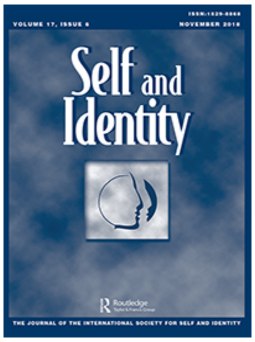

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Self-compassion and responses to negative social feedback: The role of fronto-amygdala circuit connectivity

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ABSTRACT
Self-compassion has been shown to have significant relationships with psychological health and well-being. Despite the increasing growth of research on the topic, no studies to date have investigated how self-compassion relates to neural responses to threats to the self. To investigate whether self-compassion relates to threat-regulatory mechanisms at the neural level of analysis, we conducted a functional MRI study in a sample of college-aged students. We hypothesized that self-compassion would relate to greater negative connectivity between the ventromedial prefrontal cortex (VMPFC) and amygdala during a social feedback task. Interestingly, we found a negative correlation between self-compassion and VMPFC-amygdala functional connectivity as predicted; however, this seemed to be due to low levels of self-compassion relating to greater positive connectivity in this circuit (rather than high levels of self-compassion relating to more negative connectivity). We also found significant relationships with multiple subcomponents of self-compassion (Common Humanity, Self-Judgment). These results shed light on how self-compassion might affect neural responses to threat and informs our understanding of the basic psychological regulatory mechanisms linking a lack of self-compassion with poor mental health.

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Self-compassion; fMRI; threat; emotion regulation

Self-compassion is defined as the tendency to be kind, warm, and understanding toward oneself in the midst of our pain and failures rather than being self-critical and over-identifying with negative emotions (Neff, 2003). Research on self-compassion has attracted increasing attention since it was first introduced in psychological science 15 years ago (Neff, 2003). While the importance of compassion directed toward the self has been recognized historically (Brach, 2004; Gunaratana, 2015; Kabat-Zinn, 1982; Salzberg, 1997), only recently have researchers sought to systematically understand its unique contributions for mental health and well-being (Macbeth & Gumley, 2012). Moreover, research in this area is beginning to establish connections between self-compassion and interpersonal functioning (e.g., Yarnell & Neff, 2013).

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Despite many correlational studies establishing broad associations between self-compassion and its health and interpersonal benefits, the mechanisms underlying these advantages remain poorly understood. Thus, the goal of the current study was to begin to explore the neural regulatory mechanisms that may underlie the benefits of self-compassion.

Extensive research has highlighted the benefits of self-compassion. Self-compassion has been linked to decreased risk for psychopathology and related maladaptive cognitive and behavioral patterns. For instance, self-compassion has been linked to decreased risk for depression (Krieger, Altenstein, Baettig, Doerig, & Holtforth, 2013; Macbeth & Gumley, 2012; Raes, 2010), and depressed patients, compared to healthy controls, report less self-compassion, even when statistically controlling for differences in depressive symptoms (Krieger et al., 2013). In addition, the benefits of self-compassion extend into interpersonal domains of psychological functioning. For example, self-compassion is associated with greater relationship satisfaction, perspective-taking, and forgiveness, as well as less self-defensive relationship behaviors, such as being detached, domineering, and verbally aggressive (Neff & Beretvas, 2013; Neff & Pommier, 2013). Taken together, these results suggest that self-compassion allows individuals to cope with negative affect and threats to the self in a way that preserves a healthy, confident sense of self while not being reactive. Therefore, when individuals are self-compassionate, threats to the self are met with neither self-defensiveness and anger nor avoidance and fear (e.g., Leary, Tate, Adams, Allen, & Hancock, 2007; Neff, Kirkpatrick, & Rude, 2007).

Research in social and personality psychology has recently begun to explore the mechanisms underlying self-compassion and has suggested that self-compassion may act as an emotion regulatory or coping mechanism useful for reducing feelings of threat, stress, or anxiety (Allen & Leary, 2010). For example, in an investigation of how self-compassion may be protective against threat, research has shown that trait self-compassion is linked to less avoidance coping and more positive emotional restructuring (Allen & Leary, 2010). These findings have been supported by experimental work showing that self-compassion uniquely buffers against self-evaluative anxiety in potentially threatening social settings like mock job interviews (Neff et al., 2007). Relatedly, self-compassion relates to less public self-consciousness as well as greater emotional stability, such that self-compassionate individuals' emotional states are less contingent on external circumstances (Neff & Vonk, 2009). In sum, self-compassion may lead to less ego-defensiveness, fear, and anger in response to negative social evaluation (Leary et al., 2007; Neff & Vonk, 2009).

While behavioral research has begun to dissect the mechanisms of self-compassion, neuroimaging approaches may also prove to be useful in examining the underlying basis of this trait. Unfortunately, no research to date has investigated the neural mechanisms by which self-compassion may protect against threats to the self. Even though social neuroscience research on the closely-related topic of self-esteem has emerged over the past decade (Chavez & Heatherton, 2014; Eisenberger, Inagaki, Muscatell, Haltom, & Leary, 2011; Somerville, Kelley, & Heatherton, 2010), the brain basis of self-compassion and specifically its relationship with social threats remains unknown.

Given behavioral research on self-compassion's threat-reducing effects, the effects of self-compassion as an emotion regulation mechanism may be apparent at the neural level of analysis. Neural systems that support successful emotional regulation and the regulation of threat-related processes have been well-characterized in human neuroscience research as well as in research on non-human animals. Specifically, threat-related activity in the amygdala is tightly controlled by direct projections from the ventromedial prefrontal cortex (VMPFC; Milad, Vidal-Gonzalez, & Quirk, 2004).

In some cases, the VMPFC is thought to have a direct causal effect in reducing amygdala activity and the associated patterns of fearful behavioral responding (Adhikari et al., 2015; Vidal-Gonzalez, Vidal-Gonzalez, Rauch, & Quirk, 2006). Along these lines, research has shown negative functional connectivity between these two regions in response to several different types of emotion regulatory processes, including fear extinction (Hare et al., 2008; Kim, Somerville, Johnstone, Alexander, & Whalen, 2003; Milad, Rosenbaum, & Simon, 2014; Phelps, Delgado, Nearing, & Ledoux, 2004) as well as cognitive reappraisal (Lee, Heller, Van Reekum, Nelson, & Davidson, 2012). Thus, greater negative functional connectivity is indicative of greater emotion regulatory processes.

In other cases, though, the VMPFC is thought to play a role in upregulating the amygdala's responses to threat (Johnstone, Reekum, Urry, Kalin, & Davidson, 2007). Specifically, positive functional connectivity between VMPFC and the amygdala has been shown to increase in response to both short-term exposure to unpredictable threat (Gold, Morey, & McCarthy, 2015) and longer-term responses to social threat (Veer et al., 2011). Along these same lines, neuroimaging research has shown that greater positive connectivity between ventral PFC and amygdala positively correlated with self-reported pain to a cold-pressor task (Clewett, Schoeke, & Mather, 2013). In addition, greater positive connectivity within this circuit has been found to associate with higher levels of endogenous cortisol, a stress-related hormone (Veer et al., 2012). Furthermore, another plausible way to understand positive connectivity is in terms of the use of bottom-up salience attribution from the amygdala to the frontal cortex (Cunningham and Brosch, 2012). This circuitry is thought to be necessary for effective emotional and motivational responding to personally relevant stimuli in the social environment. Taken together, these lines of research suggest that the VMPFC-amygdala circuit is broadly involved in emotion and motivation, but in particular with threat-related processes.

Based on this work, human neuroimaging research can attempt to better understand the brain bases of self-compassion by examining the interplay between self-reported levels of self-compassion and VMPFC-amygdala functional connectivity in response to negative interpersonal feedback. To examine whether self-compassion is associated with VMPFC-amygdala circuit functioning, we conducted secondary data analyses on an fMRI study utilizing a social evaluative feedback paradigm (Eisenberger et al., 2011). The data were gathered from a study that explored the neural correlates of changes in state self-esteem as a function of social feedback. For the present paper, we explored whether self-compassion was linked to differences in functional connectivity between VMPFC and amygdala in response to negative (relative to neutral) social feedback. We hypothesized that self-compassion would correlate negatively with connectivity in the VMPFC-amygdala circuit, such that greater self-compassion would be associated with relatively greater negative connectivity in this circuit and less self-compassion would be associated with relatively greater positive connectivity between the VMPFC and amygdala.

Methods

Participants

Nineteen college-aged participants (12 female; *M* = 20.316 years, range = 18–27 years) took part in the present study. Participants were recruited from UCLA and the surrounding community. The study was representative of standard UCLA demographics: 47% Asian, 16% White, 16% Filipino, 11% Latino/Chicano, 5% Black/African American, and 5% Other.

Procedure

Potential participants were excluded during phone screening due to contraindications for the MRI environment (e.g., metallic implants, left-handedness, claustrophobia) and history of neurological or psychiatric disorders. During the study session, participants met with a confederate and the experimenter in the laboratory. The participant and confederate were informed that they were taking part in an fMRI study on impression formation. They were told that, during the first part of the study, they would each fill out some questionnaires and then engage in an audio-recorded interview that would later be listened to by the other participant. During the second part of the study, they would each complete the fMRI scan while the other participant listened to their interview and gave feedback about how the person was coming across in the interview while sitting outside of the scanner. The person being scanned would simultaneously view this feedback and rate their emotional responses.

Following the explanation of the procedure, the participant and confederate were placed into different testing rooms and given questionnaire packets. The experimenter then started the interview with the participant. The interview involved asking about the participant's personal characteristics and attitudes such as "What makes you happy?" and "What is your greatest shortcoming?" Following approximately 10 min of questions, the interview was finished, and the participant was reminded of what would happen during the scanning session. The experimenter then instructed the participant to finish the questionnaires while the confederate was ostensibly interviewed for the next 10 min. Before leaving the laboratory, the experimenter requested the participant and confederate draw slips of paper to determine who would be scanned first. The drawing of the slips of paper was rigged such that the participant's name was always picked so they would be scanned first (the confederate was never scanned). After the participant and confederate picked slips of paper, the experimenter guided the participant and the confederate to the UCLA Brain Mapping Center to complete the imaging session.

Once at the neuroimaging facility, the confederate was instructed to wait in the lobby as the participant was set up in the scanner. After the participant was situated in the scanner, the experimenter brought the confederate into the scanner control room and reminded the participant and confederate of the task procedure. The confederate then asked the experimenter some additional questions about the protocol (to increase believability that the confederate was a real subject). These questions could be heard by the participant via the intercom in the scanner. The participant heard the confederate being instructed to click on a descriptive feedback button once every 10 s while listening to the participant's interview, and to give their honest impressions of the participant in their interview. Participants were reminded to rate how they felt after seeing each feedback word using the button box in the scanner.

fMRI social feedback task

While in the scanner, participants viewed the computer screen displaying an array of adjective "buttons" (i.e., "interesting," "modest," "boring") and watched a pre-recorded video of a cursor moving around the screen, which they were led to believe was the real-time display of the confederate's feedback on their interview. The number of feedback adjectives were equally divided into a positive category (e.g., "intelligent"), a neutral category (e.g., "practical") and a negative category (e.g., "annoying"). Participants watched a new adjective button selected every 10–12 s. During the entirety of the scan session, participants received fifteen each of positive, neutral and negative feedback selections. After seeing an adjective button selected, participants were told to respond to the question "How do you feel?" by responding on a 4 point Likert scale (from 1 (really bad) to 4 (really good)) with a button box. This was done during the 10–12 s period in which they were shown the adjective. Overall neural responses to this task, as well as how they relate to self-reported feelings, have been reported previously (Eisenberger et al., 2011); in this paper, we focus specifically on how self-compassion modulates functional connectivity during the task. Following the experimental session, participants were promptly debriefed in a funneled manner and informed of the true purpose of the study. No participants reported suspicion prior to debriefing about the true purpose of the study.

Self-compassion measure

To measure self-compassion, we used the self-compassion scale (SCS; Neff, 2003). This scale was administered prior to the MRI scan. The scale consists of six subscales divided into three pairs of two opposite factors: Self-Kindness (e.g., "When I'm going through a very hard time, I give myself the caring and tenderness I deserve") vs. Self-Judgment (e.g., "When times are really difficult, I tend to be tough on myself"), Common Humanity (e.g., "When I feel inadequate in some way, I try to remind myself that feelings of inadequacy are shared by most people") vs. Isolation (e.g., "When I think about my inadequacies, it tends to make me feel more separate and cut off from the rest of the world"), and Mindfulness (e.g., "When something upsets me I try to keep my emotions in balance") vs. Over-identification (e.g., "When I'm feeling down, I tend to obsess and fixate on everything that's wrong"). Participants were asked to indicate how they typically act toward themselves in difficult situations. Each statement was scored on Likert scales from 1 (almost never) to 5 (almost always). Item scores from the negative subscales representing uncompassionate responding (e.g., self-judgment, isolation, over-identification) were reverse-coded. The positive and negative subscale items were then combined and averaged to create an overall self-compassion mean score.

Trait self-compassion as measured by the SCS has been shown to be best summarized by a single general factor, including both the positive and negative items of the scale (Neff, Long et al., 2018; Neff, Tóth-Király et al., in press).). Research using bifactor exploratory structural equation modeling has shown that 94% of SCS item variance can be explained by this general factor.

The 26-item SCS measure was found to be highly reliable (α = .913). Moreover, the six subscales were shown to have good reliability: the five-item SCS-Self-Kindness subscale (α = .729), the five-item SCS-Self-Judgment subscale (α = .759), the four-item SCS-Common Humanity subscale (α = .724), the four-item SCS-Isolation subscale (α = .669), the four-item SCS-Mindfulness subscale (α = .818), and the four-item SCS-Overidentification subscale (α = .792).

MRI data acquisition

MRI data were acquired using a Siemens Trio 3-Tesla MRI scanner at the UCLA Brain Mapping Center. A high-resolution structural scan (echoplanar T2-weighted spin-echo, repetition time (TR) = 4000 msec, echo time (TE) = 54 msec, matrix size = 128 × 128, field of view (FOV) = 20 cm, 36 slices, 1.56-mm in-plane resolution, 3-mm thick) coplanar with the functional scans was obtained for coregistration with functional images during data preprocessing. Following the structural scan, the social feedback task was completed during a functional scan, which lasted 498 seconds (echoplanar T2*-weighted gradient-echo, TR = 3000 msec, TE = 25 msec, flip angle = 90°, matrix size = 64 × 64, 36 axial slices, FOV = 20 cm, 3-mm thick, 3-mm cubic voxel size, skip = 1 mm).

MRI pre-processing

MRI data were pre-processed with the Statistical Parametric Mapping software (SPM8; Wellcome Department of Cognitive Neurology, London, UK). The pre-processing pipeline incorporated image realignment to correct for head movement, co-registration of the functional to the structural images, and spatial normalization to Montreal Neurologic Institute (MNI) space (resampled at 3 mm isotropic), and spatial smoothing using an 8mm Gaussian kernel, full width at half maximum, to increase signal-to-noise ratio.

Functional connectivity analyses

To examine potential interactions between targeted neural regions of interest (ROIs), functional connectivity analyses were conducted with the CONN toolbox (nitrc.org/projects/conn) implemented through MATLAB and SPM8 software. The pre-processed functional and structural data were entered into the toolbox. Confounding variables that distort functional connectivity values were removed through the CONN CompCor algorithm for physiological noise as well as temporal filtering (f>.008Hz). Realignment parameters (representing head movement) produced during pre-processing were also entered in the toolbox as nuisance covariates to be removed from statistical analyses. For the functional data collected during the social feedback task, condition onsets and duration were specified in the toolbox, so that BOLD time series could be appropriately divided into task-specific blocks.

For the main statistical tests of interest, we conducted ROI-to-ROI analyses to determine functional connectivity (i.e., temporal correlations) between the VMPFC and both the left and right amygdala. For these analyses, we chose ROIs based on previous studies of emotion regulation (e.g., Diekhof et al., 2011). The VMPFC ROI was generated from the Harvard-Oxford probabilistic cortical atlas (Desikan et al., 2006), and the right and left amygdala ROIs were generated from the Automated Anatomical Labeling (AAL) Atlas (Tzourio-Mazoyer et al., 2002). Within the ROIs, the BOLD activation time series was averaged across all voxels. Functional connectivity values were computed on each individual's feedback condition time series from these ROIs at the single-subject level. These connectivity values provide a measure of the statistical dependence of the ROIs' BOLD activation time series. Connectivity values underwent Fisher's r-to-Z transformation to ensure assumptions of normality. This procedure was completed to generate task-evoked connectivity measures for each of the three social feedback conditions. We then explored whether self-compassion correlated with connectivity during negative (relative to neutral) feedback as well as during positive (relative to neutral) feedback. These relative connectivity measures were generated by taking the difference between connectivity values produced by the original, absolute, condition-specific (negative, positive, neutral) analyses. In other words, they should be interpreted as the difference in the functional coupling between these neural regions (i.e., VMPFC and amygdala) between these conditions (i.e., during negative feedback compared to during neutral feedback). These absolute and relative connectivity values were imported into SPSS v23 for further statistical analyses.

To examine correlations between self-compassion and VMPFC-amygdala connectivity during negative feedback specifically, we computed Pearson's correlations between self-compassion and VMPFC-amygdala connectivity during negative relative to neutral feedback (to allow for a baseline comparison). Any significant effects were followed up by additional analyses exploring whether the effects were being driven by the negative feedback condition or by the neutral feedback condition. To do this, we examined correlations between self-compassion and VMPFC-amygdala connectivity during the negative feedback condition and during the neutral feedback condition separately. These same procedures were repeated to examine correlations between self-compassion and VMPFC-amygdala connectivity during the positive vs. neutral feedback conditions. Finally, any significant correlations between self-compassion and connectivity were followed up by subscale analyses, which examined which specific subscales correlated with connectivity.

Results

Self-compassion and VMPFC-amygdala connectivity

As predicted, statistical analyses revealed that self-compassion (averaged across subscales) was negatively correlated with VMPFC- right amygdala connectivity during negative vs. neutral feedback ($r(18) = -.402$; Table 1). As displayed in Figure 1, higher self-compassion was associated with more negative functional connectivity between VMPFC and right amygdala during negative relative to neutral feedback, whereas lower self-compassion was associated with greater positive connectivity between VMPFC and right amygdala. There was no significant correlation between self-compassion and VMPFC-left amygdala connectivity in response to negative vs. neutral feedback ($r(18) = -.263$, $p = 0.165$), though the relationship was in the same direction as found with the right amygdala.

Table 1. Zero-order correlations between SCS total and subscale scores and Neg-Neu VMPFC-right amygdala connectivity.

SCS scale	Zero-order correlation	*p*-value
Self-compassion mean	−.402*	.044
Self-kindness	−.182	.227
Self-judgment	.417*	.038
Common humanity	−.518*	.012
Isolation	.070	.387
Mindfulness	−.321†	.090
Over-identification	.317†	.093

Notes: Items from the negative subscales (Self-Judgment, Isolation, Over-identification) were reverse coded before the Self-Compassion Mean values were computed.
*$p<.05$; †$p<.1$.

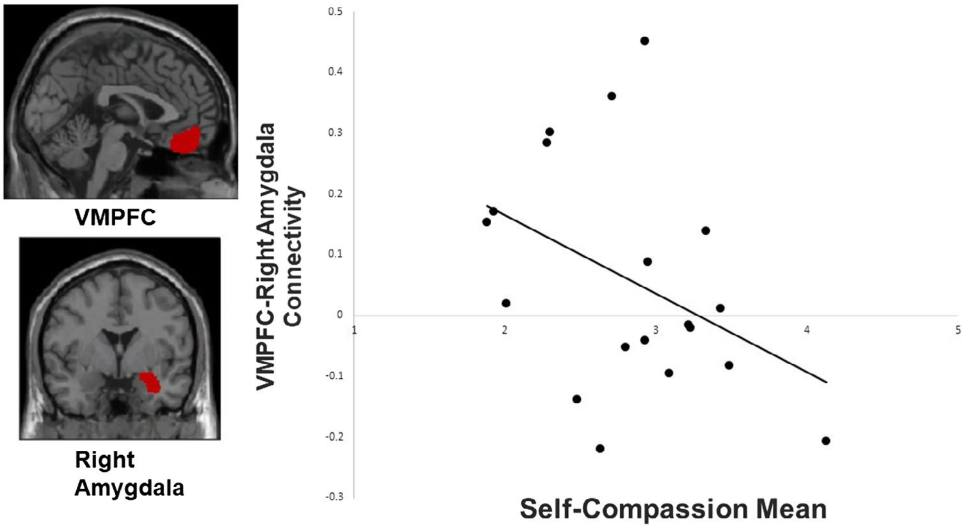

Figure 1. Scatterplot depicting the significant negative relationship between mean self-compassion generated from the average of the subscales and VMPFC-right amygdala functional connectivity during negative vs. neutral social feedback.

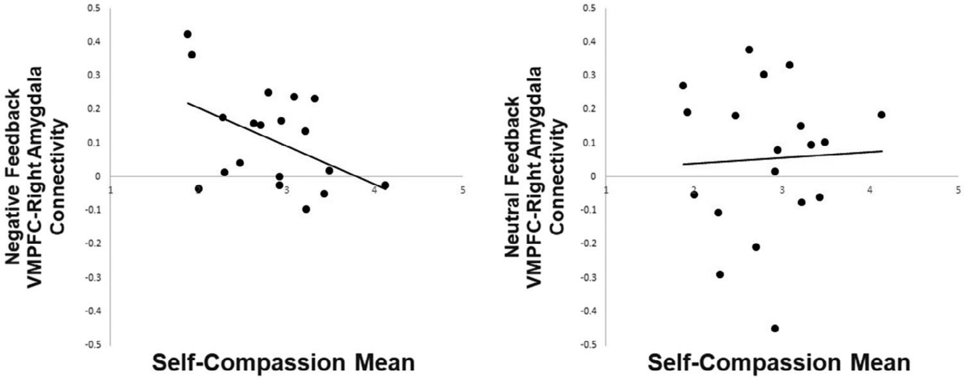

Figure 2. Scatterplot depicting the relationships between mean self-compassion and VMPFC-right amygdala functional connectivity separately during negative and neutral social feedback.

To further explore whether the relationship between self-compassion and VMPFC-right amygdala connectivity was being driven by negative feedback (as expected) or by neutral feedback, we analyzed correlations between self-compassion and connectivity during negative and neutral feedback separately. Here, we found that the relationship between self-compassion and VMPFC-right amygdala connectivity reported above appeared to be driven by connectivity in the negative feedback condition (Figure 2). Specifically, there was a negative correlation between self-compassion and connectivity in response to negative feedback ($r(18) = -.458$, $p = 0.024$), whereas, self-compassion was not associated with connectivity in response to neutral feedback ($r(18) = .044$, $p > .05$) . Somewhat surprisingly, the negative correlation between self-compassion and connectivity in response to negative feedback appeared to be explained by those lower in self-compassion showing higher positive VMPFC-amygdala connectivity, rather than those high in self-compassion showing greater negative connectivity.

We also explored whether self-compassion correlated with connectivity during positive vs. neutral feedback and found no significant effects for VMPFC-right amygdala connectivity (*r*(18) = −.262, *p* = .140) nor VMPFC-left amygdala connectivity (*r*(18) = −.366, *p* = .062). In light of these non-significant findings for the positive feedback condition, further analyses of the positive feedback condition were not explored.

Subscales of self-compassion and VMPFC-amygdala connectivity

Based on the significant relationship between self-compassion and VMPFC-amygdala connectivity during negative vs. neutral feedback, we then further examined how the subscales of the self-compassion scale correlated with these connectivity scores. In our analyses of subscales of the SCS, we found significant correlations with two of the subscales: Self-Judgment and Common Humanity (Figure 3). Specifically, there was a significant positive correlation between SCS-Self-Judgment and VMPFC- right amygdala connectivity (*r*(18) = .417; Table 1). This effect did not seem to be specific to either the negative or neutral feedback, as VMPFC-right amygdala connectivity did not significantly correlate with SCS-Self-Judgment during negative (*r*(18) = .205, *p* = .200) or neutral (*r*(18) = −.226, *p* = .176) feedback conditions when they were examined separately. There was also a significant negative correlation between SCS-Common Humanity and VMPFC-right amygdala connectivity in response to negative vs. neutral feedback (*r*(18) = −.518; Table 1). This effect was likely driven by the significant negative correlation with absolute VMPFC-right amygdala connectivity during negative feedback (*r*(18) = −.442, *p* = .029), as we did not find a significant association between SCS-Common Humanity and connectivity during neutral feedback (*r*(18) = .156, *p* = .262). Thus, it appeared that having low levels of Common Humanity was associated with greater positive connectivity between VMPFC and right amygdala during negative feedback. In addition to these subscale results, we found a marginally significant negative correlation between SCS-Mindfulness and VMPFC-right amygdala connectivity in

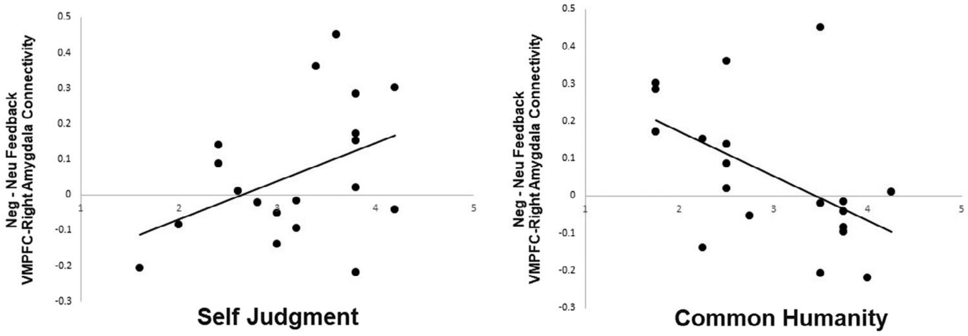

Figure 3. Scatterplots depicting the relationships between Common Humanity and Self-judgment subscales of the Self-Compassion Scale and VMPFC-right amygdala functional connectivity during negative vs. neutral social feedback.

response to negative vs. neutral feedback (*r*(18) = −.321; Table 1). We also found a marginally significant positive correlation between SCS-Over-Identification and VMPFC-right amygdala connectivity in response to negative vs. neutral feedback (*r*(18) = .317; Table 1). The other subscales were not significantly correlated with connectivity (Table 1).

Discussion

To our knowledge, this is the first study to examine the neural processes by which self-compassion relates to neural responses to social feedback. As predicted, we found a negative association between self-compassion and VMPFC-amygdala connectivity during negative (relative to neutral) feedback. Thus, those higher in self-compassion showed relatively greater negative VMPFC-amygdala connectivity in response to negative (vs. neutral) feedback, whereas those lower in self-compassion showed relatively greater positive connectivity to negative feedback. Upon further parsing of the data, these responses seemed to be driven by patterns of connectivity to negative rather than neutral feedback, as expected. However, somewhat surprisingly, rather than high levels of self-compassion being related to greater negative connectivity, we instead found that lower levels of self-compassion were related to greater positive connectivity between VMPFC and amygdala. We interpret these unexpected findings as indicating that a lack of self-compassion may lead to heightened sensitivity to negative emotional experiences. We also show that Self-Judgment and Common Humanity components of self-compassion show particularly strong associations with functioning of this circuit. Taken together, these results shed light on the emotion processing functions related to individual differences in self-compassion and the role of the VMPFC-amygdala circuit in contributing to the effects of self-compassion on responding to threats to the self. These findings may help address the underlying mechanisms that link low levels of self-compassion with poor mental health and interpersonal problems.

From a psychological perspective, the findings of this fMRI study contribute to our understanding of the functioning of emotion/affective processing mechanisms associated with self-compassion. While multiple lines of neuroimaging research link the functioning of VMPFC-amygdala circuitry to emotion regulation processes, there is also substantial evidence to suggest that this circuitry is involved in emotion generation processes as well (Gold et al., 2015; Johnstone et al., 2007; Veer et al., 2012). More specifically, based on this research, one possible interpretation of our results is that individuals lacking self-compassion elicit an over-exaggerated response to negative information in their social environments. VMPFC-amygdala circuitry has been implicated in top-down signaling mechanisms for ascribing affective salience to stimuli in the environment (Cunningham & Brosch, 2012). The function of the top-down connections from the VMPFC to the amygdala can be thought of as facilitating switching attention to, and preparing behavioral responses to, emotionally or motivationally relevant stimuli (Cardinal, Parkinson, Hall, & Everitt, 2002; Ochsner et al., 2009).

This heightened detection of salient negative social stimuli may directly lead to negative emotions in daily life. The emotional consequences associated with low levels of self-compassion have been described in the multiple behavioral studies primarily aimed at determining the special benefits of self-compassion for psychological well-being. For example, individuals lacking self-compassion were more likely to ruminate and experience negative affect after being exposed to critical social evaluations (Leary et al., 2007). Similar findings have shown that low levels of self-compassion lead to relatively greater anxious feelings when experiencing social-evaluative threat after being judged in a mock job interview (Neff, Kirkpatrick, & Rude, 2007). Many of these and other similar behavioral studies originally highlighted the unique advantages associated with high levels of self-compassion, but our neuroimaging results also point to the potential importance of determining the unique disadvantages associated with low levels of self-compassion (i.e., a tendency to up-regulate threat and negative affect). However, this is not to suggest that correlations with low levels of self-compassion were better explained by the negative subscales, given that both certain positive and negative subscales related significantly to VMPFC-right amygdala functional connectivity during negative vs. neutral feedback, as discussed below. Additionally, these neuroimaging analyses help potentially clarify the source of these experimental effects by specifically showing that low levels of self-compassion may be a key contributor to differences in emotional consequences. Given the behavioral findings alone, it is not clear which group of participants (low vs. high self-compassion individuals) may be the driver of these associations. Moreover, it is unclear whether distinct psychological processes may be involved in these different groups. These imaging approaches can be leveraged to begin to effectively resolve some of these inferential issues.

From a neuroscience perspective, the findings also inform our understanding of the emotional processing functions subserved by VMPFC-amygdala circuitry. While a great deal of research shows that the VMPFC can modulate amygdala activity in the context of learning about threat-related cues associated with nonsocial dangers (Diekhof et al., 2011), less is known about the role of VMPFC-amygdala functional interactions in the context of socially threatening/evaluative situations. While previous neuroimaging research has shown that ventral PFC activation correlates with self-reassurance in reaction to negative events (Longe et al., 2010), no research has shown an association between the functional connectivity of this region and trait-level self-compassion, as it is traditionally measured. Moreover, the social stimuli used in previous research on the emotion processing functions of this circuit (e.g., Urry et al., 2006; Gee et al., 2013) were static pictures presented in the MRI scanner. The current results extend other findings by showing that VMPFC-amygdala functional connectivity is also relevant in the context of a more dynamic social feedback task, during which participants believed they were being evaluated in real time.

Importantly, these findings reinforce multiple lines of evidence which suggest that heightened positive VMPFC-amygdala connectivity is associated with negative outcomes. While many initial studies examining this circuit focused on negative connectivity between these two regions during emotional inhibition, multiple studies have also now shown that positive connectivity is associated with negative affect and individual differences suggesting greater propensity to experience negative affect. For example, positive VMPFC-amygdala connectivity has been associated with the experience of social stress (Veer et al., 2011), the stress-related hormone cortisol (Veer et al., 2012) as well as depression and anxiety (Johnstone et al., 2007; Satterthwaite et al., 2016). Interestingly, while not as often explicitly discussed, positive VMPFC-amygdala connectivity has also been associated with poorer negative emotion regulation abilities as measured by fMRI (Morawetz, Bode, Baudewig & Heekeren, 2017) and objective psychophysiological measures, such as corrugator electromyography (Lee et al., 2012). Taken together, our current results are in line with research showing the involvement of VMPFC-amygdala circuitry in several different forms of negative emotional processing.

Considering the results of our analysis of the subscales of the SCS, we should point out the potential importance of the Self-Judgment and Common Humanity components of self-compassion. We found that individuals who scored higher in Self-Judgment were more likely to recruit greater positive VMPFC-amygdala connectivity in response to social threat. This may be due to the fact that these individuals are harshly criticizing themselves following social evaluation, and thus up-regulating their negative affect. We also found that individuals who scored lower in Common Humanity were more likely to elicit positive connectivity in this circuit. This might be because these individuals are less likely to take a more globally oriented approach to their social evaluative feedback and are thus more prone to up-regulating unpleasant feelings occurring due to negative affect. Because they underestimate how much others suffer in a similar manner to themselves, they may be more likely to perseverate on these negative emotional experiences, blaming themselves for their suffering and external circumstances. We also found *marginally* significant relationships between VMPFC-amygdala connectivity and Mindfulness as well as Over-Identification subscales. We may have been able to detect significant relationships with a larger sample size, however. These findings seem plausible given that people low in Mindfulness or high in Over-Identification are likely more prone to feeling overly attached to their negative feelings. Specific hypotheses about how these emotional tendencies associated with the Self-Judgment, Common Humanity, Mindfulness, and Over-Identification subcomponents may relate to VMPFC-amygdala functioning should be followed up in future neuroimaging studies investigating the brain basis of self-compassion.

Given the results of the subscales analyses, our results also reinforce current thinking that the positive and negative items of the SCS should be considered together as a whole (Neff, Long et al., 2018; Neff, Tóth-Király et al., in press). Moreover, it is notable that both positive (e.g., Common Humanity) and negative (e.g., Self-Judgment) subscales significantly correlated with VMPFC-right amygdala functional connectivity during negative vs. neutral feedback conditions, suggesting that it is not the case that the negative and positive subscales can be easily dissociated.

Lastly, given that positive VMPFC-amygdala connectivity was found in less self-compassionate individuals, the results are also potentially relevant to our understanding of this circuit's functioning in mediating negative affect associated with depression and related disorders (Johnstone et al., 2007; Satterthwaite et al., 2016). For example, Johnstone and colleagues (2007) showed that depression related to a similar pattern of VMPFC upregulating amygdala activity (i.e., positive connectivity) in response to negative emotional images; this same pattern of VMPFC-amygdala connectivity was seen in individuals who showed less self-compassion in the present study. Since we know that self-compassion is negatively correlated with depression (Macbeth & Gumley, 2012; Neff, 2003), an interesting direction for future studies would be to determine whether the functional interactions within this common neural circuit underlie both of these psychological factors. More specifically, future studies could test whether low levels of trait self-compassion could influence risk for increasing levels of depression though changes in VMPFC-amygdala connectivity.

The current study's findings should be contextualized by noting potential limitations regarding the research approach and methods. First, it should be noted that given the correlational nature of these results, interpretation of these findings should be treated with caution. In addition, we should note that the current study was likely underpowered due to our relatively small sample size. This lack of power could influence the detection of meaningful relationships between VMPFC-amygdala connectivity and the SCS subscales. It could also have influenced our ability to find a significant relationship between VMPFC-left amygdala connectivity and self-compassion. Importantly, because small sample sizes produce less stable estimates of effect sizes (Schönbrodt & Perugini, 2013), over-interpretation of the results should be cautioned against.

In terms of future directions for investigating the neural mechanisms underlying self-compassion, we suggest multiple potential approaches. First, it will be critically important for future researchers to understand how this neural circuitry may relate to low levels of self-compassion and risk for clinical disorders, such as for depression and anxiety. Given that this circuit's functioning has been shown to be potentially disrupted in these populations (e.g., Johnstone et al., 2007), future research may shed light on this issue. Future research could also examine whether the VMPFC-amygdala circuit is behaviorally relevant when individuals are actively engaging in self-compassion as opposed to simply exploring the correlates of self-reported compassion as was done here. Hence, researchers could implement an experimental task aimed at eliciting a short-term self-compassionate attitude in the MRI scanner. In addition, a comparison of neural responses to threat before and after a self-compassion-based psychological intervention, such as the Mindful Self-Compassion program (Neff & Germer, 2013), may elucidate how self-compassion training alters the neural correlates of self-compassion. Lastly, it will also be important for future research to investigate the overlapping and dissociable regulatory-related neural mechanisms associated with the distinct subcomponents (e.g., self-kindness vs. common humanity vs. mindfulness) of self-compassion.

In summary, the present study found an association between individual differences in self-compassion and VMPFC-amygdala task-evoked functional connectivity during negative social feedback. The results contribute to a growing body of research relating self-compassion to emotion regulation and coping mechanisms. Moreover, they may help explain the important links between lack of self-compassion and poor psychological well-being and interpersonal difficulties.

Disclosure statement

No potential conflict of interest was reported by the authors.

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