Brain structural basis of cognitive reappraisal and expressive suppression

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Cognitive reappraisal and expressive suppression, two major emotion regulation strategies, are differentially related to emotional well-being. The aim of this study was to test the association of individual differences in these two emotion regulation strategies with gray matter volume of brain regions that have been shown to be involved in the regulation of emotions. Based on high-resolution magnetic resonance images of 96 young adults voxel-based morphometry was used to analyze the gray matter volumes of the a priori regions of interest, including amygdala, insula, dorsal anterior cingulate and paracingulate cortex, medial and lateral prefrontal cortex (PFC) and their association with cognitive reappraisal and expressive suppression usage as well as neuroticism. A positive association of cognitive reappraisal with right and tendentially left amygdala volume and of neuroticism with left amygdala volume (marginally significant) was found. Expressive suppression was related to dorsal anterior cingulate/paracingulate cortex and medial PFC gray matter volume. The results of this study emphasize the important role of the amygdala in individual differences in cognitive reappraisal usage as well as neuroticism. Additionally, the association of expressive suppression usage with larger volumes of the medial PFC and dorsal anterior/paracingulate cortex underpins the role of these regions in regulating emotion-expressive behavior.

Keywords: cognitive reappraisal; expressive suppression; voxel-based morphometry; emotion regulation; amygdala; vmPFC

INTRODUCTION

Difficulties in the regulation of emotions are common characteristics of mood and anxiety disorders (Gross and Thompson, 2007). As one major form of cognitive emotion regulation, cognitive reappraisal is defined as interpreting a potentially emotion-eliciting situation in a way that changes its emotional impact (Gross and John, 2003). A more frequent use of cognitive reappraisal has been associated with better interpersonal functioning, enhanced psychological well-being, and reduced depressive symptoms in healthy individuals (Gross and John, 2003). Expressive suppression, another important form of emotion regulation, is defined as hiding the expression of emotions once an emotional response has arisen (Gross and John, 2003). Previously, the habitual use of expressive suppression has been found to be negatively associated with well-being (Gross and John, 2003), while this effect could not be replicated for everyday affective responses (Meyer et al., 2012). In order to assess individual differences in the usage of these two major emotion regulation strategies, Gross and John (2003) developed a self-report questionnaire. Based on this questionnaire, it has been shown that the habitual use of these strategies varies systematically between individuals and is stable in time (Gross and John, 2003).

In search of the underlying neurobiological substrates, several studies investigated brain structural correlates that might underlie individual differences in habitual (dispositional) cognitive reappraisal and expressive suppression usage (Welborn et al., 2009; Giuliani et al., 2011a,b; Kühn et al., 2011). Regarding the causal relationship of individual differences in personality traits in general and variations in gray matter volume, two possibilities are conceivable: either pre-existing individual volume differences may lead to differences in personality traits (as a consequence) or the volume of a brain region is affected by its usage (as a precondition). Thus, as the habitual use of emotion regulation strategies as mentioned above shows stable individual differences, it could be possible that these strategies (as a consequence or precondition) are associated with individual differences in the gray matter volume of relevant brain structures.

The first structural imaging study found that a ventromedial prefrontal cortex (vmPFC) region, in which volume differences based on participant’s gender were identified, but not lateral orbitofrontal cortex (OFC) volume was related to individual differences in cognitive reappraisal (positive correlation) and expressive suppression (negative correlation) usage (Welborn et al., 2009). In another magnetic resonance imaging (MRI) study, Giuliani and colleagues (2011b) observed a positive relation between cognitive reappraisal and the volume of the dorsal anterior cingulate/paracingulate cortex (dACC) but not the ventral anterior cingulate cortex, which was used as a control region (no relation to expressive suppression, negative affect and age). Furthermore, anterior insula volume has been shown to be positively correlated to expressive suppression, but not with cognitive reappraisal and negative affect (Giuliani et al., 2011a). Another study using an exploratory whole brain approach (Kühn et al., 2011) revealed a positive correlation of right dorsomedial prefrontal cortex (dmPFC) volume with expressive suppression, but no association of any brain region with cognitive reappraisal. These results demonstrate that distinct brain structural variations of gray matter volume in the insula, dACC, vmPFC and dmPFC might underlie individual differences in cognitive reappraisal and expressive suppression usage. However, a replication of these results is still missing because most of the above-mentioned studies focused on different brain regions. Additionally, different methodologies as well as sample selection criteria regarding for instance sex of participants were used, which prevents a reasonable comparison of the results.

In order to better understand the neural basis underlying emotion regulation processes, several functional neuroimaging studies have investigated the neural correlates of instructed emotion regulation via cognitive reappraisal (for an overview, see Ochsner and Gross, 2005). Typically, participants are presented with negative affective pictures and trained for interpreting the content of the respective pictures to reduce their emotional impact. On the
and healthy controls (Kanske et al., 2010), with reduced amygdala and stronger dACC responses when viewing negative emotional faces (Drabant et al., 2009), and with stronger dACC and dorsolateral PFC (dlPFC) responses during response inhibition towards negative emotional material (sad vs happy faces; Vanderhasselt et al., 2013). One recent functional MRI (fMRI) study demonstrated a correlation of habitual reappraisal use with reduced activation of emotional arousal-related brain structures (like the amygdala and the insula) (see Ochsner and Gross, 2005).

Furthermore, dispositional reappraisal has been associated with reduced insula activation during the anticipation of aversive emotional pictures (Carlson and Mujica-Parodi, 2010), and with stronger amygdala and dACC responses to emotional faces (Emmons et al., 2009). One functional near infrared spectroscopy (fNIRS) study demonstrated a negative correlation of habitual reappraisal use with reduced activation of emotional arousal-related brain structures and lateral prefrontal cortical control regions accompanied by reduced dACC and ventromedial PFC (vmPFC) responses during response inhibition towards negative emotional material (sad vs happy faces; Vanderhasselt et al., 2013). One functional near infrared spectroscopy (fNIRS) study demonstrated a correlation of habitual reappraisal use with reduced activation of emotional arousal-related brain structures and lateral prefrontal cortical control regions accompanied by reduced activation of emotional arousal-related brain structures and lateral prefrontal cortical control regions accompanied by.

On the other hand, only few studies have investigated the neural correlates of expressive suppression in response to emotional stimuli (Goldin et al., 2008; Vanderhasselt et al., 2013). Goldin and colleagues (2008) demonstrated stronger activation especially in several PFC areas and increased insula and amygdala activation during the late phase of suppressing disgust facial reactions in response to disgust-elicitating film clips. A further PET study, however, demonstrated a reduction of amygdala activation during suppression of emotions (Ohira et al., 2006). Beyond that, individual differences in expressive suppression usage have been associated with higher amygdala activation when inhibiting responses to sad vs happy facial expressions (Vanderhasselt et al., 2013).

These studies demonstrate that especially the amygdala has been pointed out as a target region for several emotional regulation processes, including cognitive reappraisal as well as expressive suppression. Moreover, altered activation in the amygdala is a common finding in mood and anxiety disorders related to difficulties in emotion regulation (for overviews, see Etkin and Wager, 2007; Drevets et al., 2008). Furthermore, larger amygdala gray matter volumes have been reported in numerous studies investigating anxiety-related traits/states and negative memory bias in healthy participants (Barrós-Loscertales et al., 2006; Tottenham et al., 2010; van der Plas et al., 2010; Gerritsen et al., 2012). Furthermore, there is one study showing a negative association of neuroticism and left amygdala gray matter concentration (Omura et al., 2005), whereas two other studies could not replicate this result (Andari et al., 2012; Cremers et al., 2011). Another previous study has also reported a negative association of habitual cognitive reappraisal and neuroticism (Gross and John, 2003). In addition, reduced amygdala volume is a frequent finding in patients with mood and anxiety disorders (Irle et al., 2010; for overviews see Drevets et al., 2008; Atmaca, 2011; Kempton et al., 2011; Sachse et al., 2012). Altogether, these results underpin the crucial role of the amygdala in adaptive as well as dysfunctional emotional processing and regulation.

**Aim of this study**

To sum up, greater dACC volume and sex differences in vmPFC volume have been found as structural correlates of cognitive reappraisal, whereas expressive suppression has been shown to be associated with reduced vmPFC and greater anterior insula as well as dmPFC volumes. Functional neuroimaging studies have additionally reported reduced amygdala activation as a result of reappraising emotion-eliciting stimuli and in individuals more frequently using cognitive reappraisal. However, studies examining (expressive) suppression have reported mixed results. Moreover, abnormal amygdala gray matter volumes have been reported in several psychiatric disorders related to emotional dysregulation and have been shown to be associated with anxiety-related characteristics in healthy individuals. However, these discrepant findings of enlarged as well as decreased amygdala gray matter volumes in association with anxiety-related traits and psychopathology indicate a more complex and probably multidimensional relationship of amygdala volume and adaptive emotional processing. The alterations in amygdala volume might possibly be explained by considering further underlying factors as for instance individual differences in cognitive reappraisal and expressive suppression usage.

No study to date has directly examined the association of individual differences in cognitive reappraisal and expressive suppression usage and amygdala gray matter volume. Furthermore, ventrolateral PFC (vlPFC) and dlPFC structures functionally involved in the regulation of emotions have mostly been disregarded in previous studies investigating brain structural correlates of individual differences in cognitive reappraisal and expressive suppression usage. Hence, the aim of this study was to investigate the correlation of these emotion regulation strategies with amygdala and lateral PFC gray matter volume, and to replicate previous results, concerning insula, dmPFC, vmPFC and dACC gray matter volumes in a large sample of young individuals.

The neuroticism scale, as a measure of general negative affectivity, was chosen in order to compare the effects of habitual emotion regulation on amygdala gray matter volume to general effects of trait negative affectivity with an assumed positive association with amygdala gray matter volume.

**METHODS**

**Participants**

Ninety-six individuals (50% males, mean age in years: M = 23.23, s.d. = 2.82, range: 19–32; mostly students) were recruited. They participated in two studies investigating the neural basis of emotion regulation and emotional learning (Pejic et al., 2013, and one unpublished study). All subjects gave written informed consent and the study procedure was approved by the local ethics committee/the ethics committee of the German Psychological Society (DGPs). The study was conducted according to the Declaration of Helsinki and subjects received course credits or 10 euro/h for participation. Exclusion criteria consisted of self-reported actual and past neurological and psychiatric disorders, severe physical illness, intake of psychotropic medication or any MRI contraindications. All subjects were right-handed.

**Questionnaires**

Subjects filled in the emotion regulation questionnaire (ERQ; Gross and John, 2003; German version: Abler and Kessler, 2009), a 10-item measure assessing the habitual use of ‘cognitive reappraisal’ and ‘expression suppression’ on a 7-point Likert scale (‘1’ = ‘strongly disagree’ to ‘7’ = ‘strongly agree’). Example items are ‘When I want to feel less negative emotion, I change the way I’m thinking about the situation’ for the cognitive reappraisal scale, and ‘When I am feeling negative emotions, I make sure not to express them’ for the expressive suppression scale.

Additionally, the short version of the Big Five Inventory (BFI-K; Rammstedt and John, 2005) was completed. The BFI-K consists of five subscales (extraversion, neuroticism, openness, agreeableness and conscientiousness). Its 21 items have to be answered on a 5-point Likert scale (from 1 = ‘disagree strongly’ to 5 = ‘agree strongly’). For the purpose of this study, only the neuroticism scale was used to assess an individuals’ enduring tendency to experience negative emotional states.
MRI data collection and analysis

The anatomical scans were carried out with a Siemens Symphony 1.5 T whole-body scanner with a standard head coil. Structural images were acquired using a T1-weighted 3D MPRAGE sequence consisting of 160 sagittal slices (TI = 1100 ms, TR = 1990 ms, TE = 4.18 ms, flip angle: 15°, FoV: 250 × 250 mm, voxel size: 1.4 × 1.4 × 1.1 mm). Data analysis was performed with the VBM8 toolbox (http://dbm.neuro.uni-jena.de/vbm) by C. Gaser within the Statistical Parametric Mapping (SPM8, Wellcome Department of Cognitive Neurology, London, UK) implemented in MATLAB R2007b (Mathworks Inc., Sherborn, MA) using the default settings unless otherwise specified. Implemented in VBM is an automated voxel-wise whole brain preprocessing of MRI scans (Ashburner and Friston, 2000). The T1-images were segmented into the tissue types and normalized (high-dimensional DARTEL normalization implemented in VBM 8) to the standard space of the Montreal Neurological Institute (MNI) brain. Within that normalization procedure the average T1 DARTEL template was used. The modulated normalized (non-linear only) option was applied, resulting in an analysis of the absolute amount of tissue (gray matter volume) corrected for individual brain size. MRI inhomogeneities and noise were removed by bias correction (in normalized space). After a quality check of the data, images were smoothed with a FWHM kernel of 8 mm.

Second-level analysis was also carried out with SPM8. A region of interest (ROI) approach was applied for the a priori ROI (amygdala, insula, dACC, vmPFC, dmPFC, vlPFC and dlPFC) using the small volume correction option in SPM8. The amygdala and insula masks for the ROI analyses were maximum probability masks taken from the "Harvard-Oxford cortical and subcortical structural atlases" provided by the Harvard Center for Morphometric Analysis (http://www.cma.mgh.harvard.edu) with a probability threshold at 0.50. The dmPFC, vlPFC and dlPFC masks were created in MARINA (Walter et al., 2003). According to the parcellation of Tzourio-Mazoyer et al. (2002), the bilateral dmPFC mask consists of the medial part of the superior frontal gyrus, the left and right vlPFC mask of the triangular and opercular part of the inferior frontal gyrus and the left and right dlPFC mask of the dorsolateral part of the superior frontal gyrus and the middle frontal gyrus. The dACC mask consists of a 10 mm sphere surrounding a metaanalytical derived peak voxel for neural activation during the reduction of negative affect (Diekhof et al., 2011) in the anterior cingulate gyrus (MNI: x = −8, y = 28, z = 28) and the vmPFC mask of a 10 mm sphere surrounding a peak voxel for neural activation during reduction of negative affect (MNI: x = 0, y = 40, z = −18; Diekhof et al., 2011). In order to allow for a better localization of the peak voxels found in this study, we additionally report the probabilities of these voxels to pertain to the gray matter volume of different brain regions according to the abovementioned "Harvard-Oxford cortical and subcortical structural atlases" (only probabilities >10% will be reported). Multiple regression analysis with cognitive reappraisal, expressive suppression, neuroticism, sex (covariate of no interest) and age (covariate of no interest) and regional gray matter volume in our a priori ROI was carried out. Absolute threshold masking (0.1) was applied. The significance threshold was set to p < 0.05 on voxel-level, corrected for multiple testing within a ROI (FWE correction using random field theory; Worsley, 2001). Regarding the structural images, we conducted F-tests for the hypothesized associations between amygdala, vlPFC and dlPFC volume and individual differences in emotion regulation strategies, because the direction of these associations was difficult to hypothesize based on previous findings. For replicating previously results concerning cognitive reappraisal and vmPFC and dACC volume and expressive suppression and insula, vmPFC and dmPFC volume as well as for the hypothesized positive correlation between neuroticism and amygdala gray matter volume, we used T-tests.

RESULTS

Questionnaires

For the cognitive reappraisal scale of the EQS the investigated sample reported a mean of 4.60 (s.d. = 0.83; Min = 2.67; Max = 6.83), for expressive suppression a mean of 3.41 (s.d. = 1.24; Min = 1.25; Max = 5.75) and for neuroticism (BFI-K) a mean of 3.25 (s.d. = 0.76; Min = 1.50; Max = 4.75). There was no significant correlation of cognitive reappraisal with expressive suppression (r = 0.003; P = 0.979) and neuroticism (r = −0.174; P = 0.090), whereas expressive suppression showed a negative association with neuroticism (r = −0.271; P = 0.008).

Brain structural correlates

A marginally significant correlation of individual differences in the habitual usage of cognitive reappraisal and left amygdala (MNI coordinate: −21, −13, −12, Fmax = 9.13, Pmax = 0.083; Figure 1A) as well as a significant correlation with right amygdala gray matter volume (MNI coordinate: 27, −9, −12, Fmax = 16.96, Pmax = 0.004; Figure 1B) was found. Plotting of the data (Figure 1) shows a positive association of cognitive reappraisal with amygdala gray matter volume (for all following results from F-tests, the direction of the association was inferred from inspection of the plotted data). The peak voxel in the left amygdala is located in the left amygdala with a probability of 56% and in the left hippocampus with a probability of 12% and for the right amygdala with 61% in the right amygdala according to the 'Harvard-Oxford cortical and subcortical structural atlases'.

Habitual use of expressive suppression was positively correlated to dACC gray matter volume (MNI coordinate: −12, 33, 28, Tmax = 3.48, Pmax = 0.021; Figure 2A). According to the 'Harvard-Oxford cortical and subcortical structural atlases', this peak coordinate is located in the anterior cingulate (6%) and paracingulate gyrus (31%). Additionally, a positive association of expressive suppression and dmPFC gray matter volume (MNI coordinate: 3, 39, 37, Tmax = 4.01, Pmax = 0.030; Figure 2B) was found. The probability for the localization of this peak voxel was 40% for the superior frontal gyrus and 42% for the paracingulate gyrus. Furthermore, a tendentially significant correlation of expressive suppression with vmPFC gray matter volume (MNI coordinate: 8, 36, −14, Tmax = 3.09, Pmax = 0.057; Figure 2C) was detected. This peak voxel was located in the frontal medial cortex with a probability of 33% and in the paracingulate gyrus with a probability of 12%. Additionally, a marginally significant positive correlation of the neuroticism score with left amygdala gray matter volume (MNI coordinate: −26, −12, −14, Tmax = 2.86, Pmax = 0.061; Figure 3) was found. According to the 'Harvard-Oxford cortical and subcortical structural atlases', this peak voxel pertains to the amygdala with a probability of 52% and to the hippocampus with a probability of 17%. An additional post hoc conjunction analysis of cognitive reappraisal and neuroticism was conducted in order to test for joint effects of these two variables on left amygdala gray matter volume, as both variables show a significant association with left amygdala gray matter volume. Results indicate that there was no significant effect for the left amygdala (Fmax = 7.97, Pmax = 0.129). There were no other significant positive or negative correlations of any ROI with cognitive reappraisal, expressive suppression or neuroticism.

DISCUSSION

The aim of this study was to explore the association of individual differences in cognitive reappraisal and expressive suppression usage with gray matter volume in the amygdala, insula, dACC, medial and...
lateral PFC in a large sample of young individuals. All of these brain structures have been pointed out as important composites of the neural circuit underlying emotion regulation processes in previous structural and/or functional imaging studies (Ochsner and Gross, 2005; Goldin et al., 2008; Welborn et al., 2009; Giuliani et al., 2011a,b; Kühn et al., 2011). However, no study to date has directly examined amygdala gray matter volume and its association with dispositional cognitive reappraisal and expressive suppression.

Using voxel-based morphometry to study differences in gray matter volume of our a priori ROIs, the results of this study indeed show that the right and marginally significant left amygdala gray matter volumes are positively correlated to cognitive reappraisal usage assessed by the ‘cognitive reappraisal’ scale of the ERQ (Gross and John, 2003). This association was independent of participants’ sex, age, expressive suppression and neuroticism scores, indicating a significant relationship beyond these factors.

This result matches findings from previous fMRI studies, showing an involvement of the amygdala in emotion regulation by means of cognitive reappraisal. A reduction of amygdala activation has frequently been observed during down-regulation particularly of negative emotions (for an overview, see Ochsner and Gross, 2005; Diekhof et al., 2011), whilst up-regulation is accompanied by enhanced amygdala activation (see, e.g. Eippert et al., 2007; Hermann et al., 2009). There is also one further fMRI study showing reduced amygdala activation in response to negative emotional faces in individuals more frequently using cognitive reappraisal to regulate their emotions (Drabant et al., 2009). The results of our study also underpin the amygdala as an important region for habitual cognitive reappraisal usage. People more frequently using cognitive reappraisal strategies to regulate their own emotions appear to have enhanced bilateral amygdala gray matter volume, which might be a prerequisite or consequence of the enhanced reappraisal use. This is in line with a large number of studies showing reduced amygdala gray matter volumes in various psychiatric disorders, which are characterized by deficits in emotional processing and regulation, as for instance schizophrenia (for an overview, see Shepherd et al., 2012), borderline personality disorder (for overviews, see O’Neill and Frodl, 2012; Ruocco et al., 2012), affective disorders (for overviews, see Savitz and Drevets, 2009; Sacher et al., 2012) and anxiety disorders (Irle et al., 2010; for an overview, see Atmaca, 2011). Complementing these results in patients, trait anxiety in healthy participants has been shown to be negatively associated with amygdala gray matter volume (Spampinato et al., 2009). According to these results, increased amygdala volume could reflect enhanced emotional control based on a more efficient usage of reappraisal.

Moreover, neuroticism, as a measure of general negative emotionality, has been found to be (marginally significant) positively correlated to left amygdala gray matter volume in this study, independent of sex, age, cognitive reappraisal and expressive suppression. This result seems to contradict the abovementioned positive association of amygdala volume with cognitive reappraisal usage and reduced amygdala volumes in trait anxiety and various psychiatric disorders. However, there are other studies, showing a positive association of amygdala gray matter volume with anxiety-related characteristics in healthy individuals (Barrós-Loscertales et al., 2006; Tottenham et al., 2010; van der Plas et al., 2010; Gerritsen et al., 2012). In addition, a reduction of perceived stress through mindfulness-based stress reduction has been shown to be associated with a reduction of basolateral amygdala gray matter volume in stressed but healthy subjects (Hölzel et al., 2010). However, further studies showed a negative association of neuroticism...
with left amygdala gray matter concentration (Omura et al., 2005) or even no significant association (Cremers et al., 2011; Andari et al., 2012). The differing findings from those investigations and our own study might probably result from methodological differences (e.g. analysis of gray matter concentration vs volume) or sample characteristics (e.g. age).

Altogether, these differing results from our study indicate that the amygdala possibly subserves different functions involved in the processing and regulation of emotions. Emotion regulation models typically distinguish between bottom-up emotional processing and cognitive top-down emotion regulation mechanisms (Ochsner and Gross, 2005). Transferring this approach to the current results, higher neuroticism—the more pronounced tendency to experience negative emotional states—might probably be reflected in stronger bottom-up emotional processing. The neuroticism-related enhanced amygdala gray matter volume might therefore be associated with a more pronounced or more frequent processing of negative emotions, which might primarily arise in a bottom-up manner. This is in accordance with previous studies showing larger stress-related amygdala volumes in humans (Höfzel et al., 2010) and animals (Vyas et al., 2002, 2003; Mitra et al., 2005). Cognitive reappraisal, however, is defined as a top-down regulatory process, which has frequently been shown to reduce amygdala activation (for an overview, see Ochsner and Gross, 2005). On the brain structural level, this might be related to the observed larger gray matter volumes in amygdala sub-regions, which are probably affected by these inhibitory processes. Suggesting distinct functions of different amygdala sub-regions is not a completely new topic. Different functional roles of the amygdala have already been assumed for the acquisition and extinction of conditioned fear (for an overview, see Sehlmeyer et al., 2009) supporting its role in both the development and the modification of stimulus–reinforcer associations. Previous work in rats even identified two distinct classes of neurons in the basal amygdala, which are differentially involved in fear vs extinction learning (Herry et al., 2008). This opposite functioning of the amygdala is in line with the reverse correlations of amygdala gray matter volume with the neuroticism and the cognitive reappraisal scores found in this study. An additional possible explanation for the association of amygdala gray matter volume with on the one hand cognitive reappraisal and on the other hand neuroticism might be that these variables have joint effects which manifest themselves in enhanced amygdala gray matter volume. This might be because individuals with higher neuroticism scores have or develop better reappraisal skills over the course of their lives. However, the results of this study show that there is neither a significant correlation of the cognitive reappraisal and the neuroticism score nor a joint effect on amygdala gray matter volume, as revealed by a post hoc conjunction analysis. Nevertheless, this might be due to the specific sample (healthy young subjects) and needs to be further investigated in future studies.

In summary, it can be stated that the exact meaning of enhanced amygdala gray matter volume in association with cognitive reappraisal and neuroticism as well as the underlying molecular and cellular mechanisms remain speculative.
Previous studies investigating the association of gray matter volume with cognitive reappraisal focused on other brain regions (Welborn et al., 2009; OFC and Giuliani et al., 2011b: dACC), applied different analysis strategies (Welborn et al., 2009; Giuliani et al., 2011b), or did not find a significant correlation with amygdala volume in an exploratory whole brain analysis (Kühn et al., 2011). The results of this study extend previous findings and stress the critical role of the amygdala in mediating individual differences in cognitive reappraisal usage. However, it needs to be pointed out that the results regarding left amygdala volume and cognitive reappraisal as well as neuroticism are only marginally significant and need to be replicated in future studies.

Besides cognitive reappraisal, expressive suppression is a second major strategy to regulate the (expression of) emotions in relevant situations (Gross and John, 2003). Replicating previous findings (Kühn et al., 2011), the present results show that the habitual use of expressive suppression is positively correlated to dmPFC (including paracingulate gyrus) gray matter volume, independent of participants’ sex, age, cognitive reappraisal and neuroticism scores. This brain region has also been found to be functionally involved in the expressive suppression of emotions (Goldin et al., 2008) and has been identified as a key structure in the regulation of emotions (Ochsner and Gross, 2005). Furthermore, the dmPFC is involved in the inhibition of actions (Kühn et al., 2009), a crucial component of expressive suppression. Frequent inhibition of emotional (facial) expression might lead to an increase of gray matter volume in this region. Yet, increased dmPFC volume may also be a prerequisite that might lead to an increased usage of this strategy.

A growing body of studies provides support for the idea of use-dependent brain plasticity. According to this notion, the volume of a brain region is affected by its usage (Kleim, 1998, 2002). Previous studies have shown altered brain volumes following learning and practice (Maguire et al., 2000; Gaser and Schlaug, 2003; Draganski et al., 2004). The underlying mechanisms could be based on the Hebbian learning theory (Hebb, 1949). Hence, the formation and destruction of synaptic connections might lead to adaptive changes in brain structures (Trachtenberg et al., 2002).

Based on these assumptions, the habitual use of specific emotion regulation strategies as for instance cognitive reappraisal and expressive suppression might be associated with frequent activation of certain brain structures and might as a consequence lead to changes in the volume of these brain regions. However, it is important to keep in mind that the association of brain structure and functional activity is not clear. Differences in gray matter volume do not necessarily explain differences in brain activity (Pezawas et al., 2005). In accordance with the considerations provided by Giuliani and colleagues (2011b), the frequent use of an emotion regulation strategy might lead to greater efficiency on the one hand as well as a volume-increase in relevant brain regions on the other hand. Therefore, individuals with smaller volumes in these brain areas might be less efficient in regulating their emotions. Furthermore, these individuals might exhibit stronger activation of these brain regions during emotion regulation in order to be as successful as individuals with larger volumes. However, it is furthermore important to keep in mind the possibility of pre-existing individual volume differences that might lead to different strategy usage as a consequence.

However, we did not replicate previous results regarding greater dACC volume in frequent reappraisers (Giuliani et al., 2011b) and larger anterior insula volume in individuals frequently using expressive suppression (Giuliani et al., 2011a). Furthermore, we could not replicate the findings by Welborn and colleagues (2009) who demonstrated a positive association of vmPFC volume with reappraisal and a negative correlation with expressive suppression. This is probably due to different methodological factors as for instance the applied analysis strategy (e.g. VBM vs ROI approach; Giuliani et al., 2005) or sample characteristics (women vs both sexes). In contrast, we found a positive correlation of expressive suppression with dACC (including paracingulate gyrus) and (tendentially significant) with vmPFC (including paracingulate gyrus) gray matter volume. In addition, expressive suppression scores appeared to be negatively correlated to neuroticism in our sample. Integrating these results and previous findings, it is tempting to speculate that the direction of dACC/vmPFC correlation depends on the adaptivity and functionality of expressive suppression usage and its positive or negative consequences in the respective sample. In general, these brain regions have been shown to be important in the regulation of negative affect via several processes including extinction and cognitive reappraisal (Diekhof et al., 2011). Dysfunctional, i.e. non-adaptive, usage of the vmPFC or dACC has been detected to be associated with various disorders which also display aberrant emotion regulation like bipolar disorder (Blumberg et al., 1999), mood as well as anxiety disorders (Hermann et al., 2007, 2009; Milad et al., 2009; Myers-Schulz and Koenigs, 2011) and impulsive personality disorder (Siever et al., 1999). According to this line of interpretation and coming back to the abovementioned use-dependent brain plasticity hypothesis, increased dACC/vmPFC volume associated with expressive suppression usage could be explained on the basis of an enhanced and even more efficient use of this strategy in an adaptive and functional way. But again, this kind of interpretation does not exclude the possibility of pre-existing volume differences. In order to get a broader understanding of the underlying neural mechanisms and the functional relationships of emotion regulation strategies as well as to test the different lines of interpreting the distinct results, further research is needed.

In addition, we did not find an association of cognitive reappraisal or expressive suppression usage with gray matter volume in the vlPFC.
and dlPFC. These regions have frequently been found to be activated during regulation of emotions (for an overview, see Ochsner and Gross, 2005; Diekhof et al., 2011). However, one previous structural imaging study using a whole brain exploratory approach (Kühn et al., 2011) also did not show an association of vIPFC and dlPFC gray matter volume with cognitive reappraisal and expressive suppression usage. In addition, the abovementioned previous fMRI studies mainly did not report a modulation of activation in vIPFC and dlPFC regions by dispositional cognitive reappraisal and expressive suppression. Future studies are needed that link functional and structural data as well as trait and state emotion regulation usage to get a better understanding of their interplay.

LIMITATIONS AND FUTURE DIRECTIONS

Several limitations regarding this study have to be considered. First, the study sample consisted mostly of young students; thus, it remains unclear whether the demonstrated associations are transferable to other samples. Future research should investigate if the results also apply to other subjects differing in age and cultural or socioeconomic background. It is known that the ROI-based technique can disregard important but to date still unknown areas. Third, based on the chosen cross-sectional design, no causal interpretations of the found relationships are possible. Future research should focus on longitudinal or even interventional investigations of emotion regulation strategies as well as personality and anxiety traits relating to volume differences and volume changes over time. Furthermore, we did not assess trait anxiety and its association with amygdala volume as well as other gray matter volumes. As importantly pointed out by one reviewer, future studies should include questionnaires that allow for a differentiation of anxiety and depression, rather than only measuring a global construct like neuroticism. It would be very interesting if the increased amygdala volume as observed in association with neuroticism in our study is more closely linked to anxiety or depression. In addition, future work should also investigate the relationship of gray matter volumes and emotion regulation strategies in clinical samples. Another extension of the study-design could be to revert to non-self-report measures of emotion regulation strategies in clinical samples. Furthermore, future research should attempt to combine functional and structural methods to gain insight into their relationship and to examine how gray matter volume changes influence the activity of these regions.

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