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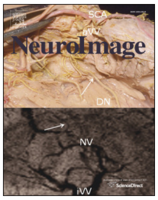

Neuroanatomical correlates of the sense of control: Gray and white matter volumes associated with an internal locus of control

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ABSTRACT

A belief that effort is rewarded can develop incentive, achievement motivation, and self-efficacy. Individuals with such a belief attribute causes of events to themselves, not to external, uncontrollable factors, and are thus said to have an internal locus of control. An internal locus of control is a positive personality trait and has been thoroughly studied in applied psychology, but has not been widely examined in neuroscience. In the present study, correlations between locus of control assessment scores and brain volumes were examined in 777 healthy young adults using magnetic resonance imaging. A whole-brain multiple regression analysis with corrections for the effects of age, gender, and intelligence was conducted. Voxel-based morphometry analyses revealed that gray matter volumes in the anterior cingulate cortex, striatum, and anterior insula positively correlated with higher scores, which indicate an internal LOC. In addition, white matter volumes in the striatum showed significant correlations with an internal locus of control. These results suggest that cognitive, socioemotional, self-regulatory, and reward systems might be associated with internal control orientation. The finding of greater volumes in several brain regions in individuals with a stronger internal locus of control indicates that there is a neuroanatomical basis for the belief that one's efforts are rewarded.

Introduction

Personality is generally stable; however, it can develop and change across the lifespan (Caspi et al., 2005). Internal locus of control (LOC) (Rotter, 1966) is defined as the belief that the outcomes of our actions are contingent on what we do (e.g., internal control, attributing causes to oneself), rather than on events outside of our personal control (e.g., external control, attributing causes to others, fate, or luck). An individual with an internal LOC is likely to be more able to improve his environmental condition and less prone to temptations.

Internal LOC is related to both subjective and physical well-being, including self-efficacy, emotional stability, stress tolerance, and health (Bollini et al., 2004; DeNeve and Cooper, 1998; Gale et al., 2008; Judge and Bono, 2001; Steptoe and Wardle, 2001). In contrast, external LOC is associated with negative emotionality traits and is similar to learned helplessness (Abramson et al., 1978). Early experiences with either reduced internal control or external control can foster later vulnerability to anxiety (Chorpita and Barlow, 1998), and children with external LOC show increased risk of psychotic symptoms in early adolescence (Thompson et al., 2011). A previous study found that an external LOC positively correlated with negative symptoms in an experimental group at high risk for psychosis and negatively correlated with social functions in the healthy control group (Thompson et al., 2013). LOC has been suggested to be a higher order concept that is related to self-esteem, self-efficacy, and neuroticism (Judge et al., 2002). Neural correlates of self-esteem (Chavez and Heatherton, 2014) and neuroticism

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(Bjornebekk et al., 2013), which are related positively and negatively with fronto-striatal white matter structures, respectively, have been documented; however, neural correlates of LOC have yet to be well elucidated.

A neurobiological model of LOC (Declerck et al., 2006) suggests that the LOC is regulated by the prefrontal cortex, anterior cingulate cortex, and subcortical–cortical dopamine pathways, which all are associated with self-regulation, flexibility, and goal directed behavior. Self-regulation, cognitive integration, and socioemotional function, which are mediated by the anterior cingulate cortex, (Pfeifer and Peake, 2012), as well as action control, cognitive regulation, and incentive motivation, which are functions of the fronto-striatal dopamine systems (Shiflett and Balleine, 2011; Somerville and Casey, 2010), have been associated with LOC. Feeling in control through emotional regulation and stability associated with the anterior cingulate cortex can be related to LOC (Kohn et al., 2014). Functional neuroimaging studies have revealed that perceiving a greater sense of leading/controlling a partner correlated both with internal LOC and right anterior insular activity (Fairhurst et al., 2014).

Furthermore, the correlation between external LOC and loss-related anterior insular activity suggests that external control is associated with a higher sensitivity to aversive events (Hernandez Lallement et al., 2014). An association between greater hippocampal volume and a stronger internal LOC was observed in a study in 16 young adult and 23 elderly subjects (Pruessner et al., 2005); however, neuroanatomical correlates of LOC have not been examined throughout the brain.

Therefore, we hypothesized that the neural network underlying LOC is associated with cognitive, socioemotional, self-regulation and reward systems, and that this putative association might be observed by whole brain volumetric analyses. In this study, we investigated neuroanatomical correlates of LOC in a large sample (777 young healthy adults). Specifically, we used voxel-based morphometry (VBM) to determine the correlation of regional gray matter volume (rGMV) and white matter volume (rWMV) with an internal LOC.

Materials and methods

Participants

Data from 777 healthy, right-handed individuals (433 males and 344 females; 20.7 ± 1.9 years of age) were used in this study, which is part of an ongoing project that comprises various types of MRI scanning and psychological test batteries in addition to those analyzed in this manuscript. We collected the data over 842 days. The overall scope of this comprehensive project is to investigate associations between brain imaging, cognitive functions, aging, genetics, and daily habits. Thus, data derived from the subjects in this study are to be used in other studies irrelevant to the theme of this manuscript. Some of the subjects who participated in this study also became subjects of intervention studies, but the psychological and imaging data used in this study were obtained before any interventions began (Takeuchi et al., 2013b). Psychological data were obtained on the same day of MRI scanning. The order of psychological testing versus MRI scanning was determined randomly for each participant. All subjects were university, college, or postgraduate students, or individuals who had graduated from these institutions within 1 year of the experiment. All participants had normal vision and 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.

Assessment of psychometric measures of general intelligence

Raven's Advanced Progressive Matrix (Raven, 1998) was used to assess intelligence and to obtain subject characteristics, as it is has often been shown to be the test most correlated with general intelligence (Raven, 1998). Additional details on the administration of Raven's Advanced Progressive Matrix can be found in previous publications (Takeuchi et al., 2010a,2010b).

Locus of control assessment

We used a validated (Cronbach's $\alpha = 0.78$, and the reliability of the scale = 0.76) Japanese version (Kamahara et al., 1982) revised from the original version for LOC assessment (Rotter, 1966). It consists of 18 questions with a 4-point Likert scale assessing an internal or external LOC. Higher scores indicate internal control and lower scores indicate external control. Subjects were asked nine questions each of which was indicative of internal or external control, such as “Do you believe envisioning what you will be in the future is useful?” and “Do you believe whether you will succeed or not is not strongly associated with your efforts?” (reverse scoring), respectively.

Five factor personality assessment

In addition, we assessed the personality traits of participants using a validated 60-item Japanese version (Shimomura et al., 1999) of the NEO Five-Factor Inventory (NEO-FFI) (Costa and McCrae, 1992) in order to examine the relationship between LOC and five personality factors (Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness). Significant correlations between LOC and NEO-FFI scores were determined by calculating Pearson's coefficients.

Image acquisition and analysis

MRI data acquisition was conducted using a 3 T Philips Achieva scanner. Three-dimensional, high-resolution, T1-weighted images (T1WI) were collected using a magnetization-prepared rapid gradient-echo (MPRAGE) sequence. The parameters were as follows: 240 × 240 matrix, TR = 6.5 ms, TE = 3 ms, TI = 711 ms, FOV = 24 cm, 162 slices, in plane resolution = 1.0 mm × 1.0 mm, slice thickness = 1.0 mm, and scan duration of 8 min and 3 s.

Pre-processing and analysis of structural data

Preprocessing of the MRI data for VBM analysis was performed using Statistical Parametric Mapping software (SPM12; Wellcome Department of Cognitive Neurology, London, UK) following the protocol from our previous study (Takeuchi et al., 2013a). Regional gray matter volume (rGMV) and regional white matter volume (rWMV) were calculated. T1WIs of each individual were segmented into six tissues using the default parameter settings of a segmentation algorithm implemented in SPM12, with three exceptions: Affine regularization was performed in accordance with the average-sized template, sampling distance (the approximate distance between sampled points when estimating the model parameters) was 1 mm, and the thorough clean option was used to get rid of any odd voxels from segmented images. We then carried out a diffeomorphic anatomical registration through an exponentiated lie (DARTEL) algebraic registration process implemented in SPM12. Specifically, we used DARTEL-imported images of gray and white matter tissue probability maps (TPMs) created through the abovementioned segmentation process. First, the template for the DARTEL procedures was created using imaging data from the 800 study participants (400 males and 400 females, data from 23 subjects were discarded because no LOC data was obtained). The resulting images were then spatially normalized to the Montreal Neurological Institute (MNI) space to obtain images with $1.5 \times 1.5 \times 1.5\ \text{mm}^3$ voxels. In addition, we performed a volume change correction (modulation) by modulating each voxel with the Jacobian determinants derived from the spatial normalization, thus allowing for the determination of regional differences in the absolute amount of brain tissue. Subsequently,

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