



Individual differences in local gray matter density are associated with differences in affective and cognitive empathy



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ABSTRACT

The understanding of empathy from a neuroscientific perspective has recently developed quickly, with numerous functional MRI studies associating different brain regions with different components of empathy. A recent meta-analysis across 40 fMRI studies revealed that affective empathy is most often associated with increased activity in the insula, whereas cognitive empathy is most often associated with activity in the midcingulate cortex and adjacent dorsomedial prefrontal cortex (MCC/dmPFC). To date, however, it remains unclear whether individual differences in brain morphometry in these regions underlie different dispositions in affective and cognitive empathy. In order to test this hypothesis, voxel-based morphometry (VBM) was used to examine the extent to which gray matter density predicts scores from an established empathy measure (Questionnaire of Cognitive and Affective Empathy; QCAE). One hundred and seventy-six participants completed the QCAE and underwent MRI in order to acquire a high-resolution, three-dimensional T1-weighted structural scans. A factor analysis of the questionnaire scores revealed two distinct factors of empathy, affective and cognitive, which confirmed the validity of the QCAE. VBM results revealed gray matter density differences associated with the distinct components of empathy. Higher scores on affective empathy were associated with greater gray matter density in the insula cortex and higher scores of cognitive empathy were associated with greater gray matter density in the MCC/dmPFC. Taken together, these results provide validation for empathy being a multi-component construct, suggesting that affective and cognitive empathy are differentially represented in brain morphometry as well as providing convergent evidence for empathy being represented by different neural and structural correlates.

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Introduction

To successfully navigate our social environment it is integral to understand and experience the emotional states of others, a process typically referred to as empathy. Empathy involves an affective component, subjective experiences of the emotions of others, and a cognitive component, the ability to understand others' motivation (Bernhardt and Singer, 2012; Decety, 2011; Shamay-Tsoory, 2011). The aim of this study is to investigate whether individual differences in affective and cognitive empathy are subserved by differences in brain anatomy.

When considering the affective component of empathy, emphasis is typically placed on experiencing the emotional states of others consciously, which implies a self-other distinction, as well as an understanding of where the emotional experience originates from (Bernhardt and Singer, 2012; Decety and Jackson, 2004). Affective empathy is different from emotion contagion (the automatic adoption of another person's

emotions; Hatfield et al., 2009) and mimicry (the synchronisation of emotional expressions and behaviours; Preston and De Waal, 2002) which act as automatic responses to another person's emotional state but not necessarily self-other distinction. Affective empathy is also differentiated from sympathy or empathic concern, as the latter represents an internal state of emotion and motivation driven by the concern for another person's welfare but not necessarily a sharing of emotions (Bernhardt and Singer, 2012; Decety and Chaminade, 2003; Decety and Cowell, 2014; Singer and Lamm, 2009). Note that we do not argue that these processes (for example empathic concern) are unrelated to affective empathy, but rather that affective empathy can be thought of as an umbrella term that encompasses multiple dimensions.

Initial neuroimaging studies on affective sharing suggested that the emotional components are shared vicariously but not the sensory components (Jackson et al., 2006; Singer et al., 2004). For example, when experiencing pain first-hand, activity in the somatosensory cortex occurs as a response to the sensory stimulation received, whereas the insula and anterior cingulate cortex activate for the affective components of pain (Morrison et al., 2004; Singer et al., 2004). In contrast, when we observed another person in pain, initial findings suggested

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that only the affective components are vicariously experienced through activation of the insula and anterior cingulate cortex (Jackson et al., 2006; Singer et al., 2004; Lamm et al., 2011). More recent evidence suggests that somatosensory cortex may also be activated in response to perceiving another person in pain (Avenanti et al., 2005; Chen et al., 2012; Fox et al., 2013; Marsh et al., 2013).

The degree of overlap between first-hand and second-hand emotional experience for the affective components is controversial (Decety, 2010, 2011). For example, the anterior insula appears to activate more so with vicarious experiences of pain (Jackson et al., 2006), whilst for first-hand experiences of pain the posterior insula is implemented (Decety and Lamm, 2006). The insula also responds to affective sharing outside empathic pain. Specifically, greater activation in the anterior insula occurs when observing videos of people with disgusted faces (Wicker et al., 2003) as well as when vicariously observing others experience unpleasant food (Jabbi et al., 2007), and in response to positive emotions such as pleasure (Small et al., 2001). Menon and Uddin (2010) identify the insula as a fundamental brain region involved in integrating visceral and autonomic information with salient stimuli, which provides infrastructure for the representation of subjective bodily feelings of positive and negative emotions. This representation ultimately intensifies our emotional awareness. It should be noted that here we have focused primarily on the insula for processing vicarious emotions, however there is ample evidence to suggest that some emotions are vicariously processed in different regions; for example, fear in the amygdala (Askew and Field, 2007; Olsson and Phelps, 2007; Phelps, 2006).

The cognitive component of empathy relies heavily on attributing emotional states onto others and may partially call on mechanisms underlying Theory of Mind (ToM; Decety, 2011). The dorsomedial prefrontal cortex (dmPFC) and temporoparietal junction (TPJ) are the two most common regions associated with theory of mind (Van Overwalle, 2009; Schurz et al., 2014). Considering the dorsal regions of the medial prefrontal cortex, there are a range of behaviours related to cognitive empathy that are recruited. A link to the dmPFC has been found for triadic relationships between two separate agents and a goal (Saxe, 2006), perspective taking (D'Argembeau et al., 2007) and direct and reflected self-knowledge (Ochsner et al., 2005). The TPJ on the other hand plays a role in several lower-level computational processes associated with a self-other differentiation and reorienting attention to salient stimuli, and as such plays a crucial role in higher-level cognitive process such as theory of mind and cognitive empathy (Decety and Lamm, 2007). There is also evidence to suggest that the TPJ can be broken into three separate sections, each interacting structurally and functionally with known areas of social cognition and attention (Mars et al., 2012).

However, neuroimaging and psychological research show that ToM and cognitive empathy are also distinct. Theory of mind involves taking on the perspective of another person and attributing to them particular cognitive states; whilst cognitive empathy is more involved in attributing emotional states (Reniers et al., 2011). That said, Perry and Shamay-Tsoory (2013) deconstruct cognitive empathy further by suggesting that it comprises higher order cognitive processes typically involved in ToM, including affective and cognitive mentalising. The former surrounds beliefs about the emotional state of another, whilst the latter concerns beliefs about the beliefs of another person. Though both mentalising processes are involved in cognitive empathy, Perry and Shamay-Tsoory (2013) suggest that affective mentalising may sustain a prioritised role in understanding and sharing the mental states of others. Völlm et al. (2006) investigated the overlap between neural correlates associated with cognitive empathy and theory of mind tasks using fMRI. The authors presented participants with static images that depicted a story but manipulated whether the story recruited theory of mind or cognitive empathy mechanisms. Both tasks involved the dmPFC and TPJ but the empathy condition also showed unique activation along the cingulate cortex.

Functional MRI evidence strongly suggests that there are differences in the neural activity associated with the different sub-components of empathy. However, fMRI methods cannot identify whether these differences are subserved by individual changes in brain anatomy. To test whether volumetric differences in brain anatomy predict a functional difference in empathic expression presupposes a relationship between blood oxygen level dependence (BOLD) responses and anatomy. Indeed, there is evidence to suggest that this may be the case. For example, fMRI studies have shown greater BOLD activity in the hippocampus when completing tasks involving spatial navigation and the use of mental maps (e.g., Astur et al., 2005; Rosenbaum et al., 2004). Greater gray matter density in the hippocampus has also been found in London taxi drivers who frequently draw upon the hippocampus to navigate (Maguire et al., 2000). This suggests that functional activation, structural gray matter density, and behaviour might be related.

Previous investigations looking at brain structure and its relationship with empathy have identified differences in several regions. Banissy et al. (2012) used VBM to infer a relationship between each of the sub-scales of the interpersonal reactivity index (IRI; Davis, 1980) and local gray matter density (local grey matter density here refers to the distribution of gray matter within each voxel to be compared across participants; Ashburner and Friston, 2000). They showed negative associations between gray matter density and the inferior frontal gyrus (IFG) and the empathic concern sub-scale, a sub-scale aimed at tapping into affective empathy. A second sub-scale tapping into affective empathy, the personal distress sub-scale, was positively associated with gray matter density in left insula. In addition, the anterior cingulate and dorsolateral prefrontal cortex were positively associated with scores on the cognitive empathy measure. In a different VBM investigation, Mutschler et al. (2013) similarly showed greater gray matter density in the left anterior insula to be associated with scores of affective empathy when using the Empathy Scale (E-Scale).

In a recent meta-analysis of 40 functional MRI studies, Fan et al. (2011) investigated the consistency of brain regions involved in affective and cognitive empathy, as well as the functional role they may play using a more comprehensive analysis. Multi-kernel density analysis (MKDA) was used to measure the peak coordinates in each statistical contrast map from each of the cognitive and affective empathy studies used in their meta-analysis. Fan et al. (2011) showed that the affective component of empathy was more associated with insula activity, whereas the cognitive component of empathy was more associated with the mid-cingulate cortex and adjacent dorsomedial prefrontal cortex (MCC/dmPFC). This highlights a consistent neural substrate for each component of empathy.

In light of this, we aimed to identify whether the different components of empathy are associated with gray matter differences. We aim to provide convergent evidence for the reliability and validity of previous VBM outcomes by conceptually replicating previous studies to show that individual differences in empathic ability are subserved by differences in gray matter density when using alternate methodologies. Conceptual replication is an important tool in psychological sciences as it helps determine the true effect between particular constructs. There are two methods commonly used to measure differences in gray matter across participants. The first, cortical thickness, measures a one-dimension scalar of cortical thickness at each voxel (surface analysis), whilst the other, voxel-based morphometry (volumetric analysis), measures the amount of tissue within each voxel (Hutton et al., 2009). In line with previous studies that associated individual differences in empathy with gray matter density (Banissy et al., 2012; Mutschler et al., 2013), and in order to replicate their findings, we also opted for the VBM method.

Considering our aims, peak MNI coordinates for affective (i.e., insula) and cognitive (i.e., MCC/dmPFC) empathy were used as regions of interest based on the findings from Fan et al. (2011). We used scores on the Questionnaire of Cognitive and Affective Empathy (QCAE; Reniers et al., 2011) as regressors for the VBM analysis. The QCAE is

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