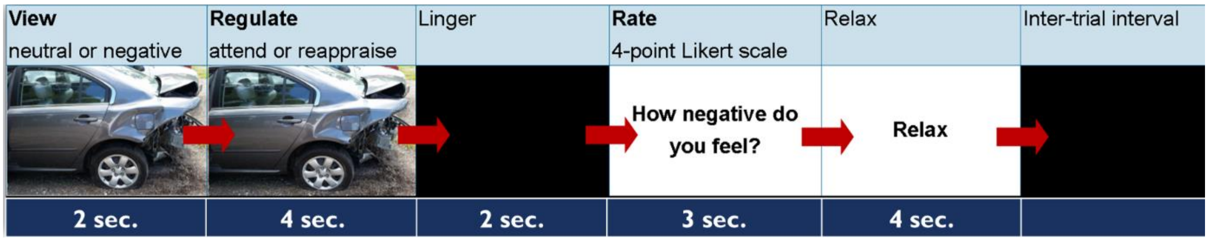


*Figure 1.* Emotion regulation task schematic depicting progression of a single trial. View (2 sec.): negative or neutral IAPS image presented. Regulate (4 sec.): instruction to attend or reappraise presented beneath the IAPS image. Linger (2 sec.): blank screen. Rate (3 sec.): negative emotional intensity rating. Relax (4 sec.): instruction to relax. Inter-trial interval (variable length): blank screen.

### *2.5.3 Rosenberg Self-Esteem Scale (RSES) – Dutch translation*

The RSES (Appendix A) is a self-report measure consisting of 10 four-point Likert-type items, scored from 0 (*strongly disagree*) to 3 (*strongly agree*; (Rosenberg, 1965). A Dutch translation of the RSES was used, given the location of the study. Franck, De Raedt, Barbez, and Rosseel (2008) demonstrated satisfactory psychometric properties for the Dutch translation of the RSES in a sample of 422 Dutch adults. Specifically, Franck et al. (2008) report high internal consistency (Cronbach's alpha = .86), and good construct validity, as determined by the significant correlation of the Dutch RSES with personality factors of a Dutch version of the well-established Five-Factor Model of personality (*Original:* Goldberg, 1990; *Dutch version:* Hoekstra, Ormel, & de Fruyt, 1996 as cited in Franck et al., 2008). Global self-esteem was negatively correlated with Neuroticism, and positively correlated with Extraversion and Conscientiousness (Franck et al., 2008).

#### *2.5.4 Positive and Negative Affect Schedule (PANAS)*

The PANAS (Appendix A) consists of 20 emotional words; 10 index positive affect (e.g. interested, excited, inspired), and 10 index negative affect (e.g. upset, ashamed, afraid; Watson et al., 1988). Items are presented in a five-pointe Likert-type style: participants are asked to rate how much they feel a particular way in a given time period by selecting a response from 1 (*not at all or very slightly*) to 5 (*very much*). In the present study, the time period specified was “right now, that is, at the present moment”. The PANAS showed satisfactory internal consistency for both positive and negative subscales in an adult UK sample (Cronbach’s $\alpha = .89$ and .85, respectively; $N = 1003$; Crawford & Henry, 2004). Both PANAS subscales also demonstrate satisfactory construct validity: positive affect correlated negatively with depression and anxiety scores, and vice versa for negative affect (Crawford & Henry, 2004).

### 2.6 Data analysis

#### *2.6.1 fMRI analysis*

The current study employed an event-related task-based fMRI design. fMRI analyses were run using Statistical Parametric Mapping (SPM12; www.fil.ion.ucl.ac.uk), in MATLAB 2017b (The MathWorks, Inc.).

**2.6.1.1 Preprocessing.** Functional scans underwent manual reorientation to the anterior commissure-posterior commissure, followed by realignment and coregistration to the T1-

weighted anatomical scans. Images were realigned using a rigid-body transformation with six parameters encompassing movement along the *x*, *y*, and *z* axes and pitch, roll and yaw rotations. Subsequently, the realignment parameters were used for motion-correction at first-level analyses. Coregistration of functional to anatomical scans was checked and manually readjusted where necessary. Thereafter, functional scans underwent spatial normalisation to MNI (Montreal Neurological Institute) space and smoothing using an 8 mm full-width, half-maximum (FWHM) Gaussian smoothing kernel (in line with Modinos et al., 2010). An 8mm kernel was preferred over 10mm (van der Meer et al., 2014) and 6mm (van der Velde et al., 2015) kernels since a larger kernel would result in loss of spatial resolution and a smaller kernel could result in a sub-optimal signal-to-noise ratio (Poldrack, Mumford, & Nichols, 2011). Furthermore, an 8mm kernel is frequently used in fMRI studies that include self-esteem as a correlate for brain activation (e.g. Eisenberger et al., 2011; Hoefler et al., 2015; Onoda et al., 2010).

**2.6.1.2 First-level analyses.** For each participant, thirteen task-related regressors were modelled with a boxcar function convolving a haemodynamic response function. Each regressor captured a different portion of the task. The View and Relax regressors were subdivided into negative and neutral (four regressors). The remaining task regressors, Regulate, Linger, and Rate, were subdivided to match the stimulus/instruction pairings. Specifically: Reappraise (negative images), Attend Negative, and Attend Neutral (nine regressors). Lastly, I controlled for participants' head motion in the scanner by including rigid body transformation values (x, y, z, pitch, roll, yaw) from the realignment step in preprocessing as motion regressors. View and Regulate were conditions of interest, while the remaining regressors were included in the model as covariates of no interest. Three contrast maps per participant were created: 1) View Negative versus View Neutral; 2) Attend Negative versus Attend Neutral; 3) Reappraise versus Attend Negative.

**2.6.1.3 Second-level analyses.** Prior to self-esteem related hypothesis testing, I analysed task-related brain activation to ensure that the View Negative and Reappraise conditions activated a priori defined brain regions in the entire sample. For the View contrast I anticipated that negative compared to neutral images would be associated with increased activation in emotion generative appraisal regions, such as the middle temporal gyrus (MTG), inferior temporal gyrus, supramarginal gyri, calcarine sulci, IFG and dmPFC (van der Velde et al., 2015). For the Reappraisal contrast I anticipated typical reappraisal activation involving prefrontal control regions and semantic processing regions such as the dlPFC, dmPFC, IFG, ACC, and MTG (Buhle et al., 2014; Frank et al., 2014; Modinos et al., 2010; Morawetz et al., 2017; van der Meer et al., 2014; van der Velde et al., 2015). These analyses for task effects were thresholded at $p < .001$, k20, and $p < .05$ family-wise error (FWE) corrected at cluster level. This followed previous publications using the same fMRI emotion regulation task that I employ (van der Meer et al., 2014; van der Velde et al., 2015).

To examine whether individual differences in self-esteem were predictive of task-related activity, RSES scores were entered as a covariate of interest in a whole-brain multiple regression analysis. To adjust for potential confounding influences, sex and age were included as covariates of no interest. The analyses were performed separately for each of the three contrasts created in first-level analysis. While some of self-esteem papers applied more stringent thresholds (Gyurak et al., 2012; Hoefler et al., 2015), a number of key self-esteem fMRI studies, discussed previously, threshold their analyses at the more lenient $p < .005$, and $p < .05$ FWE correction for multiple comparisons at cluster level (Frewen et al., 2013; Onoda et al., 2010). Following the latter studies, the current study employed a threshold of $p <.005$, and $p<.05$ FWE corrected at cluster level to balance the risk of type I and type II errors for self-esteem fMRI analyses.

**2.6.1.4 Region of interest (ROI) selection and analysis.** ROIs were selected by maximising contribution from both self-esteem-related fMRI studies and emotion regulation-related fMRI studies (with preference for the cognitive reappraisal technique), including meta-analyses and previous studies that used the same fMRI emotion regulation task as the current study. Two final self-esteem/emotion regulation regions of interest were selected: dACC/BA 32 (Buhle et al., 2014; Eisenberger et al., 2011; Frank et al., 2014; Hoefler et al., 2015; Kashdan et al., 2014; Modinos et al., 2010; Somerville et al., 2010; van der Velde et al., 2015; Yang et al., 2012) and dorsal PFC/BA 6 (Buhle et al., 2014; Eisenberger et al., 2011; Frank et al., 2014; Modinos et al., 2010; Onoda et al., 2010; van der Meer et al., 2014; van der Velde et al., 2015). WFU PickAtlas (Maldjian, Laurienti, Kraft, & Burdette, 2003) was used to create a single mask encompassing BA32 and BA6. The mask was dilated using a 2D dilation function of 2mm to maintain the spatial location of the Brodmann Areas (BA) while thickening the originally thin cortical strip defined by the Brodmann atlas. Since I had specific hypotheses pertaining to the ACC (BA32) and dorsal PFC (BA6), small volume correction was applied for the volume of these regions bilaterally.

**2.6.1.5 Post-hoc ROI analysis.** I performed a post-hoc ROI analysis to confirm whether any self-esteem-correlated activation captured in the dACC ROI overlapped with meta-analytic ACC activation associated with emotion regulation (Frank et al., 2014). To this end, I defined search volume centred on ACC emotion regulation meta-analysis coordinates ($x$ = -8, $y$ = 20, $z$ = 32) reported in Frank et al. (2014). The post-hoc ROI was defined as a sphere with a radius of 8mm to account for potential loss of spatial resolution that occurred during the spatial smoothing stage of data preprocessing.

### *2.6.2 Behavioural analysis*

Statistical analyses of behavioural data were carried out in SPSS 25 (SPSS Inc., Chicago, IL, USA). Statistical assumptions for each analysis were checked, and where necessary, analyses were adjusted. In particular, while comparing emotional intensity ratings for each of the three trial types would usually suggest the use of an omnibus test, heterogenous variance between these groups precluded use of an ANOVA. Instead, I used two paired-sample *t*-tests, bootstrapped at the 1000-level to correct for the unequal variance of ratings in each trial type in the raw data in order to validate the emotion regulation task. To this end, I tested whether ratings of emotional intensity were highest for negative images in the absence of reappraisal, intermediate for negative images after reappraisal, and lowest for neutral images in the whole sample. Specifically, I compared neutral to reappraisal ratings, and reappraisal to negative ratings.

Next, I tested the relationship between reappraisal success and self-esteem scores with correlation analysis. For this purpose, reappraisal success was calculated for each participant by subtracting average emotional intensity ratings after reappraisal from the average ratings after negative attend trials. The rating-calculated measure of reappraisal success was validated by two secondary correlation analyses, testing whether it correlated with participants' self-report ratings of how successful they were at reappraising stimuli and how difficult they found the emotion regulation task.

To test whether higher levels of self-esteem were associated with decreased negative emotional response to negative emotional cues, I assessed the correlation between self-esteem scores and emotional reactivity. Emotional reactivity was calculated by subtracting negative emotional intensity ratings following Attend Neutral trials from those following Attend Negative trials to control for baseline negative emotion. Furthermore, I tested the correlation between self-esteem and post-scan positive and negative affect, as measured by PANAS

# 3. Results

## 3.1 Behavioural results

### *3.1.1 Overview of behavioural measures*

An overview of questionnaire and behavioural task data descriptive statistics are presented in Table 1. RSES scores for the current sample fell within the top third (*min* = 20, *max* = 30) of the possible range of scores for this measure. This suggests generally high levels of self-esteem in the present sample. On average, with a comparatively small standard error, reappraisal success scores ($M$ = 0.52, $SE$ = 0.12) were positive on a scale of -3 to 3. These results indicate that, in general, ratings for negative images following reappraisal were lower than those following attending to negative images. In other words, participants appeared to successfully reduce their negative emotions (see sections 3.1.2 and 3.2.2). Emotional reactivity in the present sample was in the expected (positive) direction without exception, indicating that attending to negative images evoked more intense negative emotion than attending to neutral images. Mean responses for the PANAS scales show that participants experienced higher levels of positive affect ($M$ = 36.10, $SE$ = 1.32) than negative affect ($M$ = 11.00, $SE$ = 0.30) following scanning.

Table 1.

*Descriptive statistics for behavioural measures of trait self-esteem, emotional reactivity and emotion-regulatory success during the task, and post-scan affective state*

| | *M* | *SE* | Min. | Max. | Measurement scale |
|---|---|---|---|---|---|
| RSES | 26.07 | 0.55 | 20 | 30 | 0 – 30 |
| Reappraisal success | 0.52 | 0.12 | -0.29 | 2.24 | -3 – 3 |
| Emotional reactivity | 1.74 | 0.08 | 0.90 | 2.52 | -3 – 3 |
| PANAS-positive | 36.10 | 1.32 | 17 | 46 | 10 – 50 |
| PANAS-negative | 11.00 | 0.30 | 10 | 16 | 10 – 50 |

*Note*. *N* = 29. *M* = mean. *SE* = standard error.

***3.1.2 Negative emotional intensity ratings during the fMRI emotion regulation task***

In line with expectations, negative emotional intensity ratings were statistically significantly lower after participants engaged in cognitive reappraisal compared to merely attending to negatively-valenced images (mean difference=-0.523, $t(28)=4.269$, $p=.002$, bootstrapped at 1000-level). Nonetheless, negative emotional intensity ratings were substantially higher for negative than for neutral images, even after cognitive reappraisal (mean difference=1.214, $t(28)=10.271$, $p=.001$, bootstrapped at 1000-level). Negative emotional intensity ratings for the different task conditions are graphically depicted in Figure 1.

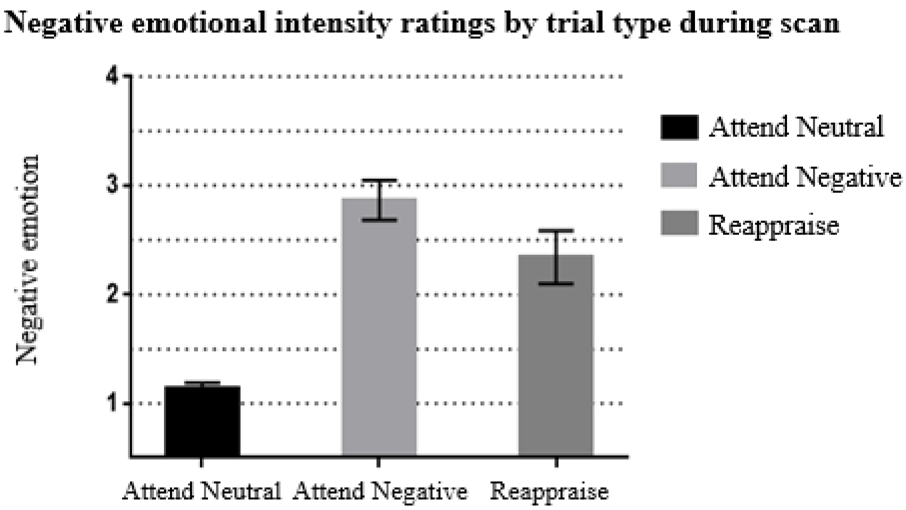


*Figure 2*. Negative emotional intensity means for each trial type, with error bars illustrating 95% confidence intervals.

***3.1.3 Validation of reappraisal success as measured by emotional intensity ratings***

The rating-calculated measure of reappraisal success was moderately associated with self-reported reappraisal success after the emotion regulation task was completed ($r=.449$, $p=.015$). In addition, the rating-calculated measure of reappraisal success was moderately negatively associated with self-reported emotion regulation task difficulty ($r=-.429$, $p=.020$).

### *3.1.4 Self-esteem in relation to emotional responses and post-scan affective state*

Contrary to expectations, self-esteem was not significantly associated with reappraisal success (*r*=.157, *p*=.208), nor with emotional reactivity to negative images (*r*=.164, *p*=.198) during the fMRI emotion regulation task. Higher self-esteem was moderately associated with lower post-scan negative affect ratings (*r*=-.493 *p*=.004), but no association was detected for post-scan positive affect ratings (*r*=.136 *p*=.241).

## 3.2 Neuroimaging results

### *3.2.1 Emotion regulation task-related brain activation*

Results for emotion regulation task-related brain activation are presented in Table 2. In comparison to viewing neutral pictures, viewing negative pictures was associated with stronger activation in the right inferior temporal gyrus and bilateral MTG. A cluster in the left supramarginal gyrus/postcentral gyrus approached the cluster threshold but did not meet it.

Reappraisal versus attending to negative pictures was associated with increased bilateral activation in the SMA and dmPFC, including the BA6 ROI, and increased activation in the left angular gyrus/supramarginal gyrus, left MTG, left BA6/middle frontal gyrus, and left IFG/temporal pole. Reappraisal in contrast to attending to negative pictures was also associated with increased activation in the right angular gyrus/supramarginal gyrus, right BA6/middle frontal gyrus. A summary of results can be found in Table 2.

Table 2.

*fMRI emotion regulation task-related blood-oxygenation-level-dependent (BOLD) brain activation*

| | | Cluster | | Peak | | MNI coordinates | | |
|---|---|---|---|---|---|---|---|---|
| | L/R | *k* | *p*-FWE | *p*-uncorr. | *T* | *x* | *y* | *z* |
| View Negative > View Neutral | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MTG | L | 315 | <.001 | <.001 | 6.41 | -51 | -64 | -1 |
| Inferior temporal gyrus/ MTG | R | 280 | <.001 | <.001 | 7.39 | 45 | -64 | -7 |
| Supramarginal gyrus/ postcentral gyrus | L | 69 | .050 | <.001 | 5.31 | -60 | -28 | 38 |
| View Neutral > View Negative | | | | | | | | |
| None | | | | | | | | |
| Attend Negative > Attend Neutral | | | | | | | | |
| None | | | | | | | | |
| Attend Neutral > Attend Negative | | | | | | | | |
| None | | | | | | | | |
| Reappraise > Attend Negative | | | | | | | | |
| SMA/dmPFC | L/R | 349 | <.001 | <.001 | 6.07 | 12 | 20 | 59 |
| Angular gyrus/ supramarginal gyrus | L | 168 | .002 | <.001 | 4.87 | -48 | -64 | 44 |
| MTG | L | 155 | .003 | <.001 | 5.75 | -60 | -37 | 2 |
| Middle frontal gyrus/ dlPFC | L | 149 | .003 | <.001 | 5.30 | -45 | 8 | 53 |
| IFG/ temporal pole | L | 143 | .004 | <.001 | 5.79 | -48 | 20 | -1 |
| Angular gyrus/ supramarginal gyrus | R | 79 | .044 | <.001 | 4.22 | 45 | -64 | 47 |
| Middle frontal gyrus /dlPFC | R | 77 | .048 | <.001 | 5.32 | 48 | 20 | 41 |
| Attend Negative > Reappraise | | | | | | | | |
| None | | | | | | | | |

*Note*. L/R = left/right. *k* = cluster size (voxels). FWE = family-wise error. MNI = Montreal Neurological Institute. MTG = middle temporal gyrus. SMA = supplementary motor area. dmPFC =

dorsomedial prefrontal cortex. dlPFC = dorsolateral prefrontal cortex. IFG = inferior frontal gyrus. Findings significant at $p$<0.001 uncorrected at peak, $p$<.05 FWE-corrected at cluster level, $k$>20.

### *3.2.2 Self-esteem-related brain activation by contrast*

**3.2.2.1 View Negative > View Neutral.** For viewing negative images versus neutral images, self-esteem correlated positively with activation in the superior temporal gyrus, anterior and mid cingulate cortex, MTG, insula, IFG, thalamus, and cerebellum (see Figure 3 and Table 3). Self-esteem correlated positively with activation in the ACC/BA32 ROI during viewing of negative versus neutral images (see Table 4). However, no clusters were significant after FWE-correction at the cluster level.

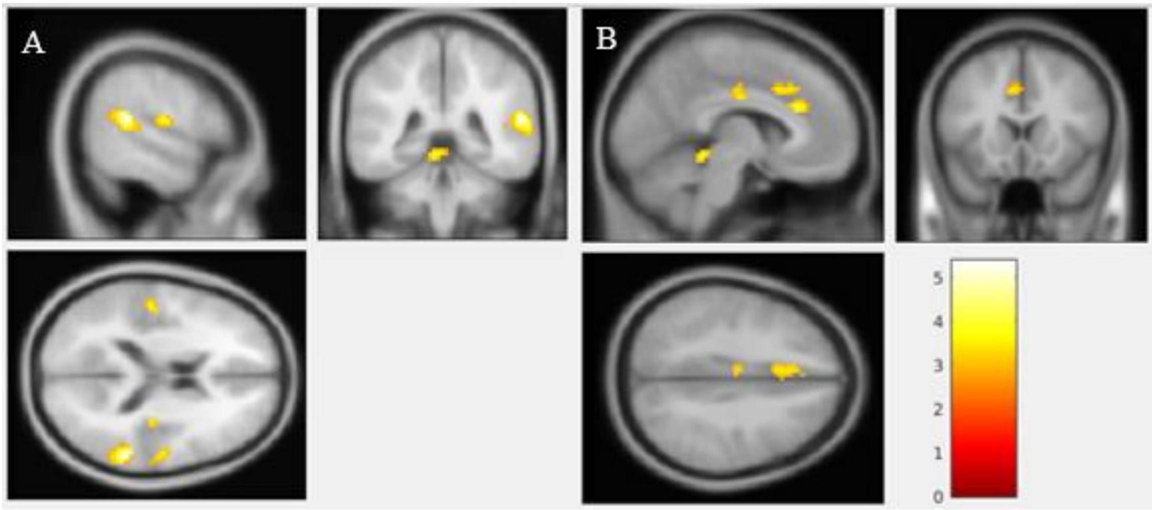


*Figure 3.* Brain activation positively correlated with self-esteem during viewing of negative vs. neutral pictures. A) Superior temporal gyrus ($x$, $y$, $z$ = 57, -40, 17); B) Cingulate cortex ($x$, $y$, $z$ = -6, 17, 38).

Table 3.

*Self-esteem-related brain activation by contrast, adjusted for age and sex*

| | | | Cluster | | Peak | | MNI coordinates | | |
|---|---|---|---|---|---|---|---|---|---|
| | L/R | +/- | $k$ | $p$-FWE | $p$-uncorr. | $T$ | $x$ | $y$ | $z$ |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| View Negative > View Neutral | | | | | | | | | |
| Superior temporal gyrus | R | + | 100 | .251 | <.001 | 5.18 | 57 | -40 | 17 |
| ACC | L | + | 52 | .728 | .001 | 3.45 | -6 | 26 | 38 |
| Midcingulate cortex | R | + | 51 | .740 | .001 | 3.52 | 6 | -7 | 32 |
| MTG/superior temporal gyrus | L | + | 45 | .813 | <.001 | 4.00 | -54 | -28 | -1 |
| ACC | L | + | 30 | .951 | <.001 | 4.29 | -9 | 32 | 26 |
| Insula | R | + | 21 | .989 | <.001 | 4.26 | 36 | -22 | 20 |
| Inferior frontal gyrus | R | + | 21 | .989 | <.001 | 3.76 | 57 | -13 | 14 |
| Thalamus | R | + | 21 | .989 | .001 | 3.68 | 9 | -13 | 2 |
| Cerebellum | R | + | 21 | .989 | .001 | 3.50 | -6 | -40 | -10 |
| Attend Negative > Neutral | | | | | | | | | |
| None. | | | | | | | | | |
| Reappraise > Attend Negative | | | | | | | | | |
| Insula | L | + | 34 | .959 | <.001 | 4.04 | -30 | -10 | 17 |
| Mid/posterior cingulate | R | - | 24 | .805 | .001 | 3.68 | 3 | -34 | 35 |

*Note.* L/R = left/right. +/- = direction of association with self-esteem. *k* = cluster size (voxels). FWE = family-wise error. MNI = Montreal Neurological Institute. ACC = anterior cingulate cortex. MTG = middle temporal gyrus. Analyses thresholded at $p<0.005$ uncorrected at peak, $p<.05$ FWE-corrected at cluster level, $k>20$.

**3.2.2.2 Reappraise > Attend Negative.** For reappraisal versus attending to negative images, self-esteem correlated positively with activation in the left insula, and negatively with activation in the mid cingulate cortex, although neither cluster met FWE-significance. Self-esteem did not correlate with activation in either ROI for this contrast.

**3.2.2.3 Post-hoc ROI analysis for the ACC.** Statistically significant self-esteem-related activation occurred in the 8mm radius sphere centred on ACC emotion regulation meta-analysis coordinates (*x*, *y*, *z* = -8, 20, 32; Frank et al., 2014) during the View Negative > View Neutral contrast (see Table 4).

Table 4.

*Brain activation in ROIs positively correlated with self-esteem during viewing of negative > neutral images*

| | | Cluster | | Peak | | MNI co-ordinates | | |
|---|---|---|---|---|---|---|---|---|
| Region | L/R | *k* | *p*-FWE * | *p*-uncorr. | *T* | *x* | *y* | *z* |
| BA32 ROI | | | | | | | | |
| ACC | L | 25 | .644 | <.001 | 3.98 | -9 | 32 | 26 |
| ACC | L | 43 | .368 | .001 | 3.12 | -6 | 17 | 38 |
| | | | | .001 | 3.41 | -6 | 23 | 38 |
| | | | | .004 | 2.87 | -3 | 35 | 41 |
| Post-hoc ACC ROI [a] | | | | | | | | |
| ACC | L | 25 | .021 | .001 | 3.42 | -6 | 23 | 38 |
| | | | | .001 | 3.36 | -6 | 17 | 38 |

*Note.* L/R = left/right. *k* = cluster size (voxels). FWE = family-wise error. MNI = Montreal Neurological Institute. ACC = anterior cingulate cortex.

[a] 8mm spherical ROI centred at MNI *x, y, z* = -8, 20, 32.

Analyses thresholded at $p < .005$, and $p < .05$ FWE correction, $k >= 20$.

* Small-volume corrected.

## 4. Discussion

The aim of the current study was to investigate whether individual differences in self-esteem were associated with recruitment of brain regions when negative emotions were evoked, and when individuals attempted to downregulate these emotions using cognitive reappraisal. I hypothesised that lower levels of self-esteem would be associated with potentiated ACC responses to negative emotional stimuli, and with atypical ACC and dorsal PFC recruitment during cognitive reappraisal of negative emotional stimuli. Contrary to expectations, I found that higher levels of self-esteem were associated with potentiated activation in the ACC in response to negative emotional cues. Interestingly, a similar pattern of increased responsivity to negative cues was observed in other regions previously implicated in emotion regulation, although these findings did not reach significance after multiple comparison correction. Self-esteem was not related to ACC or dorsal PFC activation during cognitive reappraisal. However, higher self-esteem may be weakly associated with increased posterior insula activation and decreased posterior cingulate activation during cognitive reappraisal. Lack of statistical significance for these findings following FWE correction for multiple comparisons requires that these results are interpreted with caution. Finally, whereas emotional intensity ratings indicated that participants succeeded in regulating their emotions, self-esteem did not predict individual differences in emotion regulation success. Possible implications for understanding the relationship between self-esteem and emotion processing and regulation are discussed below.

### 4.1 Self-esteem in healthy individuals and neural responsivity to negative emotional cues

Previous work using social rejection and social exclusion paradigms has linked higher ACC activation to lower levels of self-esteem (e.g. Eisenberger et al., 2011; Kashdan et al., 2014; Onoda et al., 2010). In the current study, although individual levels of trait self-esteem correlated with ACC activation during viewing of images that evoked negative emotions, the correlation was in the opposite direction to what was expected: the higher someone's level of self-esteem, the stronger the activation observed in the ACC. One possible explanation for this discrepancy could be the stimulus that was used to evoke negative emotions in participants. While social rejection may evoke negative emotions and social pain that is related to self-threat (Leary, 2015), the current stimuli depicted painful situations where the focus of the negative emotion was completely unrelated to the self. Indeed, it has been suggested that individuals with low self-esteem show a specific sensitivity to social rejection that does not generalize to other negative emotional cues (Gyurak & Ayduk, 2007). Therefore, it is likely that ACC potentiation in low self-esteem individuals during processing of self-relevant negative cues reflects an intense experience of social pain, whereas ACC potentiation in high self-esteem individuals during processing of negative cues unrelated to self is reflective of a different cognitive process.

The ACC has not only been linked to social pain, but also been implicated in both voluntary and automatic emotion regulation processes according to the neural emotion regulation model developed by Phillips et al. (2008). Supporting the notion that the ACC activation observed during the View stage of the experiment (i.e. the first two seconds of exposure to IAPS images) may represent a regulatory process, ACC clusters of the current study were proximally located to ACC clusters from emotion regulation meta-analyses (Buhle et al., 2014; Frank et al., 2014; Morawetz et al., 2017). Furthermore, the post-hoc ROI analysis confirmed significant overlap between the current study's ACC activation and the ACC portion of an emotion regulation cluster in Frank et al.'s (2014) meta-analysis that included both reappraisal and suppression emotion regulation techniques. From visual inspection, the self-esteem related ACC cluster derived from the View stage of the experiment overlapped with reappraisal-related task activation in the current study, and in a previous study using the same task (Modinos et al., 2010). Taken together, these results point to self-esteem-related ACC activation that I observed during the View stage as being linked to an emotion regulation process.

Relating the possible emotion regulatory role of the ACC observed in the present study to the literature on self-esteem, previous work has suggested that the ACC may play a critical role in regulating state self-esteem during self-referential processing following self-threat (Hoefler et al., 2015). This regulation may be facilitated by self-knowledge accessibility, indexed by response latencies. In particular, reduced accessibility of negative traits (i.e. slower reaction time) and enhanced accessibility of positive traits (i.e. faster reaction time) were both associated with potentiated ACC activation for individuals with high self-esteem (Hoefler et al., 2015). These prior self-esteem related findings link potentiated ACC activation to high self-esteem and support a buffering role for the ACC against negative emotional outcomes following self-threat, possibly through moderating accessibility of self-knowledge.

In the present task, rather than engaging in self-evaluation, participants viewed pictures of others in distress, which may have engaged theory of mind processes. Interestingly, previous work has shown that inhibition of the posterior medial PFC, extending into the dACC, using repetitive transcranial magnetic stimulation, reduced participants' ability to distinguish their own beliefs from others' (Schuwerk et al., 2014). The potentiated ACC activation for individuals with high self-esteem in the present study overlaps with the ACC cluster peak reported in Schuwerk et al. (2014). This may suggest that individuals with higher self-esteem are better able to separate their own experience from what they infer to be the experience of the people depicted in the IAPS stimuli. A unifying explanation of Hoefler et al. (2015) and Schuwerk et al.'s (2014) findings may be that the role of the ACC in relation to self-esteem is context-dependent modulation of information about self and other, resulting indirectly in emotion regulation. In the process of self-reflection, the ACC may contribute to emotion regulation by inhibiting access to knowledge of one's own less desirable traits (Hoefler et al., 2015); additionally, in the context of relationship with others, it may allow one to separate one's own mental experience from others' (Schuwerk et al., 2014), and this separation may facilitate better emotion regulation. The findings suggest that the protective role played by the ACC for high self-esteem individuals may generalise to non-self-related negative emotional cues, such as the distress of others, as depicted in IAPS stimuli. Thus, the ACC activation associated with self-esteem in response to viewing negative emotional stimuli may represent early deployment of automatic emotion regulation processes by individuals with higher self-esteem.

Consistent with the notion that individuals with higher self-esteem might be engaging in some form of early onset emotion regulation, activation in several other regions involved in emotion regulation using reappraisal or suppression techniques (e.g. Frank et al., 2014) were correlated with trait self-esteem during the View contrast. These regions included the MTG, the insula, and the IFG. In addition to appearing in emotion regulation meta-analyses, visual inspection showed that the self-esteem related MTG cluster overlapped with the MTG task activation cluster during reappraisal, both in the present study and in a previous study employing the same fMRI emotion regulation task (Modinos et al., 2010). Previous work has suggested that temporal regions that are part of the semantic processing network, including the MTG, perform the function of representing the emotional meaning of a stimulus during reappraisal (Buhle et al., 2014). Therefore, it may be that individuals with higher self-esteem are engaging with the emotional meaning of the stimuli earlier on than their lower self-esteem counterparts. Interestingly, the IFG (or vlPFC) is also involved in semantic processing (Binder et al., 2009) and is speculated to select appropriate emotional meaning while inhibiting others in the context of (re)appraisal (Buhle et al., 2014). Others have argued that the specific role played by the insula and IFG in emotion regulation may be to trigger the need to regulate emotion rather than carrying out the regulation per se (Kohn et al., 2014). These findings, in conjunction with other clusters that were observed, might indicate that individuals with higher self-esteem may be receiving an earlier neural call to regulate their emotions than individuals with lower levels of self-esteem.

**4.2 Self-esteem in healthy individuals and neural activation during cognitive reappraisal**

Dorsolateral and dorsomedial regions of the PFC are core areas supporting emotion regulation, especially strategies that rely on cognitive control, such as reappraisal (Buhle et al., 2014; Etkin et al., 2015; Frank et al., 2014; Ochsner & Gross, 2005). I selected BA6, encompassing medial and lateral dorsal prefrontal regions, as a region of interest to explore in relation to self-esteem during emotion regulation. Two previous studies found activation in BA6 associated with self-esteem in response to implicit (Onoda et al., 2010) or explicit (Eisenberger et al., 2011) social feedback. While unfavourable social feedback may elicit negative emotions and thus trigger emotion regulation, no activation in the BA6 ROI correlated with self-esteem during cognitive reappraisal. Given that I found strong task activation in this region during reappraisal (consistent with the literature), this suggests a true negative (or null) finding for the association of self-esteem and activation in BA6 in an emotion regulatory capacity. This null finding for the association of BA6 with self-esteem during cognitive reappraisal is supported by the behavioural findings for reappraisal success: there was no relationship between level of self-esteem and participants' success at reducing the negative emotion induced by IAPS stimuli. Taken together, these findings suggest that healthy individuals, regardless of their level of self-esteem, are successfully able to downregulate negative emotion using cognitive reappraisal.

However, it is possible that self-esteem related BA6 activation in prior studies did not represent engagement of emotion regulation. Activation in motor-related regions, including

BA6, has previously been linked to appraisals of agency (Dixon et al., 2017). It is possible that perceived social acceptance and rejection are relevant for an individual's sense of agency in a social context. Interestingly, Jiang et al. (2018) found increased activity in the SMA (BA6) when individuals endorsed others' agentic (compared to communal) evaluations of themselves. Agentic evaluations encompassed traits associated with exertion of control over one's environment and personal achievement (e.g. intelligence; Jiang et al., 2018). Therefore, BA6 may have reflected endorsement of negative opinions about one's agency inferred from social exclusion for individuals with low trait self-esteem (Onoda et al., 2010), or fluctuating sense of agency that correlated with state self-esteem evoked by others' social evaluations (Eisenberger et al., 2011). In the context of the present study, the lack of an association with self-esteem for BA6 activation during reappraisal, despite strong task activation in this region, could suggest that unlike receiving social feedback pertinent to one's self, regulating negative emotions arising from viewing others in unpleasant situations may not be as relevant to one's sense of agency.

While self-esteem was not associated with activation in BA6 during cognitive reappraisal, I found clusters suggesting that higher self-esteem may be weakly associated with increased posterior insula activation and decreased posterior cingulate activation. As discussed previously, the insula may be signalling the need to regulate emotion (Kohn et al., 2014). This may, in part, occur as a result of the crucial role played by the insula in interoception, or the representation of internal bodily states in the brain (Cameron, 2001; Craig, 2002; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Herbert & Pollatos, 2012). In addition to contributing to emotional awareness (Craig, 2009; Zaki, Davis, & Ochsner, 2012), interoception may support cognitive reappraisal (Füstös, Gramann, Herbert, & Pollatos, 2013). The posterior cingulate cortex, on the other hand, has previously been associated with attribution of emotional states to the self and others (Ochsner et al., 2004). Taken together, in the context of the current study, these findings could suggest that individuals with higher self-esteem engage interoceptive processes marginally more than their lower self-esteem counterparts. Furthermore, the reduced activation in the posterior cingulate may represent more successful emotion regulation, either as a result of participants' own diminished negative emotion or by viewing the IAPS emotional images less emotionally (i.e. reducing attribution of emotion to others).However this speculation is tentative, given that neither the insula cluster nor the posterior cingulate cluster reached statistical significance after correction for multiple comparisons, and consequently may be spurious findings.

**4.3 Self-esteem in healthy individuals and self-reported emotional reactivity and affect**

Previous work has linked lower self-esteem to patterns of emotional experience characterised by more intense and prolonged experiences of negative emotion (i.e. emotional reactivity; Benetti & Kambouropoulos, 2006; Houben et al., 2015; Kuppens & Verduyn, 2015; Liu et al., 2014). However, I found no relationship between self-esteem and my measure of emotional reactivity (negative emotional intensity rated following Attend Neutral trials subtracted from Attend Negative trials to index reactivity from a personal baseline). Given that the relationship between self-esteem and emotional reactivity is particularly pronounced for low self-esteem (Houben et al., 2015; Kuppens & Verduyn, 2015), one possible factor that may have contributed to this lack of association in the present work was the limited range of self-esteem in the participants, as I had no participants with (true) low self-esteem (but see discussion below).

In contrast to the lack of association between self-esteem and emotional reactivity during scanning, self-esteem was negatively associated with the post-scan measure of negative affect (Negative Affect from PANAS; Watson et al., 1988). In other words, the lower a participant's trait self-esteem, the higher their negative affect following scanning. This mirrors earlier findings that also found that self-esteem and negative affect were negatively associated (Benetti & Kambouropoulos, 2006; Liu et al., 2014). However, the current study failed to replicate the association of positive affect with self-esteem found in Benetti and Kambouropoulos (2006) and Liu et al. (2014). The relationship with negative but not positive affect may be visible since previous research has indicated that the link between self-esteem and affect is particularly pronounced for negative affect (Houben et al., 2015). Importantly, when completing the affect measurement, participants were asked to rate how they were feeling “right now, at this moment”, rather how much they felt a given way “in general” as in the two previous studies (Benetti & Kambouropoulos, 2006; Liu et al., 2014). In addition, given that the range of the PANAS is 10-50, and that the maximum score for negative affect was 16, it is unlikely that the association between self-esteem and negative affect post-scan is clinically meaningful. Without a baseline measurement, it is not clear whether the association of negative affect with self-esteem emerged as a direct result of negative affect during the task or was present before the task commenced. However, the fact that I found an association between self-esteem and negative post scan affect but not negative emotional reactivity during scanning might suggest that at least within healthy variation in self-esteem, lower levels of self-esteem were not related to more *intense* negative emotion, but rather *prolonged* negative emotional experience even after the task ended (Kuppens & Verduyn, 2015). Future research should investigate this further and explore possible mechanisms of prolonged negative emotion (e.g. rumination).

### 4.4 Emotion regulation task-related brain activation

Brain activation observed during the View condition likely captures participants’ initial emotional appraisals of the images they were exposed to. Regions previously reported for negative compared to neutral IAPS images include bilateral MTG and right inferior temporal gyrus, bilateral supramarginal gyri, calcarine sulci, IFG and dmPFC (van der Velde et al., 2015). Consistent with previous findings, I observed significant task-related activation in the bilateral MTG/right inferior temporal gyrus, and left supramarginal gyrus. Interestingly, both the MTG and the supramarginal gyrus are part of the semantic processing network (Binder et al., 2009). Although the MTG was recruited across the whole sample, it was engaged more strongly by individuals with higher levels of self-esteem. Aside from its involvement in semantic processing, the MTG may also be involved in appraising the novelty of a situation during emotional appraisal taking (Dixon et al., 2017). Forming part of the mirror neuron system, activation in the supramarginal gyrus has also been associated with processing others' gestures and movements (Carlson, 2013). Taken together, this suggests that participants may have been processing the actions of people depicted in the IAPS images and engaged in assigning meaning to these.

View and Attend conditions elicited weaker neural activation than previous studies using IAPS stimuli (van der Velde et al., 2015), with no statistically significant clusters in the Attend contrast. Since the View and Attend conditions capture the brain's response to negative compared to neutral images, lower activation in these conditions might suggest that participants in the present study found negative images less emotionally evocative. However, compared to previous studies employing the same emotion regulation task (Modinos et al., 2010; van der Meer et al., 2014; van der Velde et al., 2015) and established IAPS norms (cf. supplementary data from van der Meer et al., 2014), the current behavioural negative emotional intensity ratings were as expected. This suggests that participants did not experience the IAPS images less negatively. Rather, the weaker task activation that I observed for View and Attend conditions compared to Van der Velde et al. (2015) may be due to their superior power, with a sample size of 51. Furthermore, the bilateral MTG clusters they report were the largest clusters in their View contrast – hence our replication of those particular clusters, but fewer of their smaller clusters, may speak to a power-limitation for the present study. Another study using

IAPS images to evoke emotion reported less activation than the present study for viewing negative compared to neutral images (Kanske, Heissler, Schönfelder, & Wessa, 2012), but at twenty-five (healthy) participants, their sample size was marginally smaller than ours. This suggests that viewing and attending to images in contrast to actively reappraising them may have a lower effect size, and thus be more sensitive to sample size.

Our cognitive reappraisal task condition produced very similar activation patterns to both reappraisal meta-analyses (Buhle et al., 2014; Frank et al., 2014; Morawetz et al., 2017) and previous results obtained from the same fMRI emotion regulation task (Modinos et al., 2010; van der Meer et al., 2014; van der Velde et al., 2015). Importantly, cognitive reappraisal activated regions within cognitive control and semantic processing networks, including the dlPFC, dmPFC, IFG, ACC, and MTG, supporting the notion that cognitive reappraisal relies on a combination of cognitive control and semantic processing to manipulate the emotional meanings of stimuli (Buhle et al., 2014).

**4.5 Strengths and limitations of the present study**

The present study demonstrates several strengths. It is a novel investigation of the neural correlates of self-esteem in relation to non-self-related negative emotional cues, which sets it apart from studies employing social rejection or self-referential processing paradigms. In addition, the combination of emotional reactivity and regulation conditions in the current study makes it possible to gain a broader understanding of the unfolding timeline of emotion generation and regulation in relation to individual differences in self-esteem. Interpretation of the findings regarding the key region of interest, the ACC, is supported by a post-hoc ROI analysis based on meta-analytic ACC emotion regulation coordinates, which reduces the likelihood that it is a spurious finding. Furthermore, the use of the well-established RSES facilitates comparability of findings with the existing self-esteem literature and ensures good construct validity. Finally, the current study employed a careful screening procedure which reduced the likelihood of confounding (psycho)pathology, particularly of those that may involve altered self-worth, such as depression.

However, the present study also has some limitations. One lesser limitation pertains to the lack of a baseline PANAS measurement. In the current study, positive and negative affect were measured following scanning. However, although there was a negative correlation between self-esteem and negative affect following scanning, the lack of a pre-scan measure of affect precludes determining whether the lower affect following scanning for individuals with lower self-esteem was as the result of the negative emotions evoked during the emotion regulation task, or, instead, whether individuals with lower self-esteem had higher negative affect in general.

The present study also has two notable limitations that may have contributed to the lack of significant self-esteem related findings following correction for multiple comparisons. The first is the limited range of self-esteem levels represented in this study. RSES scores for participants in this study ranged from average and to above average levels of self-esteem, both in relation to established Dutch norms (Franck et al., 2008) and other self-esteem neuroimaging studies in European populations (e.g. Hoefler et al., 2015; van Schie et al., 2018; Will et al., 2017). Notably, the present study did not include any below-average self-esteem scores. As a result, the present study cannot comment on true *low* self-esteem. It may also be the case that there is a ceiling effect for the association of self-esteem and emotional outcomes, which could have contributed to the lack of significant findings. The lack of representation of low self-esteem may be a result of the stringent screening procedure of the study; however, since the focus of this study was on variation of self-esteem in healthy individuals, the rigorous screening was important to ensure recruitment from the population of interest. It is also possible that individuals with low self-esteem may have been less motivated to participate in a research study, and as a result did not apply to participate.

The second notable limitation is the small sample size of this study. While the current sample size is well above the minimum recommendation of 20 participants for a single group for fMRI research (Simmons et al., 2011) and is on par with typical fMRI sample sizes (Poldrack et al., 2017; Szucs & Ioannidis, 2017) the study still underpowered for the detection of the effects of self-esteem and negative emotion induction on brain activation. Although this is a limitation of the current study, the issue of small sample sizes and underpowered studies in fMRI research remain a relevant concern of the field at large (Poldrack et al., 2017; Szucs & Ioannidis, 2017). This reduction of in the ability to detect effects may be one of the primary reasons why the current findings did not survive correction for multiple comparisons. Consequently, this limits the conclusions that can be drawn from the current findings. It is also possible that a full range of self-esteem scores (i.e. including low self-esteem) might have increased effect size and made the self-esteem analyses more sensitive. As is, the greatest contrast in self-esteem scores in the current study is only achieved between average (rather than true *low* self-esteem) and high self-esteem. However, given the novelty of the present work, the tentative findings in relation to neural correlates of self-esteem in response to general, non-self-related negative emotional cues may be relevant to provide some direction for future research.

This latter limitation should be placed in the context of other critiques that have been levelled at fMRI methods (Eickhoff, Laird, Fox, Lancaster, & Fox, 2017; Eklund, Nichols, & Knutsson, 2016; Poldrack et al., 2017; Szucs & Ioannidis, 2017). Such recent critiques have raised concerns regarding the reliability and validity of fMRI research. In addition the challenges presented by typically small sample sizes (Poldrack et al., 2017; Szucs & Ioannidis, 2017), the validity of fMRI results has been called into question by the high likelihood of false positive results (i.e. reporting brain activation where it is absent) due to erroneous statistical assumptions present in commonly used fMRI software packages (Beisteiner, 2017; Eickhoff et al., 2017; Eklund et al., 2016). The ability to distinguish true results may be further harmed by publication bias against publishing null findings (Nissen, Magidson, Gross, & Bergstrom, 2016). However, where individual studies fall short, slightly more security may be offered by meta-analytic aggregation of findings from multiple studies (Eickhoff et al., 2017), such as those used to select ROI in the present study.2 Finally, rather than seeing the emergence of critiques against fMRI methods as crippling for fMRI, we should see it as a sign of the health of the field. The present moment is only the most recent point in the long evolution of scientific thought (Andersen & Hepburn, 2016), and it is rigorous critique of methods and assumptions that propels the field forward.4.6

**Directions for future research**

The results of the current study suggest that individuals with higher self-esteem may process negative emotions differently from their lower self-esteem counterparts, and that this may be linked to increased activation in the ACC. In particular, self-esteem related differences in brain recruitment were apparent when participants were first exposed to negative emotional stimuli in contrast to neutral stimuli, but were no longer apparent later in the processing stream (as evidenced by a lack of findings for the attend negative compared to attend neutral contrast). This suggests that self-esteem may affect how emotions unfold over time. This is in line with self-esteem-related findings from the field of emotion dynamics such as Houben et al. (2015) and Kuppens and Verduyn (2015). The changes in brain responsivity to negative compared to neutral emotional cues may be relevant for the design of future studies, with particular attention paid to when during the course of the experiment participants are asked to rate emotions (i.e.

[2] However, meta-analyses may not be exempt from all critiques levelled at fMRI (e.g. software errors and publication bias).

immediately after first exposure, or after a period of extended attention or an attempt to regulate). While I have argued that the pattern of self-esteem related brain activation during the View condition may represent the implementation of an early form of emotion regulation for individuals with higher self-esteem, I did not have emotional intensity ratings immediately the first four seconds spent viewing the IAPS pictures. Although the behavioural data gathered further down the timeline did not differ as a function of self-esteem, it may be that earlier emotion ratings would have been different.

Extending exploration of the emotion dynamics associated with self-esteem, it may be valuable to determine whether exposure to negative emotions during an fMRI task such as ours has a longer-lasting negative effect for individuals with lower self-esteem (Houben et al., 2015; Kuppens & Verduyn, 2015). For example, by administering the PANAS before and after scanning. Should it be the case that individuals with lower levels of self-esteem experience more negative affect after completing the emotion regulation task (as reflected by a difference in pre- and post-scan affect), the mechanism would be of interest. In particular, it may be useful to consider whether default negative thought processes such as rumination might be involved. Rumination may be a likely mechanism given prospective, longitudinal evidence that the link between low self-esteem and depression is mediated by rumination (Kuster, Orth, & Meier, 2012). That might explain why on the one hand individuals with differing levels of trait self-esteem were able to use cognitive reappraisal to equal effect in the short term, yet after scanning, individuals with lower levels of self-esteem reported more negative affect. In other words, it may be that individuals engaged in rumination after completing the fMRI task. This could also be explored at a neural level by gathering resting state fMRI data in conjunction with task fMRI.

Lastly, results did not support self-esteem-related differences in the ability to successfully perform cognitive reappraisal of negative emotional images. On the one hand, this suggests that cognitive reappraisal is an effective emotion regulation technique, regardless of individual levels of self-esteem, at least as far as non-self-related negative emotional challenges are concerned. Future research might combine social feedback and emotion regulation paradigms to see whether cognitive reappraisal remains effective for self-related stimuli (such as negative social feedback or social exclusion). On the other hand, although self-esteem may not influence an individual's capacity to successfully use cognitive reappraisal in the context of general negative emotions, self-esteem may still influence reappraisal in service of upregulating positive emotions. Some research shows self-esteem related differences in responsivity to, and biased processing of, positive social feedback (Somerville et al., 2010). Furthermore, since self-esteem may influence selection of emotion regulation techniques and the choice of whether or not to engage in a regulation process at all (Heimpel et al., 2002; Shafir et al., 2016; Wood et al., 2009), it may yet affect the ability to perform emotion regulation techniques other than cognitive reappraisal. The general tendency toward more intense and prolonged negative emotions for individuals with low self-esteem may be related to the choice of whether or not to regulate emotion and/or selection of suboptimal emotion regulation techniques on a day-to-day basis, rather than a reduced ability to perform a particular technique, such as cognitive reappraisal.

**4.7 Concluding remarks**

Individual levels of trait self-esteem may affect recruitment of the ACC during processing of negative stimuli that are not self-related. This may reflect successful automatic emotion regulation in the initial appraisal stage in individuals with higher self-esteem, in line with demonstrated spatial overlap between the presently reported activation and ACC activation reported in meta-analyses of emotion regulation tasks. While self-esteem may affect brain responsivity during cognitive reappraisal, the observed trends must be interpreted with caution, since the findings do not survive correction for multiple comparisons, and the emotional outcomes of applying the technique do not differ as a function of self-esteem. Taken together, the findings suggest that high trait self-esteem may be advantageous in allowing for rapid automatic emotion regulation in response to negative emotional cues, whereas this advantage is no longer evident when explicitly instructed to engage in cognitive reappraisal. Whereas the current work offers novel insight into self-esteem related brain activation in early emotion processing of non-self-related negative emotional cues, the findings are preliminary and can be strengthened by future direct comparisons of self-related and non-self-related negative emotional challenges and closer examination of the temporal dynamics of emotion processing and regulation in relation to self-esteem.

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## Appendix A: Questionnaires

### Beck Depression Inventory-II

(BDI-II)

**Instructions**: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the one statement in each group that best describes the way you have been feeling during the past two weeks, including today. Circle the number beside the statement that you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group. Be sure that you do not choose more than one statement for any group, including Item 16 (Changes in Sleep Pattern) and Item 18 (Changes in Appetite). There are no correct answers. Feel free to ask the researcher about any questions or concerns you may have.

**1. Sadness**
0 I do not feel sad.
1 I feel sad much of the time.
2 I am sad all of the time.
3 I am so sad or unhappy that I can't stand it.

**2. Pessimism**
0 I am not discouraged about my future.
1 I feel more discouraged about my future than I used to be.
2 I do not expect things to work out for me.
3 I feel my future is hopeless and will only get worse.

**3. Past Failure**
0 I do not feel like a failure
1 I have failed more than I should have.
2 As I look back, I see a lot of failures.
3 I feel I am a total failure as a person.

**4. Loss of Pleasure**
0 I get as much pleasure as I ever did from the things I enjoy.
1 I don't enjoy things as much as I used to.
2 I get very little pleasure from the things I used to enjoy.
3 I can't get any pleasure from the things I used to enjoy.

**5. Guilty Feelings**
0 I don't feel particularly guilty.
1 I feel guilty over many things I have done or should have done
2 I feel quite most of the time.
3 I feel guilty all of the time.

**6. Punishment Feelings**
0 I don't feel I am being punished.
1 I feel I may be punished.
2 I expect to be punished.
3 I feel I am being punished.

**7. Self-Dislike**
0 I feel the same about myself as ever.
1 I have lost confidence in myself.
2 I am disappointed in myself.
3 I dislike myself.

**8. Self-Criticalness**
0 I don't criticise or blame myself more than usual.
1 I am more critical of myself than I used to be.
2 I criticise myself for all my faults.
3 I blame myself for everything bad that happens.

**9. Suicidal Thoughts or Wishes**
0 I don't have any thoughts of killing myself.
1 I have thoughts of killing myself, but I would not carry them out.
2 I would like to kill myself.
3 I would kill myself if I had the chance

**10. Crying**
0 I don't cry anymore than I used to.
1 I cry more than I used to.
2 I cry over every little thing.
3 I feel like crying, but I can't.

**11. Agitation**
0 I am no more restless or wound up than usual.
1 I feel more restless or wound up than usual.
2 I am so restless or agitated that it's hard to stay still.
3 I am so restless or agitated that I have to keep moving or doing something.

**12. Loss of Interest**
0 I have not lost interest in other people or activities.
1 I am less interested in other people or things than before.
2 I have lost most of my interest in other people or things.
3 It's hard to get interested in anything.

**13. Indecisiveness**
0 I make decisions as well as ever.
1 I find it more difficult to make decisions than usual.
2 I have much greater difficulty in making decisions than I used to.
3 I have trouble making any decisions.

**14. Worthlessness**
0 I do not feel I am worthless.
1 I don't consider myself as worthwhile and useful as I used to be.
2 I feel more worthless as compared to other people.
3 I feel utterly worthless.

**15. Loss of Energy**
0 I have as much energy as ever.
1 I have less energy than I used to have.
2 I don't have enough energy to do very much.
3 I don't have enough energy to do anything.

**16. Changes in Sleep Pattern**
0 I have not experienced any change in my sleeping pattern.
1a I sleep somewhat more than usual.
1b I sleep somewhat less than usual.
2a I sleep a lot more than usual.
2b I sleep a lot less than usual.
3a I sleep most of the day.
3b I wake up 1-2 hours early and can't get back to sleep.

**17. Irritability**
0 I am no more irritable than usual.
1 I am more irritable than usual.
2 I am much more irritable than usual.
3 I am irritable all the time.

**18. Changes in Appetite**
0 I have not experienced any changes in my appetite
1a My appetite is somewhat less than usual.
1b My appetite is somewhat more than usual.
2a My appetite is much less than usual.
2b My appetite is much more than usual.
3a I have no appetite at all.
3b I crave food all the time.

**19. Concentration Difficulty**
0 I can concentrate as well as ever.
1 I can't concentrate as well as usual.
2 It's hard to keep my mind on anything for very long.
3 I find I can't concentrate on anything.

**20. Tiredness or Fatigue**
0 I am no more tired or fatigued than usual.
1 I get more tired or fatigued more easily than usual.
2 I am too tired or fatigued to do a lot of the things I used to do.
3 I am too tired or fatigued to do most things I used to do.

**21. Loss of Interest in Sex**
0 I have not noticed any recent change in my interest in sex.
1 I am less interested in sex than I used to be.
2 I am much less interested in sex now.
3 I have lost interest in sex completely.

**Rosenberg Self-Esteem Scale**

RSES

Items

Rate the items using the following scale:

1 = strongly agree 2 = agree 3 = disagree 4 = strongly disagree

_____ 1. I feel that I am a person of worth, at least on an equal basis with others.

_____ 2. I feel that I have a number of good qualities.

_____ 3. All in all, I am inclined to feel that I am a failure. *

_____ 4. I am able to do things as well as most other people.

_____ 5. I feel I do not have much to be proud of. *

_____ 6. I take a positive attitude toward myself.

_____ 7. On the whole, I am satisfied with myself.

_____ 8. I wish I could have more respect for myself. *

_____ 9. I certainly feel useless at times. *

_____ 10. At times I think I am no good at all. *

*reverse-scored

**Positive and Negative Affect Schedule**

(PANAS)

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you feel this way **right now, that is, at the present moment**. Use the following scale to record your answers.

1 = very slightly or not at all

2 = a little

3 = moderately

4 = quite a bit

5 = extremely

| | |
|---|---|
| _______ interested | _______irritable |
| _______ distressed | _______alert |
| _______ excited | _______ashamed |
| _______ upset | _______inspired |
| _______ strong | _______nervous |
| _______ guilty | _______determined |
| _______ scared | _______attentive |
| _______ hostile | _______jittery |
| _______ enthusiastic | _______active |
| _______ proud | _______afraid |