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Comprehensive neural networks for guilty feelings in young adults

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ABSTRACT

Feelings of guilt are associated with widespread self and social cognitions, e.g., empathy, moral reasoning, and punishment. Neural correlates directly related to the degree of feelings of guilt have not been detected, probably due to the small numbers of subjects, whereas there are growing numbers of neuroimaging studies of feelings of guilt. We hypothesized that the neural networks for guilty feelings are widespread and include the insula, inferior parietal lobule (IPL), amygdala, subgenual cingulate cortex (SCC), and ventromedial prefrontal cortex (vmPFC), which are essential for cognitions of guilt. We investigated the association between regional gray matter density (rGMD) and feelings of guilt in 764 healthy young students (422 males, 342 females; 20.7 $\pm$ 1.8 years) using magnetic resonance imaging and the guilty feeling scale (GFS) for the younger generation which comprises interpersonal situation (IPS) and rule-breaking situation (RBS) scores. Both the IPS and RBS were negatively related to the rGMD in the right posterior insula (PI). The IPS scores were negatively correlated with rGMD in the left anterior insula (AI), right IPL, and vmPFC using small volume correction. A post hoc analysis performed on the significant clusters identified through these analyses revealed that rGMD activity in the right IPL showed a significant negative association with the empathy quotient. These findings at the whole-brain level are the widespread comprehensive neural network regions for guilty feelings. Interestingly, the novel finding in this study is that the PI was implicated as a common region for feelings of guilt with interaction between the IPS and RBS. Additionally, the neural networks including the IPL were associated with empathy and with regions implicated in moral reasoning (AI and vmPFC), and punishment (AI).

Introduction

Feelings of guilt are universal among human beings (Takahashi et al., 2004) and may mediate the relationship-enhancing effects of empathy to improve relationships (Leith and Baumeister, 1998). The ability to feel guilt is a superordinate function and generally interculturally important for living together (Ausubel, 1955). Guilty feelings are associated with the violation of moral norms. Psychologists contend that feelings of guilt and empathy assist individuals in establishing positive relationships with others (Lewis and Sullivan, 2005). Individuals with greater empathy are sensitive to feelings of guilt because empathy involves sharing another's emotional experience using the cognitive ability to take another person's perspective (Tangney et al., 2007).

Abbreviations: AI, anterior insula; CSF, cerebrospinal fluid; DARTEL, diffeomorphic anatomical registration through the exponentiated lie algebra; EQ, empathy quotient; GFS, guilty feeling scale; IPL, inferior parietal lobule; IPS, interpersonal situation; MNS, mirror neuron system; OFC, orbitofrontal cortices; PI, posterior insula; RAPM, Raven's advanced progressive matrix; RBS, rule-breaking situation; rGMD, regional gray matter density; SCC, subgenual cingulate cortex; STS, superior temporal sulcus; TIV, total gray matter volume; vmPFC, ventromedial prefrontal cortex.

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We should focus on empathy because empathy is closely related to feeling guilty (Leith and Baumeister, 1998; Tangney et al., 2007). Guilt requires a feeling of attachment towards another person (Zahn et al., 2009a). Empathy is implemented by a complex network of neural regions including the insula and orbitofrontal cortices (OFC) (Decety, 2010). Empathy for others' pain, which is an important function for feeling guilt, is associated mainly with AI activity (Bernhardt and Singer, 2012; Engen and Singer, 2013).

Functional and structural neuroimaging studies of healthy subjects have investigated the neural correlates related to guilt. Functional neuroimaging studies have focused on imagining the event in which they felt the most guilt that they had ever experienced (Shin et al., 2000), intentionally or accidentally (Berthoz et al., 2006), gender difference (Michl et al., 2014), interpersonal (altruistic) guilt (Yu et al., 2014) or deontological guilt (Basile et al., 2011), compensation that might be stimulated by guilt (Yu et al., 2014), differences between guilty and embarrassment (Takahashi et al., 2004), compassion (Zahn et al., 2009a), pride (Zahn et al., 2009b), shame (Wagner et al., 2011) (Michl et al., 2014), and sadness (Wagner et al., 2011). In these functional studies, feelings of guilt were related to activation of the superior temporal/inferior parietal lobule (IPL) including the superior temporal sulcus (STS) (Takahashi et al., 2004; Michl et al., 2014), ventromedial prefrontal cortex (vmPFC) (Zahn et al., 2009b; Morey et al., 2012), insula (Shin et al., 2000; Yu et al., 2014; Michl et al., 2014), amygdala, and subgenual cingulate cortex (SCC) (Zahn et al., 2009a,b, 2013). A structural neuroimaging study dealing with healthy subjects linked proneness to guilt with individual variations in anterior brain regions (Zahn et al., 2013).

Clinical structure studies related to feelings of guilt have been conducted in patients with antisocial disorder (Raine et al., 2000), psychopathy (de Oliveira-Souza et al., 2008), and conduct disorder (Wallace et al., 2014). Clinically, the OFC and vmPFC (Koenigs et al., 2007; Wallace et al., 2014) seem to play critical roles in feelings of guilt, as those regions are necessary for integrating outcome and belief information during moral reasoning (Ciaramelli et al., 2012) and affective processing (Wagner et al., 2011). Abnormalities in a specific amygdala–OFC limbic network might elucidate the neurobiological underpinning of psychopathy (Craig et al., 2009).

Our specific motivation in this study was to identify the widespread neural correlates of feelings of guilt at the whole-brain level with a statistically strong number of healthy subjects for the following reasons: the previous functional studies of guilt focused on some elements of feelings of guilt in small numbers (double figures) of healthy subjects. Further, the previous structural studies, apart from the one by Zahn et al. (2013), were clinical studies, in which the numbers of subjects were small and the identified regions were not directly related to feeling guilty. For example, the regions identified were found to relate to autonomic nerve activity (skin conductance and heart rate) when participants gave a videotaped speech under social stress on their lies. The prefrontal GM volumes of those with antisocial personality disorder were compared with healthy subjects (Raine et al., 2000). In other studies, the regions identified were related not to the feeling guilt, but to the interpersonal/affective dimension of psychopathy (de Oliveira-Souza et al., 2008), and callous-unemotional traits (Wallace et al., 2014). To our knowledge, there has been only one brain-structure study of healthy subjects related directly to feelings of guilt (Zahn et al., 2013). However, that study found no specific significant relationship to the degree of feeling guilt and there were too few subjects ($N = 64$) to demonstrate the neural correlates at the whole-brain level. As described in a previous report (Takeuchi et al., 2012), structural imaging studies are especially useful for investigating the anatomical correlates of personal characteristics that involve a wide range of behaviors or cognitions that occur outside the laboratory. Unlike fMRI studies, the results of structural imaging studies are not limited to the specific regions engaged in the task or responding to stimuli during scanning. Using MRI correlation studies (including studies with fMRI) to investigate the neural basis of individual differences, we established cognitive measures with proven reliability and validity to tap individual differences in cognition.

Considering the outcomes of activation and brain structural studies related to guilty feelings and the fact that empathy, moral reasoning, and punishment are essentially associated with guilty feelings (Ciaramelli et al., 2012), we hypothesized that the comprehensive neural networks for feeling guilty were widespread in regions related to empathy, moral reasoning, and punishment, especially the insula, IPL, amygdala, SCC, and vmPFC. The purpose and novelty of this study were to elucidate the comprehensive neural networks for feelings of guilt by revealing the anatomical correlates of feeling guilt in gray matter structures in healthy young adults because no neural networks have been detected as regions significantly and directly related to the degree of feeling guilt in the whole brain, probably due to the small numbers of subjects. To assess guilty feelings in scenario-based approaches, we used the guilty feeling scale (GFS), which consists of interpersonal situation (IPS) and rule-breaking situation (RBS) scores (Ishikawa and Uchiyama, 2002). Using this classification of feelings of guilt is also a novelty of this study. To test our hypothesis, we investigated whether individual differences in IPS/RBS were associated with widespread regional gray matter densities (rGMD) using voxel-based morphometry (VBM) (Good et al., 2001) and whether these rGMD-correlated guilty feelings were associated with empathy and with rGMD of regions previously implicated in moral reasoning, and punishment. We controlled anger as a confounding variable because there is a relationship between feelings of guilt and anger (Zahn et al., 2009a; Teicher et al., 2010).

Furthermore, one brain study has investigated gender differences in guilt and demonstrated activation of the frontal cortex and amygdala in men only in the guilt condition (Michl et al., 2014). Previous studies have shown that females experience more guilt than males (Else-Quest et al., 2012). Furthermore, Ishikawa and Uchiyama (2002) found that for male students, empathy was positively correlated with guilt feelings in the IPS, whereas empathy was positively correlated with guilt feelings in both the IPS and RBS for female students. Thus, we hypothesized the existence of sex-related differences in empathy in the RBS and rGMD. We tested this hypothesis.

Materials and methods

Subjects

A total of 764 healthy, right-handed individuals (422 males and 342 females; mean age 20.7 ± 1.8 years) participated in this study as part of an ongoing project investigating associations among brain images, cognitive functions, aging, genetics, and daily habits (Takeuchi et al., 2011, 2012). Data derived from the subjects in this study will be used in other studies unrelated to the theme of this study. All subjects had normal vision and were university, college, or postgraduate students or had graduated from these institutions within 1 year before the experiment. None had a history of neurological or psychiatric illness. Handedness was evaluated using the Edinburgh Handedness Inventory (Oldfield, 1971). Written informed consent was obtained from each subject in accordance with the Declaration of Helsinki (1991). This study was approved by the Ethics Committee of Tohoku University.

Psychological outcome measures

Assessment of guilty feelings

We used the reliable and valid GFS (Ishikawa and Uchiyama, 2002), which consists of the IPS (11 items) and RBS (10 items) tests (Ishikawa and Uchiyama, 2002). Accordingly, the GFS consisted of 21 statements, which were divided into two dimensions. The possible scores for the IPS range from 11 to 44 and those for the RBS from 10 to 40. This scale was constructed using an open-ended questionnaire, and 315 guilt experiences were collected and categorized into 37 situations (Arimitsu, 2002). Exploratory factor analysis with promax rotation was performed