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Regional gray matter volume in the posterior precuneus is associated with general self-efficacy

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Abstract

Motivation in doing a task is influenced not only by the expected outcome of the task, but also by the belief that one has in successfully executing the task. Over time, individuals accumulate experiences that contribute to a general belief in one's overall ability to successfully perform tasks, which is called general self-efficacy (GSE). We investigated the relationship between regional gray matter volume and individual differences in GSE. Brain anatomy was analyzed using magnetic resonance images obtained from 64 healthy right-handed participants who had completed Sherer's GSE scale. After controlling for other factors related to motivation, age, sex, and total gray matter volume of each subject, results showed that regional gray matter volume in the posterior part of the precuneus significantly and positively correlated with GSE score. These results suggest that one's accumulated experiences of success and failure, which contribute to GSE, also influence the anatomical characteristics of the precuneus.

Keywords

VBM; General self-efficacy; Precuneus; Motivation

Introduction

One is constantly making decisions about what actions to take, and each decision is influenced by one's motivation to perform a given action. Motivation for completing a task is based not only on the expected outcome of that action, but also on the predicted likeliness of successfully completing that action. This concept of "self-efficacy," proposed by Albert Bandura decades ago [1], has been used to explain the motivational aspects of behaviors such as resilience to failure [2], amount of time spent doing a task [3] and actual performance [4].

As Bandura stated, self-efficacy is largely affected by past experiences with the same task that the agent is about to do; experience of success will increase self-efficacy, and vice versa [5]. There are individual differences in the strength of one's belief in their ability to succeed in a variety of tasks, which is called general self-efficacy (GSE) [6]. GSE results from past outcomes of tasks and will affect our motivation to do them. We process outcome information of our actions, and our neural mechanisms change anatomically by this processing [7]. Since GSE is a grand sum of these experiences, the brain regions that would be most relevant to GSE would likely be regions that process outcomes of tasks and expectation of future outcomes. Therefore we hypothesized that individual differences in GSE may also be reflected in the brain structure.

In the present paper, we investigated the regional gray matter volume specific to GSE. GSE correlates with other factors related to motivation, such as subjective evaluation of self worth or self-esteem [8], desire for accomplishment or achievement motivation [9], and sensitivity to punishment or behavioral inhibition [10]. Therefore, we used subjects' scores on questionnaires related to these factors in order to exclude them. Thus we found a significant correlation between gray matter volume in the posterior precuneus and GSE specifically.

Methods

Participants. Sixty-four healthy participants [mean age = 20.1, SD = 1.4, 29 males] recruited from Tamagawa University (Tokyo, Japan) took part in this study. All participants gave written informed consent and the experimental protocol was approved by the Ethics Committee of Tamagawa University.

Questionnaire. Self-reported GSE was measured using a questionnaire developed by Sherer and colleagues [6], which was translated into Japanese and its reliability and validity was demonstrated in Japanese subjects [11]. The GSE scale consists of 23 items, with responses made on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In order to find a gray matter region that specifically correlates with GSE score, we used other personality questionnaires that are related to motivation and hypothesized to correlate with the GSE scale as controls. These questionnaires included a self-esteem scale [12; 13], a behavioral inhibition system and behavioral activation system (BIS/BAS) scale [14; 15] and an achievement motivation scale [16]. For each questionnaire used in the study, validity was verified by correlation with the indexes that the questionnaire is predicted to reflect; reliability was verified by correlation between two tests done within a few weeks [12; 14; 16]. The internal reliabilities for each questionnaire measured by Cronbach's alpha were: GSE, $\alpha = 0.80$; self-esteem, $\alpha = 0.79$; BIS, $\alpha = 0.79$; BAS, $\alpha = 0.75$; achievement motivation, $\alpha = 0.72$.

Neural data acquisition & analysis. A structural image of the brain was acquired for each subject using a 3-tesla Siemens Trio A Tim MRI scanner with a 32-channel head coil. T1 weighted images were acquired using the 3D-MPRAGE sequence [TR = 2000 ms, TE = 1.98 ms, TI = 900 ms, Flip angle = 10 degrees, Echo space = 6.1 ms, Field of view = 256 × 256 mm, 192 slices, voxel size = 1 × 1 × 1 mm] which took about 5 minutes. To correct for B1 inhomogeneities, images were reconstructed using pre-scan normalization. Image analysis

was performed using Statistical Parametric Mapping software (SPM version 8; http://www.fil.ion.ucl.ac.uk). Preprocessing of the structural images was done by segmenting the brain tissues into six categories (Gray matter, White matter, CSF, Skull, Soft tissue, Air) based on the East Asian brain template. We used diffeomorphic anatomical registration using exponentiated lie algebra (DARTEL) to improve the realignment of small inner structures. Registered images were smoothed with a gaussian kernel (full width at half maximum = 8 mm) and were transformed to Montreal Neurological Institute (MNI) stereotactic space using affine and non-linear spatial normalization.

In order to limit the analysis to voxels that would include gray matter, we created a binary mask to include the voxels with a gray matter probability of over 30% in the gray matter template (grey.nii), and we excluded all of the other voxels from the multiple comparison [17]. In the whole-brain multiple regression analysis using a generalized linear model (GLM), we tested for a relationship between GSE score and regional gray matter volume. Age, sex, and total gray matter volume were included in the GLM as covariates of no interest, in order to regress out the effects correlating with these variables. This was also true for other personality scores related to motivation (i.e. self-esteem, BIS/BAS and achievement motivation). The total gray matter volume was calculated for each participant as the total gray matter within the voxels that were included in the multiple comparison. The threshold was set to family-wise error (FWE)-corrected at a cluster-level of $p < 0.05$ after thresholding at $p < 0.001$ in the whole brain, in order to find a region specifically correlated with GSE, but not with other similar personality concepts.

Results

The correlation analysis showed a significant correlation between GSE score and other questionnaires as seen in previous studies: self-esteem, $r = 0.332$, $P = 0.007$; BIS, $r = -0.355$, $P = 0.004$; BAS, $r = 0.296$, $P = 0.018$; achievement motivation, $r = 0.533$, $P < 0.001$ [6; 9; 10] (Table 1). The GSE score positively correlated with the gray matter volume in the right posterior precuneus ($x = 5$, $y = -72$, $z = 50$; $t = 4.85$; standard partial regression coefficients: GSE: $\beta = 0.620$, self-esteem: $\beta = -0.114$, BIS: $\beta = 0.192$, BAS: $\beta = -0.218$, achievement motivation: $\beta = -0.135$) (Fig. 1). Within the same GLM, other questionnaires showed no significant relation with the gray matter volume in any part of the brain (including the precuneus) that would exceed the threshold set for the multiple comparison.

Discussion

In the present study, we investigated the relationship between regional gray matter volume and individual differences in GSE. We found that the gray matter volume in the posterior precuneus showed a positive correlation with GSE across subjects. No significant relation was found between other questionnaires related to motivation (i.e., Achievement Motivation, Self-esteem, and BIS/BAS) and gray matter volume (which exceeded the threshold for multiple comparison within the whole brain), even though these questionnaires showed significant correlation with GSE score. Thus, the GSE appears to be specifically correlated with the gray matter volume within the posterior precuneus.

Since GSE correlates with the other questionnaires, it is assumed that there is an overlap between these traits. However, since we have identified that the precuneus has a specific relationship with GSE, we discuss below the distinct features of GSE that may relate to the function of the precuneus.

The precuneus, especially its posterior part, has been associated with episodic memory [18]. Firstly, the precuneus shows activity during the retrieval of autobiographical events compared to general memories about the past [19]. Secondly, it has been shown that when we predict what will happen in the future, a neural network including the precuneus that is needed to recall past experiences is activated [20]. Finally, the gray matter volume in a part of the precuneus correlates with the tendency for an individual to take first-person perspective when recalling autobiographical memories [21]. Thus, the precuneus seems to accumulate past experiences and create a self-image in relation with the outside world. Since the GSE is not determined by one’s experience of a single task, but rather the accumulated experiences that add up to a general expectation that an individual holds before executing a task [1; 6], it seems reasonable that the precuneus is a key region involved in GSE.

Since the degree of self-efficacy one experiences in a task is related to past and present success or failure, it makes sense that the parts of the brain where feedback is processed would show a correlation with GSE score. In fact, Themanson and colleagues found that the amplitude of error-related negativity (ERN), which is generated in the medial prefrontal cortex after an error is made during a task, positively correlates with self-efficacy and post-error performance on that task [22]. The present results concerning GSE, however, point to a gray-matter region that stores episodic memories (posterior precuneus), rather than regions that are involved in feedback processing. One possibility is that the degree of self-efficacy one experiences in various tasks is gathered in the precuneus and sums up to determine a person's degree of GSE, which is represented by the gray matter volume in the posterior precuneus. This idea is supported by the fact that the precuneus is functionally and anatomically interconnected with regions including the medial prefrontal cortex [18; 23; 24].

This study is subjected to the limitations of the method of voxel-based morphometry (VBM). Since there is only the information about the volume of gray matter within the voxel, how the gray matter is structured within that voxel cannot be assumed from VBM. Differences in gray matter volume may result from folding within that voxel rather than from actual differences in thickness [25]. The underlying biological structure of the differences between gray matter volume between individuals needs further investigation.

Our finding opens the door to new questions in both neuroscience and psychology, challenging ideas about how personality affects decision-making and how decisions affect personality. Specifically, we hope to address three new questions raised by the current findings: 1) how is information integrated in the precuneus, 2) how could differences in GSE be represented by precuneus gray matter volume differences, and 3) how might accumulated information in the precuneus actually affect our actions or decisions.

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Table 1 Correlation between GSE scale and other questionnaires

Self-esteem	BIS	BAS	Achievement motivation
0.332 **	-0.355 **	0.296 *	0.533 ***

* P < 0.05, ** P < 0.01, *** P < 0.001

GSE = general self-efficacy, BIS = behavioral inhibition system, BAS = behavioral activation system

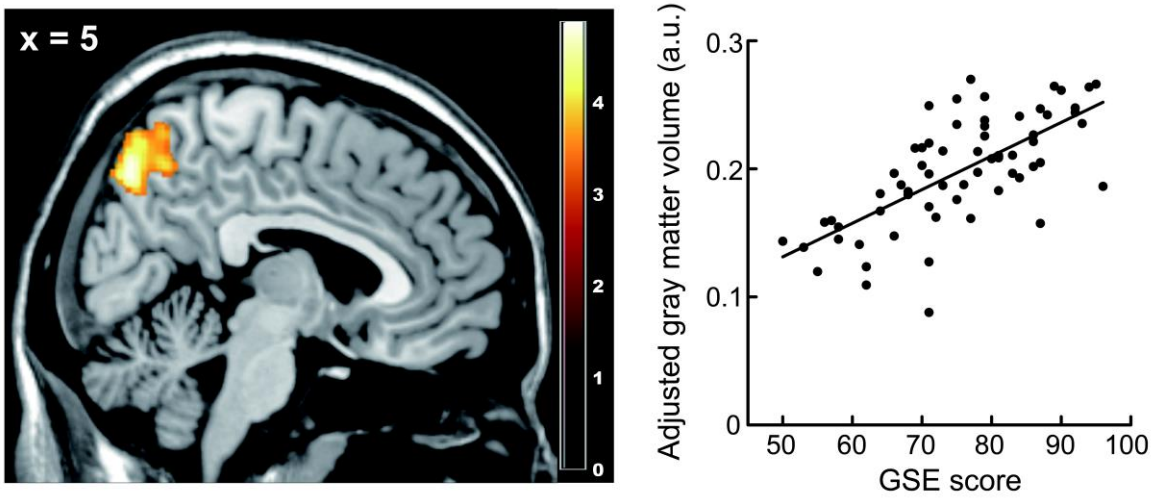

Fig. 1 Region where gray matter volume showed significant association with GSE score Left: Gray matter volume in the right posterior precuneus (x=5, y=-72, z=50; t = 4.85) showed significant positive correlation with GSE scale. Scale shows the t-value. Right: A scatter plot of the adjusted gray matter volume taken from the peak voxel, as a function of GSE score. This plot is shown only for illustrative purpose and was not used for any statistical inference.