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Structural and functional associations of the rostral anterior cingulate cortex with subjective happiness

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ABSTRACT

Happiness is one of the most fundamental human goals, which has led researchers to examine the source of individual happiness. Happiness has usually been discussed regarding two aspects (a temporary positive emotion and a trait-like long-term sense of being happy) that are interrelated; for example, individuals with a high level of trait-like subjective happiness tend to rate events as more pleasant. In this study, we hypothesized that the interaction between the two aspects of happiness could be explained by the interaction between structure and function in certain brain regions. Thus, we first assessed the association between gray matter density (GMD) of healthy participants and trait-like subjective happiness using voxel-based morphometry (VBM). Further, to assess the association between the GMD and brain function, we conducted functional magnetic resonance imaging (MRI) using the task of positive emotion induction (imagination of several emotional life events). VBM indicated that the subjective happiness was positively correlated with the GMD of the rostral anterior cingulate cortex (rACC). Functional MRI demonstrated that experimentally induced temporal happy feelings were positively correlated with subjective happiness level and rACC activity. The rACC response to positive events was also positively correlated with its GMD. These results provide convergent structural and functional evidence that the rACC is related to happiness and suggest that the interaction between structure and function in the rACC may explain the trait–state interaction in happiness.

Introduction

Since ancient times, people have thought about and desired happiness. Although happiness may be difficult to define scientifically, it has been defined to correspond to the sum of one's recent levels of positive affect, high life satisfaction, and infrequent negative affect (Diener, 1984, 1994; Diener et al., 1999). Because no appropriate device exists that can measure happiness objectively, researchers have generally relied on self-report measurements of happiness (i.e., subjective happiness level; Lyubomirsky and Lepper, 1999). Although subjective assessment of happiness has been shown to be associated with a wide variety of factors, including demographic status, personality traits, and circumstances (Lyubomirsky et al., 2005; Schimmack, 2008), subjective happiness appears to be trait-like and relatively stable over long periods of time (Lyubomirsky et al., 2005). In contrast, there is also a temporal aspect to happiness (hedonia; Diener, 1984, 1994; Diener et al., 1999). The temporal hedonic component of happiness is usually generated when we get the material objects and action opportunities we wish to possess or experience (Berridge and Kringelbach, 2011; Otake et al., 2006; Oyama, 2012; Schimmack, 2008; Seligman et al., 2005). Previous studies have demonstrated that individuals with high trait-like subjective happiness tend to evaluate their current emotional states more positively when they experience positive events (Matsunaga et al., 2011b; Schimmack, 2008). It also has been indicated that repetitive experiences of hedonic events elevate our subjective happiness level (Otake et al., 2006; Schimmack, 2008; Seligman et al., 2005). Two psychological models explain this interaction in happiness: a top-down and bottom-up model (Schimmack, 2008). The top-down model assumes that individuals with a positive propensity, such as optimism, evaluate their long-term happiness and temporal happy events more positively than others who experience a similar number of positive life events (Schimmack, 2008). In contrast, the bottom-up model suggests that consecutive hedonic experiences in each of the life domains (e.g., household income, housing conditions) elevate long-term happiness (Schimmack, 2008). Thus, the sum of positive life events may be important for constructing long-term happiness. However, previous

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epidemiological data could not indicate biological mechanisms underlying the interaction between the two aspects of happiness.

The biological mechanisms underlying trait–state interactions in happiness may be explicable by means of structural and functional interactions in certain brain regions. Numerous structural magnetic resonance imaging (MRI) studies have reported structural plasticity in the adult human brain (Driemeyer et al., 2008; Hamzei et al., 2012; Kwok et al., 2011). Gray matter is a major component of the central nervous system, consisting of neuronal cell bodies, neuropil (dendrites and unmyelinated axons), glial cells (astroglia and oligodendrocytes), and capillaries; changes in gray matter reflect changes in cells or neuropil within the brain (Cook and Wellman, 2004; Wellman, 2001). Previous structural MRI studies have demonstrated associations between gray matter density (GMD), personality, and higher cognitive functions, including perception, intelligence, and memory (Giménez et al., 2004; Kanai et al., 2012; Kanai and Rees, 2011; Mårtensson et al., 2012; Spampinato et al., 2009). For example, lonely individuals show a reduction in gray matter in the left posterior superior temporal sulcus (pSTS), an area implicated in basic social perception (Kanai et al., 2012). Further, the GMD of the rostral anterior cingulate cortex (rACC) is reduced in patients with depression compared to healthy individuals (Du et al., 2012). Sharot et al. (2007) have previously suggested an association between gray matter reduction in the rACC in patients with depression and difficulties in creating detailed images of future events. Individual differences in human behavior and cognition may be explicable in terms of brain anatomy because greater cortical volume, or greater GMD, is associated with greater computational efficacy (Kanai and Rees, 2011). Therefore, if trait-like subjective happiness is represented in the structure of certain brain regions, and temporal happy feelings are represented by the activation of similar brain regions, the interaction between structure and function may be a key concept explaining the biological mechanisms underlying the interaction between the two aspects of happiness. This is because individuals with greater volumes of trait happiness-related brain regions may have higher-magnitude responses to positive stimuli and more easily experience happy feelings. This may be linked to the biological foundation of the top-down theory of happiness. Further, several structural MRI studies have reported training-related structural plasticity in the adult human brain (Driemeyer et al., 2008; Hamzei et al., 2012; Kwok et al., 2011). It has been demonstrated that motor skill training and a variety of trial and error learning increase GMD in cortical motor areas, which is also accompanied by performance improvements (Hamzei et al., 2012). Thus, repetitive stimulation of certain brain regions may increase their cortical volume, suggesting that continuous experiences of positive events might stimulate temporal happiness-related brain regions and enlarge the cortical volumes associated with trait happiness. This may be the biological foundation of the bottom-up theory of happiness.

However, the neural substrates of subjective happiness remain somewhat ambiguous. A recent structural MRI study demonstrated an association between gray matter volume in the insular cortex and subjectively assessed eudemonic well-being (Lewis et al., 2014). Eudemonia is one of the important trait-like aspects of happiness and corresponds to certain cognitive and/or moral aspects of a well-lived life (Berridge and Kringelbach, 2011). The insular cortex is associated with interoceptive awareness because it is the top-level center of the ascending pathways of information flow from the body to the brain (Craig, 2009). Because one of the concepts of happiness centers on positive inner feelings, such as pleasure and joy (Oishi et al., 2013), such an association between the interoception-related brain region and subjective happiness might make sense. Another structural MRI study indicated an association between subjective happiness and gray matter volume in the precuneus (Sato et al., 2015). When we evaluate our life events, there is no objective answer based on external circumstances; rather, the evaluation is based on our own experiences or preferences. A recent neuroimaging study indicated that various neural networks including the medial prefrontal cortex, precuneus, and the superior temporal gyrus are consistently activated by such subjective evaluation (Nakao et al., 2012). These neural networks are involved in episodic memory retrieval, theory of mind, and prospection, which is the act of thinking about the future (Buckner and Carroll, 2007; Krueger et al., 2009; Nakao et al., 2012; Northoff and Bermpohl, 2004; Roy et al., 2012). Thus, the association between the precuneus and subjective happiness also has face validity. However, a meta-analysis of neuroimaging studies—indicating the brain regions associated with happiness through a variety of psychological tasks, such as happy face recognition, listening to happy music, and recollection of happy memories, all of which can induce temporary states of happiness (Cerqueira et al., 2008; Damasio et al., 2000; Mitterschiffthaler et al., 2007; Sato et al., 2004)—confirmed that experimentally induced happiness consistently activates the superior temporal gyrus (STG; Brodmann area [BA] 22), rACC (BA 24), cerebellum, thalamus, lingual gyrus, inferior occipital gyrus, insular cortex, and basal ganglia (Vytal and Hamann, 2010). A different meta-analysis indicated that happiness consistently activates only the peristriate (Lindquist et al., 2012). In contrast, Berridge and Kringelbach (2011) advocated the importance of reward-related regions such as the nucleus accumbens and ventral pallidum in happiness processing. The lack of consistency between the neural correlates of trait-like subjective happiness and of temporal happy feelings is problematic, although it is possible that not just one cortical area is involved in happiness processing.

In the present study, in order to clarify the association between structure–function interactions in the brain and trait–state interactions in happiness, we conducted both voxel-based-morphometry (VBM, Experiment 1) and functional MRI using a task that induced happy feelings (Experiment 2). We first measured the GMD of 106 healthy Japanese participants using VBM. In Experiment 1, participants were asked to evaluate their subjective happiness level using the Japanese version of the Subjective Happiness Scale (JSHS; Matsunaga et al., 2011a, 2011b; Shimai et al., 2004). The JSHS is a four-item scale that measures relatively stable, trait-like subjective happiness. We searched for brain regions in which there were positive correlations between GMD and the JSHS score. Subsequently, to assess the association between the GMD and temporal happiness-related brain activations, we conducted Experiment 2, in which 26 healthy Japanese participants took part in an fMRI study. They were asked to imagine how happy they would feel when they encountered several types of emotional life events (positive, neutral, negative, and non-emotional), while images depicting each life event were presented (Fig. 1). The participants rated their present level of happiness subsequent to imagining each event by means of a visual analog scale (VAS). We assessed associations between blood oxygen level-dependent (BOLD) response and GMD. We revealed structural and functional associations of the rACC with subjective happiness by combining the results of Experiments 1 and 2.

Methods

Experiment 1

Participants

We recruited 106 right-handed healthy volunteers (49 men and 57 women; age range: 18–34 years; mean age: 21.4 years), following approval of the study by the Ethics Committee of the National Institute for Physiological Sciences. All participants provided written informed consent in accordance with the Declaration of Helsinki. Participants were excluded if they had any chronic and infectious illnesses, and if they had taken medication in the week prior to the experiment. Although we did not record the social status of all participants, almost all participants in Experiment 1 were Japanese undergraduate and graduate students of universities located near the National Institute for Physiological Sciences. We did not record the body mass index (BMI) in Experiment 1.