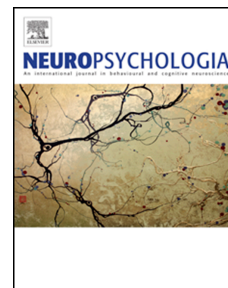# Journal Pre-proof

Neurostructural correlates of dispositional self-compassion

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Running head: VBM Study of Self-compassion

Neurostructural correlates of dispositional self-compassion

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Abstract: Self-compassion is an important emotion regulation strategy predicting positive psychological health and fewer psychopathological problems, but little is known about its structural neural basis. In the current study, we investigated the neurostructural correlates of dispositional self-compassion and its components using voxel-based morphometry (VBM). We found that self-compassion was inversely correlated with gray matter volume (GMV) in the left dorsolateral prefrontal cortex (DLPFC), which was primarily driven by the reduced self-judgment component. We also found that the mindfulness component was associated with greater GMV in the dorsomedial prefrontal cortex/anterior cingulate cortex and the left supplementary motor area, while the isolation and the over-identification components were both correlated with greater GMV in the right inferior temporal gyrus, and over-identification additionally related to less GMV in visual areas. Our findings suggest that dispositional self-compassion and its components are associated with brain structures in regions involved in emotion regulation, self-referential and emotion processing, with implications for the cognitive and neural mechanisms of self-compassion as well as those underlying the effects of self-compassion on its health outcomes.

Keywords: self-compassion; self-judgment; mindfulness; emotion regulation; voxel-based morphometry

1. Introduction

Self-compassion is an emotionally positive self-attitude in the face of one's suffering (Neff, 2003b), which entails three positive components (i.e., self-kindness, recognition of common humanity, and mindfulness) and three negative components (i.e., [reduced] self-judgment, isolation, and over-identification) (Neff, 2003a). Previous studies have established that self-compassion is an effective emotion regulation strategy (Diedrich et al., 2014; Neff, 2003b; Trompetter et al., 2017), which significantly predicts positive psychological health and fewer psychopathological problems (Muris & Petrocchi, 2017; Neff et al., 2018). Despite the important protective roles of self-compassion, the structural neural basis of this trait remains unclear. The present study aimed to address the issue using voxel-based morphometry (VBM).

No study has hitherto examined the neurostructural correlates of dispositional self-compassion, but VBM studies have examined similar constructs. First, self-compassion and self-esteem are both positive self-attitude and they are highly correlated ($r = 0.59$) (Neff, 2003a). Second, the definition of self-compassion is closely related to the more general construct of compassion (Neff, 2003b). Based on these similarities, VBM studies of self-esteem and compassion may provide insight into the neurostructural correlates of self-compassion. It has been found that both self-esteem and compassion (or its practice) are linked to increased gray matter volume (GMV) in the anterior cingulate cortex (ACC) and the right dorsolateral

prefrontal cortex (DLPFC) (Agroskin et al., 2014; Hou et al., 2017), as well as insula (Hou et al., 2017) or the right temporo-parietal junction (TPJ) (Agroskin et al., 2014; Leung et al., 2013). These regions were thought to be associated with emotion regulation or empathic processes (Agroskin et al., 2014; Hou et al., 2017). In addition to VBM studies of similar constructs, functional magnetic resonance imaging (fMRI) studies of dispositional self-compassion may reveal candidates for neural regions supporting this trait and may inform hypotheses about regions whose morphology may correlate with it. So far, most of these fMRI studies (Berry et al., 2020; G. Liu, Zhang, et al., 2020; Williams et al., 2020) have found that dispositional self-compassion or self-kindness was associated with activation in DLPFC, dorsal ACC and/or posterior cingulate cortex (PCC)/precuneus, regions thought to be associated with emotion regulation and self-referential processing (Sui & Gu, 2017; Yankouskaya & Sui, 2021). These studies suggest that dispositional self-compassion may be correlated with regions associated with emotion regulation and self-referential processing (e.g., DLPFC, ACC, PCC/precuneus) as well as those associated with empathy/theory of mind (e.g., insula, TPJ).

As for the components of self-compassion, VBM studies of similar constructs have also provided insight into their neurostructural correlates. The most studied construct similar to certain component of self-compassion is mindfulness, which refers to a process of openly attending, with awareness, to one's present moment experience (Creswell, 2017). The difference between the mindfulness component of

self-compassion and mindfulness more generally is that the former refers to mindfulness only in face of one's personal suffering. It has been found that trait mindfulness was linked to greater GMV in ACC and hippocampus/amygdala, and less GMV in PCC and orbito-frontal cortex (Lu et al., 2014). Another construct similar to certain component of self-compassion whose neurostructural correlates have been examined is brooding. Brooding is a subcomponent of rumination, referring to self-critical moody pondering (Raes, 2010; Treynor et al., 2003), and thus is closely associated with self-criticism or the self-judgment component of self-compassion (Neff et al., 2018). Brooding has been found positively correlated with GMV in ACC and the left DLPFC (Sin et al., 2018). Because self-compassion correlates inversely with brooding (Raes, 2010), it might show an opposite relationship (i.e., negative correlations) with GMV in these regions.

The present study aimed to identify the neurostructural correlates of dispositional self-compassion and its components using exploratory analyses since no studies have hitherto investigated this issue. However, because VBM studies of constructs similar to compassion and its components as well as fMRI studies of self-compassion have convergingly found the involvement of ACC and DLPFC, we expected that dispositional self-compassion and its components may be correlated with GMV in these regions (i.e., ACC and DLPFC). We did not have specific hypotheses regarding how the individual components of self-compassion may be differentially correlated with GMV in certain regions.

2. Methods

2.1 Participants

One hundred and nine healthy university students (70 females; mean age = 20.49 years, SD = 1.65), with no history of neurological, psychiatric, or physical abnormalities, were recruited from South China Normal University for the current study. All individuals were right-handed with normal or corrected-to-normal vision. The protocol was approved by the Brain Imaging Center Institutional Review Board of South China Normal University and carried out in accordance with its recommendations. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

2.2 Measures

The Self-Compassion Scale (SCS) developed by Neff (2003a) was used to measure dispositional self-compassion. It comprises 26 items that assess the degree of self-compassion across three positive (i.e., self-kindness, recognition of common humanity, and mindfulness) and three negative dimensions (i.e., self-judgment, isolation, and over-identification). Each item was scored on a 5-point Likert-type scale (from 1 = *almost never* to 5 = *almost always*). Average scores for each dimension were calculated by averaging scores of all corresponding items, with higher scores representing higher levels of each dimension. An average score of dispositional self-compassion was calculated by averaging all items after those of the three negative dimensions were reverse coded. Higher scores thus represented higher

levels of dispositional self-compassion.

2.3 Image acquisition

Structural MRI was performed on a Trio 3.0 T Siemens Tim scanner (Siemens, Erlangen, Germany) at the Brain Imaging Center at South China Normal University, Guangzhou, China. During imaging, the participants were asked to refrain from moving their head or closing their eyes and to remain awake. A three-dimensional magnetization-prepared rapid gradient-echo (3D MP-RAGE) sequence was used to obtain high-resolution T1-weighted anatomical images with the following parameters: repetition time (TR) = 1900ms, echo time (TE) = 2.52ms, flip angle = 9°, matrix = 256 $\times$ 256, slice thickness = 1.0 mm, field of view (FOV) = 230 $\times$ 230 mm^2, and voxel size = 1 $\times$ 1 $\times$ 1 mm^3.

2.4 Image preprocessing

Images were preprocessed using the Statistical Parametric Mapping (SPM) software (SPM12; Wellcome Department of Cognitive Neurology, London, United Kingdom; www.fl.ion.ucl.ac.uk/spm), following the VBM protocol by Ashburner (2010). First, each image was displayed in SPM12 to screen for artifacts and gross anatomical abnormalities. For better registration, the manual method was used to reorient the images to the anterior commissure. Next, the T1-weighted anatomical images were segmented into Gray Matter (GM), White Matter (WM), and Cerebrospinal Fluid (CSF) using the segmentation procedure. The registration and normalization processes were conducted through Diffeomorphic Anatomical

Registration Through Exponentiated Lie Algebra (DARTEL) in SPM12 (Ashburner, 2007). These probability maps were manually examined first, to ensure proper segmentation, and were then spatially normalized (Friston et al., 1995) to Montreal Neurologic Institute (MNI) space (resampling to 1.5mm cubic isotropic voxels). Finally, the modulated GM images were spatially smoothed with an isotropic Gaussian kernel with full width at half maximum (FWHM) = 8 mm.

2.5 Statistical analyses

2.5.1 Neural correlates of dispositional self-compassion

To identify the neurostructural correlates of dispositional self-compassion, a voxel-wise multiple regression model (Model 1) was performed across the whole brain, with dispositional self-compassion as covariate of interest and age, gender, and total GMV as confounding covariates. Age and gender were set as confounding covariates because these variables affect brain structure (Smith et al., 2007) and are generally controlled for in VBM studies (Guan et al., 2018; Kanai et al., 2010; Kanai et al., 2011; G. Liu et al., 2018). A gray matter mask was created by binarizing SPM's prior probability gray matter map at the threshold of 0.2 and was applied to the analysis (G. Liu, Cui, et al., 2020; F. Wang et al., 2017). The voxel-wise intensity threshold was set at $p_{uncorr} < 0.001$, and the cluster-extent threshold of $p_{FWE} < 0.05$ was calculated using Monte Carlo simulations with AFNI 18 (Cox, 1996). Clusters surviving the threshold of $p_{FWE} < 0.1$ were reported as trending results. Eigenvariate values of each significant cluster were extracted for visualization and partial

correlation analyses.

2.5.2 Neural correlates of self-compassion components

To explore neurostructural correlates of self-compassion components, another six voxel-wise multiple regression models were performed across the whole brain, with self-kindness, self-judgment, recognition of common humanity, isolation, mindfulness and over-identification as the respective variable of interest, and age, gender, and total GMV as confounding covariates. The other details were the same as those mentioned above in Model 1.

3. Results

3.1 Descriptive statistics of behavioral measures

Table 1 presents the minimum value, maximum value, mean, and SD for dispositional self-compassion and its components.

3.2 Neuroimaging results

3.2.1 Neural correlates of dispositional self-compassion

The results of the whole-brain VBM analysis of dispositional self-compassion revealed a negative correlation between self-compassion and GMV in the left DLPFC (MNI coordinates: −32, 59, 18; r_p = -0.37; Table 2 and Fig. 1) after controlling for age, gender and total GMV.

3.2.2 Neural correlates of self-compassion components

Self-judgment showed a correlation with greater GMV in the left DLPFC (MNI coordinates: -47, 53, 14; r_p = -0.37; Table 2 and Fig. 2a), which was the same region

where GMV correlated with dispositional self-compassion, suggesting that the link between dispositional self-compassion and less GMV in the DLPFC was primarily driven by (reduced) self-judgment. In addition, isolation showed a correlation with greater GMV in the right inferior temporal region (ITG)/temporal pole (MNI coordinates: 51, 5, -45; r_p = 0.38; Table 2 and Fig. 2b), mindfulness showed a correlation with greater GMV in dorsomedial prefrontal cortex (DMPFC)/ACC (MNI coordinates: -9, 39, 38; r_p = 0.42) and the left supplementary motor area (SMA) (MNI coordinates: -9, -8, 57; r_p = 0.37; Table 2 and Fig. 2c), and over-identification showed a correlation with greater GMV in the right ITG (MNI coordinates: 51, 5, -45; r_p = 0.36) and less GMV in the right superior occipital gyrus (SOG)/middle occipital gyrus (MOG) (MNI coordinates: 26, -92, 32; r_p = -0.39; Table 2 and Fig. 2d). On the other hand, self-kindness and recognition of common humanity only showed positive trends with GMV in calcarine/precuneus and cerebellum/fusiform, respectively.

4. Discussion

The current study investigated the neurostructural correlates of dispositional self-compassion and its components, using VBM in healthy adults. The results revealed that dispositional self-compassion was negatively correlated with GMV in the left DLPFC while self-judgment was positively correlated with GMV in the same region. Furthermore, we found that mindfulness was positively correlated with GMV in DMPFC/ACC and the left SMA, while both isolation and over-identification were positively correlated with GMV in the right ITG, and over-identification was

additionally negatively correlated with GMV in visual areas (i.e., the right SOG/IOG).

We found that dispositional self-compassion was negatively correlated with GMV in the left DLPFC. It has been suggested that DLPFC is associated with executive control (Diamond, 2013; Miller & Cohen, 2001; Sui et al., 2013) and emotion regulation (Golkar et al., 2012). Correspondingly, self-compassion has been established as an effective emotion regulation strategy (Diedrich et al., 2014; Neff, 2003b; Trompetter et al., 2017) and previous research has consistently found that dispositional self-compassion is correlated with DLPFC activity (Berry et al., 2020; G. Liu, Zhang, et al., 2020; Williams et al., 2020). For example, G. Liu, Zhang, et al. (2020) reported that higher self-compassion was associated with lower activity in the right DLPFC during sad self-face recognition among depressed adolescents, which might indicate lower engagement of cognitive control or emotion regulatory processes for dampening negative emotions induced by sad self-face. Moreover, we found that self-judgment was positively corelated with GMV in the same region, suggesting the relationship between self-compassion and smaller DLPFC was primarily driven by reduced self-judgment. Likewise, Longe et al. (2010) found that self-criticism activated the left DLPFC, suggesting the engagement of inhibitory processes. Together with previous findings on the link between self-compassion and typical circuit connectivity (i.e., VMPFC-amygdala) engaging in emotion regulation during negative social feedback (Parrish et al., 2018), the present results in the DLPFC volume might specifically reflect the role of DLPFC in emotion regulation.

The direction of the link between self-compassion and the left DLPFC volume deserves further discussion. On the one hand, the negative correlation between self-compassion and the left DLPFC volume is different from the past findings of a positive relationship between self-esteem/compassion practice and the right DLPFC volume (Agroskin et al., 2014; Leung et al., 2013). On the other hand, the positive correlation between self-judgment and the left DLPFC volume is consistent with that between brooding and the left DLPFC volume (Sin et al., 2018). Though the negative link between self-compassion and the left DLPFC volume is somewhat unexpected, some previous studies have shown that the premise of "the larger the volume, the better the function" is not always true (H. Liu et al., 2016). Specifically for the left DLPFC volume, it has been found to be negatively correlated with positive constructs such as social well-being (Kong et al., 2015) and trait elevation (a positive emotion induced by witnessing moral beauty) (G. Liu et al., 2018), and positively with negative constructs such as brooding (Sin et al., 2018) and permissive attitudes toward suicide (H. Liu et al., 2016). It has been reported that young adults exhibit growth in executive control function but reduced gray matter density because of events such as increased myelination and synaptic pruning in dorsal frontal cortex (Sowell et al., 2001). According to this account, a smaller left DLPFC among self-compassionate individuals might be reflective of more efficient myelination or synaptic pruning and thus better ability in emotion regulation, which might further contribute to lower level of brooding and permissive attitudes toward suicide. The potential relationship

between self-compassion, a smaller left DLPFC and brooding/permissive attitudes toward suicide deserves further investigation.

Considering that the link between self-compassion and smaller left DLPFC volume was primarily driven by (reduced) self-judgment, an alternative interpretation of the negative link between self-compassion and the left DLPFC volume is that larger left DLPFC may correspond to more frequent spontaneous compensatory emotion regulation processes evoked by self-judgment/criticism. Previous research has found that self-criticism activated the left DLPFC (Longe et al., 2010), and that brooding, a construct closely associated with self-judgment/criticism, showed positive correlation with the left DLPFC volume (Sin et al., 2018). It is possible that a larger left DLPFC among less self-compassionate individuals might be reflective of more frequent spontaneous regulation of negative emotions induced by perceived self-discrepancies from self-judgment/criticism. Consistent with this account, negative affect has been found to be positively correlated with cortical density in the left DLPFC (Zhu et al., 2020). Together with the findings that healthy and unhealthy emotion regulation strategies (i.e., reappraisal and suppression, respectively) both activated DLPFC (Etkin et al., 2015; Goldin et al., 2008), it is possible that a single index of GMV in DLPFC cannot be an indicator of how good one is at regulating emotions, without more information about what strategies they frequently use.

In addition to the negative link between self-compassion and the left DLPFC volume, the oppositive direction with that between self-esteem/compassion and the

right DLPFC volume observed in previous studies (Agroskin et al., 2014; Leung et al., 2013) also suggests the hemispheric lateralization of DLPFC (Rêgo et al., 2015; Shi et al., 2021). It has been shown that the left and the right DLPFC have distinct roles in emotion regulation, with the left DLPFC involved in meaning reinterpretation of affective responses and the right DLPFC mediating psychological distancing from affective stimuli (Ochsner et al., 2012; Rêgo et al., 2015). In addition, a recent study reported that the left DLPFC was dominant in inhibiting ipsilateral primary motor cortex (Y. Wang et al., 2020). According to these findings, self-compassion and self-esteem may facilitate positive self-attitudes through distinct emotion regulation mechanisms. Specifically, self-compassion may do so by reducing self-judgment and inhibitory processes (disengaging the left DLPFC), while self-esteem by encouraging distancing from negative stimuli (engaging the right DLPFC). Nevertheless, this hypothesis requires further investigation.

In addition to self-judgment, we also found that the mindfulness component was positively correlated with regions associated with emotion regulation, i.e., DMPFC/ACC and the left SMA. The positive link between mindfulness and ACC volume is especially consistent with previous findings (Fox et al., 2014; Lu et al., 2014). The mindfulness component of self-compassion indicates that one's failings are seen clearly rather than being ignored or disregarded (Neff, 2003a). Consistent with this, ACC has been associated with error detection (Bush et al., 2000) and emotional awareness (Lane et al., 1998). These are also functions that mindful

individuals are good at (Fox et al., 2014). It may be that larger ACC enables stronger error detection/emotional awareness and thus higher level of mindfulness. In addition to ACC, a meta-analysis has shown that SMA is involved in the process of emotion regulation (Kohn et al., 2014). Etkin et al. (2015) proposed that ACC and SMA are involved in two different types of emotion regulation, i.e., model-free and model-based. While model-free emotion regulation proceeds based on prediction error feedback, model-based emotion regulation relies on the application of rule-based decision making. The positive correlation between mindfulness and GMV in both ACC and SMA may indicate that those with higher level of the mindfulness component are good at both types of emotion regulation. On the other hand, both DMPFC and ACC are part of the cortical midline structures, which have been proposed to enable self-referential processing (Northoff & Bermpohl, 2004; Northoff et al., 2006). It is possible that larger DMPFC and ACC in more mindful individuals reflects increased capacity for self-awareness.

The present study showed that both the isolation and the over-identification components were correlated with greater GMV in the right ITG. Longe et al. (2010) has found that self-criticism (similar to self-judgment) activated ITG/MTG and interpreted the association in terms of ITG's role in enhanced emotional salience during self-criticism (Narumoto et al., 2000). However, a meta-analysis (Fox et al., 2014) found that meditation (including mindfulness) practitioners showed significantly greater GMV in ITG, which has been interpreted as the tendency to feel

deep pleasure and experience of insight into the unity of all reality. This interpretation is at odds with the positive link between isolation/over-identification and the right ITG volume. A more parsimonious interpretation is that a larger right ITG may reflect stronger tendency to experience salient emotions, irrespective of positive or negative. Consistent with this interpretation, it has been found that dispositional gratitude was positively correlated with GMV in the right ITG (Zahn et al., 2013). Taken together, it is possible that a larger right ITG among those with higher level of isolation and over-identification may reflect stronger tendency to experience salient emotions in face of personal failure or setback.

Finally, we found a negative association between over-identification and GMV in visual areas. Although the visual cortex is traditionally thought to be involved in visual processing, it has recently been found that patterns of human visual cortex activity encode emotion category (Bo et al., 2021; Kragel et al., 2019), consistent with the theory of emotions as adapted canonical responses to situations linked to survival in evolutionary terms (Tooby & Cosmides, 2008). Therefore, a smaller visual cortex in individuals with higher level of over-identification may represent a weaker ability in generating emotions corresponding to the current situations and thus a tendency to be stuck in the negative emotions in the face of failure or setback. This assumption, however, needs further examination.

There are some limitations to this study. First, because it is an exploratory study, the present findings require further validation. Second, it is correlational, and thus

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cannot establish the causal relationship between dispositional self-compassion and brain structure. Future studies should examine their causal relationship with experimental designs. Third, participants in the present study were all in their early adulthood. Considering the special brain growth of increased myelination and synaptic pruning during this stage (Sowell et al., 2001), it may be necessary to examine the neurostructural corelates of self-compassion and its components in a sample with a broader age range in the future.

5. Conclusion

We investigated the neurostructural correlates of dispositional self-compassion and its components using VBM in a sample of young adults. We showed that dispositional self-compassion was correlated with less GMV in the left DFLPC, which was primarily driven by the reduced self-judgment component. We also found that the mindfulness component was correlated with greater GMV in DMPFC/ACC and the left SMA, while both the isolation and the over-identification component were correlated positively with GMV in the right ITG, and over-identification additionally correlated with smaller GMV in visual areas. Our findings suggest that a lack of self-compassion is associated with brain structure in regions involved in emotion regulation, self-referential and emotion processing, which may not only have implications for the cognitive and neural mechanisms of self-compassion but also those underlying the effects of self-compassion on its health outcomes.

Credit author statement

F. Guan, G. Liu, O. Chen, S. Zhao and K. Peng designed the study. F. Guan, G. Liu and O. Chen analyzed the data. F. Guan and G. Liu drafted the manuscript. W. S. Pedersen, J. Sui and K. Peng provided critical revisions. All authors contributed to revisions and approved the final version of the manuscript for submission.

Acknowledgments

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Table 1. Descriptive statistics of the self-report measures.

	Min	Max	Mean	SD
Dispositional Self-compassion	1.65	4.46	3.14	0.50
Self-kindness	1.60	5.00	3.51	0.62
Self-judgment	1.80	4.60	3.08	0.60
Recognition of common humanity	1.75	5.00	3.51	0.68
Isolation	1.00	5.00	3.18	0.85
Mindfulness	1.75	5.00	3.55	0.61
Over-identification	1.50	5.00	3.49	0.76

Table 2. Structural neural correlates of dispositional self-compassion and its components ($p_{uncorr} < 0.001$ at voxel level, cluster-level $p_{FWE} < 0.05$).

Region	Direction	Hemisphere	Cluster Size (K)	MNI coordinates x	y	z	Z
Dispositional self-compassion							
DLPFC (MFG), BA10/46	Negative	Left	228	-32	59	18	4.06
Self-kindness							
Calcarine/precuneus, BA23	Positive	Right	162†	8	-59	14	3.78
Self-judgment							
DLPFC (MFG/IFG), BA10/46	Positive	Left	286	-47	53	14	4.71
Recognition of common humanity							
Cerebellum/fusiform, BA18/19	Positive	Left	167†	-39	-83	-20	4.37
Isolation							
ITG/temporal pole, BA21/38/20	Positive	Right	369	51	5	-45	4.57
Mindfulness							
SMA, BA6	Positive	Left	251	-9	-8	57	4.34
DMPFC (SFG)/ACC, BA9/32/10/6	Positive	Left/Right	782	-9	39	38	4.33
Over-identification							
ITG, BA21/20/38	Positive	Right	232	51	5	-45	4.12
SOG/MOG, BA19/7	Negative	Right	276	26	-92	32	3.94

† trending results ($p_{uncorr} < 0.001$ at voxel level, cluster-level $p_{FWE} < 0.1$)

DLPFC, dorsolateral prefrontal cortex; MFG, middle frontal gyrus; IFG, inferior frontal gyrus; ITG, inferior temporal gyrus; SMA, supplementary motor area; DMPFC, dorsomedial prefrontal cortex; SFG, superior frontal gyrus; ACC, anterior cingulate cortex; SOG, superior occipital gyrus; MOG, middle occipital gyrus.
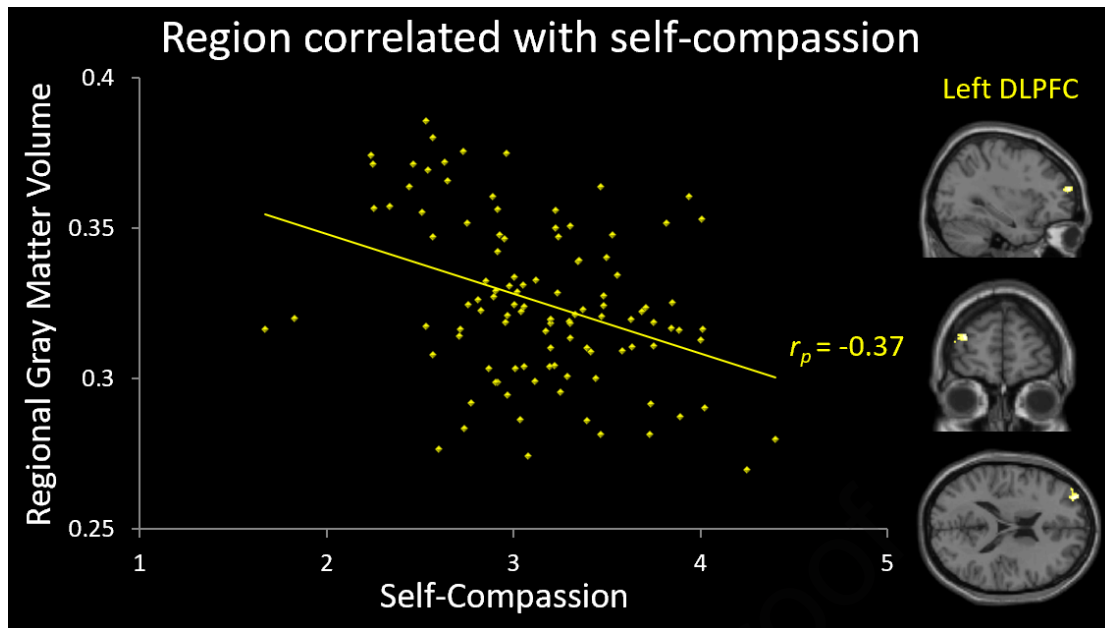
Figure 1. Neurostructural correlates of dispositional self-compassion. Self-compassion was negatively correlated with GMV in the left dorsolateral prefrontal cortex (DLPFC).
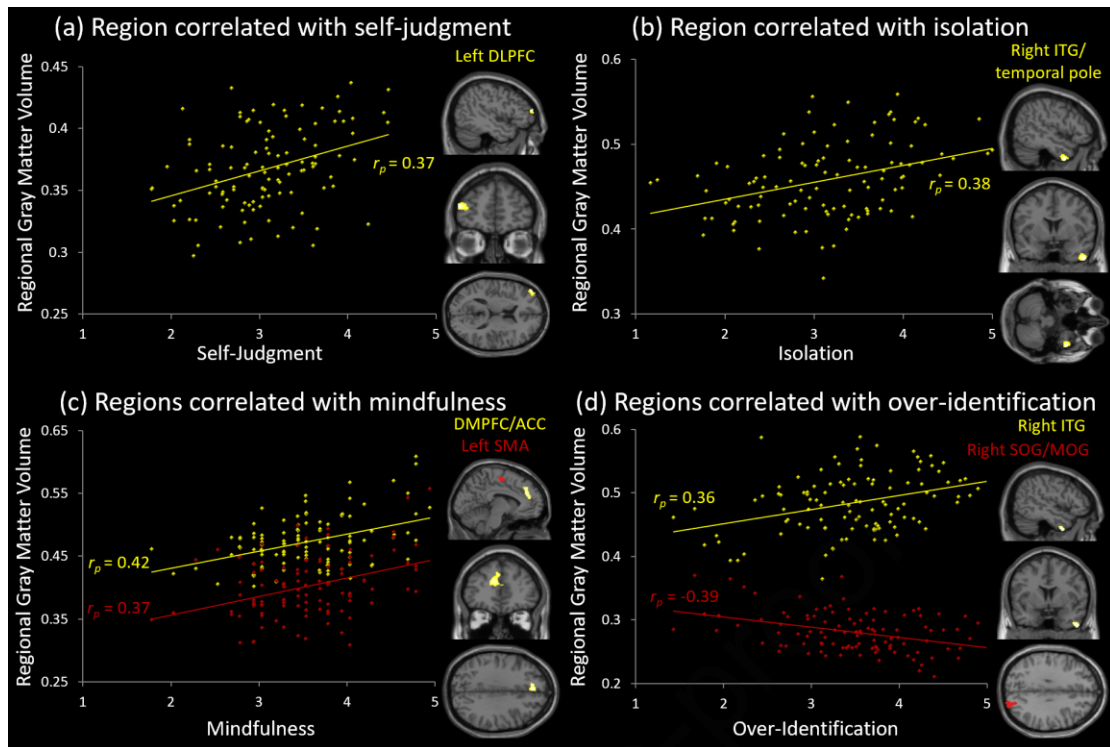
Figure 2. Neurostructural correlates of self-compassion's components. (a) Self-judgment was associated with greater GMV in the left dorsolateral prefrontal cortex (DLPFC). (b) Isolation was associated with greater GMV in the right inferior temporal gyrus (ITG)/temporal pole. (c) Mindfulness was associated with greater GMV in the left supplementary motor area (SMA) and dorsomedial prefrontal cortex (DMPFC)/ anterior cingulate cortex (ACC). (d) Over-identification was associated with greater GMV in the right ITG and less GMV in the right superior occipital gyrus (SOG)/ middle occipital gyrus (MOG).

- Dispositional self-compassion (SC) is inversely linked to GMV in the left DLPFC.
- The link between SC and smaller DLPFC is primarily driven by reduced self-judgment.
- The mindfulness component of SC is linked to greater GMV in DMPFC/ACC and left SMA.
- SC relates to brain structures in regions involved in emotion processes/regulation.