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The Importance of the Default Mode Network in Creativity—A Structural MRI Study

ABSTRACT

Anecdotal reports as well as behavioral studies have suggested that creative performance benefits from unconscious processes. So far, however, little is known about how creative ideas arise from the brain. In the current study, we aimed to investigate the neural correlates of creativity by means of structural MRI research. Given that unconscious and less controlled processes are important in creative thinking, structural brain research may find a positive correlation between well-established creativity measures and cortical thickness in brain structures of the default mode network (i.e., the counterpart of the cognitive control network). Individuals performed the Alternative Uses task by which an individual's cognitive flexibility and the average uniqueness and average creativity of a participant's ideas were assessed. We computed optimized voxel-based-morphometry (VBM) to explore the correlation between inter-individual differences in creativity and inter-individual differences in gray matter volume. For all creativity measures, a positive correlation was found between creative performance and gray matter volume of the default mode network. These findings support the idea that the default mode network is important in creativity, and provide neurostructural support for the idea that unconscious forms of information processing are important in creativity. Theoretical and practical implications are discussed.

Keywords: creativity, problem solving, unconscious processes, structural MRI, default mode network.

Creativity, which means "to create, to make", is a highly valued human trait. Great accomplishment in the arts and sciences depend on creativity (Fiest & Gorman, 1998; Kaufman, 2002), and creativity is associated with the development of novel social institutions (Bass, 1990; Mumford, 2002) and economic growth (Amabile, 1997; Simonton, 1999). On the individual level, creativity helps people to cope with changes (Runco, 2004) and to solve everyday problems (Cropley, 1990).

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In the scientific literature, it is now widely accepted that a creative idea comprises two elements: novelty (i.e., creative work has to be original) and quality (i.e., creative work has to be good or useful) (e.g., Amabile, 1983; Sawyer, 2012; Sternberg & Lubart, 1999). During the last decades, creativity researchers have mainly investigated what circumstances facilitate creativity, and knowledge has been obtained about personality (e.g., Helson, 1996; Simonton, 1998), product (Sternberg, Kaufman & Pretz, 2002), and environmental (e.g., Csikszentmihalyi, 1996) factors related to creativity. However, besides knowing what psychological circumstances are associated with creative performance, it is also important to investigate how creative ideas arise in the brain. In the current study, we aimed to investigate the neural correlates of creativity by means of structural MRI research.

Previous electroencephalography (EEG) research has associated creative thinking with lower prefrontal cortical arousal and lower cognitive control (Fink & Neubauer, 2006; Mölle et al., 1996; Razumnikova, 2007). Moreover, lower levels of noradrenaline and dopamine, which are directly linked to cognitive control (e.g., Chamberlain, Müller, Robbins & Sahakian, 2006), have been shown to be beneficial for creativity (Heilman, Nadeau & Beversdorf, 2003). The idea that less controlled and unconscious forms of information processing are important in creativity has also been stressed by various creative minds (for anecdotal evidence, see Claxton, 1997; Ghiselin, 1952; Koestler, 1964). The most prominent anecdotal example is probably Poincare's description of how he discovered the Fuchsian functions: "The incidents of the travel made me forget my mathematical work. Having reached Coutances, we entered an omnibus […]. At the moment when I put my foot on the step, the idea came to me, without anything in my former thoughts seeming to have paved the way for it" (Poincaré quoted in Hadamard, 1945, p. 13).

When cognitive control is low, activation is observed in the default mode network (Andreasen, 1995; Binder et al., 1999; Christoff, Gordon, Smallwood, Smith & Schooler, 2009; Mason et al., 2007; Raichle et al., 2001), a set of interconnected brain regions including the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), and lateral and medial temporal lobes (Spreng, Stevens, Chamberlain, Gilmore & Schacter, 2010). The default mode network is involved in complex, evaluative, and unconscious forms of information processing and contrasts with the cognitive control network, a set of brain regions including the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), inferior frontal junction, anterior insular cortex (AIC), dorsal pre-motor cortex (dPMC), and posterior parietal cortex (Cole & Schneider, 2007). Indeed, when one network is activated, the other is deactivated (Fox et al., 2005). Activity in the default mode network has been associated with mind-wandering, that is, a shift of attention away from a primary task (Mason et al., 2007), and with unconscious processing (Vincent et al., 2007; Yang, Weng, Zang, Xu & Xu, 2010). Both mind-wandering (Baird et al., in press) and unconscious processing have been related to increased creative performance (Gallate, Wong, Ellwood, Roring & Snyder, 2012; Zhong, Dijksterhuis & Galinsky, 2008). Moreover, functional Magnetic Resonance Imaging (MRI) research has shown that during a cognitive task, creative individuals are less prone to suppress activity in the precuneus, a key node of the default mode network (Takeuchi et al., 2011).

Research has shown a correlation between certain capabilities, trait characteristics or habitual behavior and volume in involved brain areas. For example, a correlation has been demonstrated between gray matter volume and political orientation (Kanai, Feilden, Firth & Rees, 2011). Moreover, activity-dependent selective changes in gray matter volume have been shown in taxi drivers (Maguire et al., 2000), musicians (Gaser & Schlaug, 2003) and in participants who were trained in juggling (Draganski et al., 2004). In the current study, we aimed to investigate the structural correlates of creativity. Given that unconscious and "less controlled" processes are important in creative thinking, structural brain research may find a positive correlation between well-established creativity measures and cortical thickness in brain structures of the default mode network (i.e., the counterpart of the cognitive control network).

Previous structural MRI research has provided a first indication that the default mode network may be involved in creativity. Jung et al. (2010) have linked cortical thickness measures to psychometric measures of creativity and found a negative correlation between creative performance and activity in the lingual gyrus and a positive correlation between creative performance and gray matter volume in the right PCC, a brain area that is part of the default mode network. However, besides the PCC, the default mode network also includes other brain areas, for example, the MPFC and the precuneus (prec) (Raichle et al., 2001; Shulman et al., 1997). In the current study, we aimed to provide further support for the involvement of the default mode network in creative thinking by using an alternative method for gray matter comparison and a different approach to measure creative performance.

Whereas Jung et al. (2010) used cortical thickness measurements for gray matter comparison, we used a viable methodological alternative: voxel-based morphometry (VBM). Cortical thickness only provides information about cortical regions, whereas VBM allows drawing inferences about cortical as well as subcortical regions. In addition, in the previous study, structural magnetic resonance imaging was obtained at a 1.5 Tesla scanner, whereas in the current study, a 3 Tesla scanner was used to yield more anatomic detail. The most important difference, however, is how creative performance was measured. In the study done by Jung et al. (2010), three divergent thinking tasks were administered. In the first two tasks, the "Free Condition" and the "Four Line Condition" of the Design Fluency Test, participants were instructed to draw as many unique designs as they could. In task three, participants had to produce as many novel and creative uses as they could think of for common objects. The output of each creativity measure was assessed by independent college-aged raters who were instructed to bin the output of each subject into one of five creativity categories ranked on their own perception of creativity, and to rank order each subject's output for creativity relative to others within each category. Rankings for each subject were averaged across the three measures to form a composite creativity index.

Whereas in the study from Jung et al. (2010), creativity was assessed by rank ordering a subject's output relative to others based on the independent judges own perception of creativity, in the current study, participants' output relative to others was measured by a less subjective measure. We assessed the "average uniqueness" of a participant's ideas by calculating the frequency of how often a specific idea was mentioned among all participants. Besides measuring a participant's creative performance relative to other participants' performance, we were interested in the distinct creative performance of each individual. Independent raters coded each idea for how creative it was. As recommended by Friedman and Förster (2001, 2005), the scores given by each rater were averaged across ideas, for each participant, revealing an "average creativity" score. The "average uniqueness" and "average creativity" score used in the current study, as well as the "ranking measure" used by Jung et al. (2010), represent a holistic evaluation of the creative products, rather than a specific creative process. Therefore, also a basic cognitive mechanism responsible for creativity—cognitive flexibility (i.e., how flexibly one can switch between categories)—was measured. Cognitive flexibility is the ability to break old cognitive patterns, overcome functional fixedness, and thus make novel and creative associations between concepts (Guilford, 1967). Researchers conceptualize cognitive flexibility as the cognitive core of creativity, and a necessary (albeit not sufficient) component of "real-life" creativity (Baghetto & Kaufman, 2007; Hennessey & Amabile, 2010). A positive correlation was expected between an individual's cognitive flexibility, as well as the average uniqueness and average creativity of a participant's ideas, and gray matter volume of the default mode network.

METHOD

PARTICIPANTS

Twenty-one healthy volunteers participated on the basis of written informed consent. The study was approved by the Ethics Committee of the University Hospital Ghent and was conducted in accordance with the Declaration of Helsinki. The participants (16 female, 5 male) had a mean age of 21.33 (SD = 1.85, ranging from 19 to 25) and were all right-handed as assessed by a handedness questionnaire (Oldfield, 1971). No subject had a history of neurological, major medical, or psychiatric disorder. Subjects were, moreover, screened for conditions that prohibit undergoing an MRI scan (e.g., mental implants, claustrophobia).

PROCEDURE

Subjects were placed in the scanner and were instructed to keep their eyes closed during the structural MRI data acquisition. After structural data acquisition, participants' creativity was assessed outside the scanner. They completed a version of the Alternative Uses Task (AUT; Guilford, 1967). The AUT is a widely used and well-validated measure of creativity, and is comparable to the Uses of Objects Test (UOT) that was assessed in the Jung et al. (2010) study. Whereas the UOT asks subjects to list uses for five common objects and examples are given for each object, such as "Brick—build houses, doorstop," in the current study, participants were given two minutes to generate and list as many ideas as they could, answering the question "What can you do with a brick?" To prevent the activation of a certain mind-set, no examples were provided. Moreover, participants were asked to write as many uses as they can for one, instead of several objects. This allows measuring individuals' cognitive flexibility (i.e., how flexibly one can switch between categories) instead of a task-induced switch between categories. Next to participant's cognitive flexibility, the average uniqueness and average creativity of a participant's ideas were measured.

IMAGE ACQUISITION

Images were collected with a 3T Magnetom Trio MRI scanner system (Siemens Medical Systems, Erlangen, Germany) using an 8-channel radiofrequency head coil. High-resolution anatomical images were acquired using a T1-weighted 3D MPRAGE sequence (TR = 1550 ms, TE = 2.39 ms, TI = 900 ms, acquisition matrix = 256 $\times$ 256 $\times$ 176, sagittal FOV = 220 mm, flip angle = 9°, voxel size = 0.9 $\times$ 0.9 $\times$ 0.9 mm^3).

DATA ANALYSIS

Anatomical data were processed by means of the VBM8 toolbox (http://dbm.neuro.uni-jena.de/vbm) by Gaser and the SPM8 software package (http://www.fil.ion.ucl.ac.uk/spm). The VBM8 toolbox makes use of the segmentation algorithm of SPM8 and its implementation of a Hidden Markov Random Field approach that has been demonstrated to be superior to previous SPM versions (Ashburner & Friston, 2005). We employed the optimized VBM protocol proposed by Good et al. (2001). We first resampled the anatomical images to a voxel size of 1 $\times$ 1 $\times$ 1 mm^3. Then the images were segmented into the different tissue types and the gray matter segmentations were normalized to a gray matter template. Then modulation was applied in order to preserve the volume of a particular tissue within a voxel. Modulation was achieved by multiplying voxel values in the segmented images by the Jacobean determinants derived from the spatial normalization step. In effect, the analysis of modulated data tests for regional differences in the absolute amount (volume) of gray matter. Finally, images were smoothed with a FWHM kernel of 8 mm. Then statistical analysis was carried out by means of whole brain correlation of gray matter volume with the individuals' creativity scores derived from the brick task (cognitive flexibility, average uniqueness, average creativity). Sex, age, and whole brain volume were entered as covariates of no interest. The resulting maps were thresholded with $p < 0.001$ and the statistical extent threshold was corrected for multiple comparisons combined with a non-stationary smoothness correction (Hayasaka & Nichols, 2004).

BEHAVIORAL CREATIVITY MEASURES

Cognitive flexibility

Using Guilford's (1967) original coding scheme, two raters measured cognitive flexibility by counting the total number of different categories that a participant's ideas belonged to (e.g., "build a house, build a bridge, build a tower," would lead to a score of one as they are all related to "building something", whereas "build a house, break a window, use it as a pen holder" would lead to a score of three). The raters showed a high inter-rater reliability (Cronbach's *alpha* = .93); therefore, we used averaged scores throughout the analyses.

Average uniqueness

For each idea, a uniqueness score was calculated by dividing the frequency of how often a specific idea was mentioned among all participants by the total number of named ideas. For each participant, the uniqueness scores were added and divided by the number of ideas a participant generated. Participants could, thus, receive a score between 0 (highly unique) and 1 (not at all unique). Different from the other two variables, a *lower* average uniqueness score would represent higher creativity. To make sure that higher average uniqueness scores represent higher creativity, participants' average uniqueness score was subtracted from 1.

Average creativity

To receive an average creativity score, two raters had to score the creativity of each idea on a five-point scale (1 = "not at all creative", to 5 = "extremely creative"). For each idea, a mean of the two scores was calculated (inter-rater reliability $\alpha = .93$), and for each participant, these mean scores were added. To make sure that a participant's creativity score was independent of the number of ideas generated (i.e., verbal fluency), this sum score was divided by the number of ideas that the participant listed.

RESULTS

BEHAVIOURAL DATA

Among all participants, the cognitive flexibility score was 4.64 (*SD* = 1.58, range 2.00–8.00), the average uniqueness score was 0.90 (*SD* = 0.04, range 0.82–0.98), and the average creativity score was 2.43 (*SD* = 0.64, range 1.30–3.75).

STRUCTURAL MRI DATA

In the structural anatomy scans, we found significant overlapping correlation between the inter-individual differences in creativity scores and inter-individual differences in the gray matter volume of the default mode network. Cognitive flexibility scores were positively correlated with gray matter volume in the ventromedial medial prefrontal cortex (vmPFC), right temporo-parietal junction (rTPJ), right superior frontal gyrus (rSFG), right inferior temporal gyrus (rITG) and left insula (Table 1; Figure 1). For the average uniqueness score, a positive correlation with gray matter volume was observed in vmPFC, precuneus, left frontal pole, left thalamus and left insula (Table 2; Figure 1). Average creativity scores were positively correlated with gray matter volume in vmPFC, rTPJ, left precuneus and left insula (Table 3; Figure 1). No cluster of gray matter volume survived for the negative correlation with number of categories, average uniqueness or average creativity. Clusters of negative correlation would have implied that subjects scoring low on the creativity measure show less gray matter in the identified regions. Overlap was observed

TABLE 1. Areas Showing Significant Positive Correlation between Gray Matter Volume and *Cognitive Flexibility* (p-values are Thresholded with $P < 0.001$ and the Statistical Extent Threshold was Corrected for Multiple Comparisons Combined with a Nonstationary Smoothness Correction)

Area	BA	Peak coordinates (MNI)	Z-score	Extent
Ventromedial prefrontal cortex (vmPFC)	10/11	5, 15, −12	5.17	1697
Right temporo-parietal junction (rTPJ)	37	44, −66, 10	4.75	297
Right superior frontal gyrus (rSFG)	10/46	18, 63, 22	4.41	176
Right inferior temporal gyrus (rITG)	27	60, −61, −9	3.96	182
Left insula	13	−42, 11, −8	3.51	162

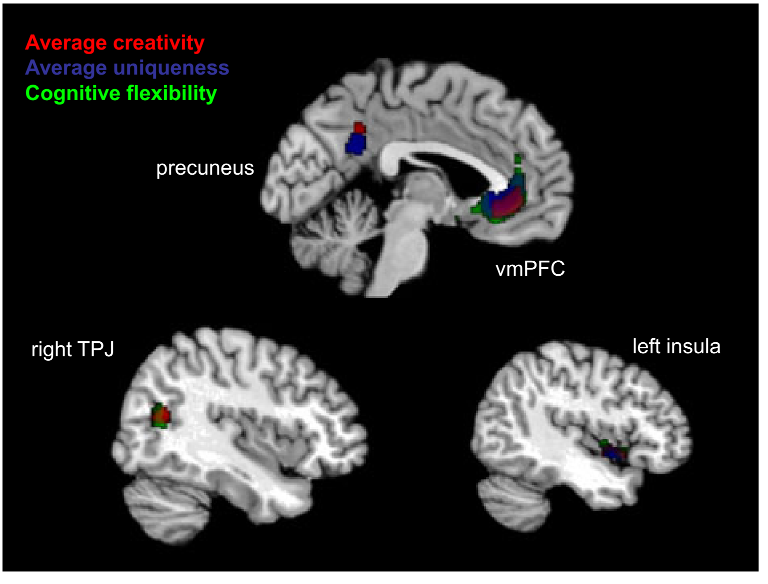

FIGURE 1. Brain regions showing an association between creativity scores and gray matter volume; p-values are thresholded with $p < 0.001$ and the statistical extent threshold was corrected for multiple comparisons combined with a non-stationary smoothness correction. vmPFC = ventromedial Prefrontal Cortex; TPJ = Temporo-Parietal Junction.

between the structural correlates of all three creativity measures (cognitive flexibility, average uniqueness, and average creativity) computed separately in the vmPFC, a core region of the default mode network (Figure 1).

TABLE 2. Areas Showing Significant Positive Correlation Between Gray Matter Volume and *Average Uniqueness* (p-values are Thresholded with $P < 0.001$ and the Statistical Extent Threshold was Corrected for Multiple Comparisons Combined with a Non-stationary Smoothness Correction)

Area	BA	Peak coordinates (MNI)	Z-score	Extent
Ventromedial prefrontal cortex (vmPFC)	10/11	3, 29, −12	5.25	1692
Precuneus	23	0, −53, 26	4.04	216
Left frontal pole	10	−20, 60, 6	3.96	374
Left thalamus		−26, −34, 12	3.90	580
Left insula	13	−45, 11, −9	3.80	160

TABLE 3. Areas Showing Significant Positive Correlation Between Gray Matter Volume and *Average Creativity* (p-values are Thresholded with $p < .001$ and the Statistical Extent Threshold was Corrected for Multiple Comparisons Combined with a Non-stationary Smoothness Correction)

Area	BA	Peak coordinates (MNI)	Z-score	Extent
Ventromedial prefrontal cortex (vmPFC)	10/11	−3, 36, −9	4.26	739
Right temporo-parietal junction (TPJ)	37	42, −63, 17	4.76	268
Left precuneus	23	−17, −56, 39	3.99	198
Left insula	13	−45, 12, −9	3.84	140

BA = Brodmann area; Extent = Cluster extent.

DISCUSSION

In the current study, we aimed to investigate the structural correlates of creativity by means of structural MRI research. Participants performed the Alternative Uses task, a well-established creativity measure by which a participant's cognitive flexibility and the average uniqueness and average creativity of a participant's ideas were assessed. For all psychometric measures of creativity, a positive correlation was observed between inter-individual differences in creative performance and inter-individual differences in volume of the default mode network (i.e., the counterpart of the cognitive control network). Based on these findings, it can be assumed that greater volume in the default mode network provides more neural resources for generating creative ideas. These findings support the idea that less controlled processes are important in creativity.

There is a popular belief that creativity is located in the right hemisphere of the brain, and various books and seminars are provided on how to activate your creative right-brain potential. Research on lateralization, however, generally does not provide evidence for the popular belief that creativity is located in the right hemisphere of the brain (e.g., Sawyer, 2011). Also in the current research, positive correlations were found between creative performance and gray matter volume in several regions of the brain in both hemispheres. For cognitive flexibility, these brain regions were mainly located in the right hemisphere, for the uniqueness scoring mostly in the left hemisphere, and for the overall creativity rating in both hemispheres. Overlap was observed between the structural correlates of all three creativity measures in the vmPFC, a core region of the default mode network that has no hemispheric lateralization. The current findings, thus, support the idea that creativity involves both hemispheres.

An interesting question is whether the increased default mode network volume in creative individuals is an *a priori* condition and/or a consequence of frequent creative thinking. We suspect a bi-directional relationship, that is, individual differences in gray matter volume in the default mode network may exist and, in addition, frequent creative thinking may lead to more gray matter volume in the default mode network. The idea that training induces gray matter changes is in accordance with previous studies, which have demonstrated that practice induces gray matter changes as, for example, in taxi drivers (Maguire et al., 2000), musicians (Gaser & Schlaug, 2003), and in participants who were trained in juggling (Draganski et al., 2004).

Previous studies have shown that creativity training can enhance everyday creative performance (e.g., Scott, Leritz & Mumford, 2004), and the current findings may have important implications for creativity trainings. Many tactics have been identified to facilitate creative thinking skills, such as, set-shifting, questioning assumptions, or using analogies (i.e., finding correspondence of inner relationship or function between different concepts). It is important to notice that tactics have to be explicitly communicated in order to enhance creative performance. Therefore, next to providing individuals with knowledge about how to stimulate creative thinking, tactics also make individuals aware of the fact that they are expected "to be creative". This can put pressure on individuals and may, thereby, result in a decrease in creative performance. By demonstrating that less deliberative and less controlled processes are essential in creativity, the current findings may encourage researchers to also focus on unconscious and implicit forms of information processing to enhance creative thinking.

Divergent thinking tests are the most commonly used estimates of the potential for creative thought (Runco, 2007). However, several cognitive skills are needed in order to produce something that is both "novel and useful", and likely these skills manifest differentially within various creative domains (e.g., visual art vs. scientific discovery). Although the current research suggests that the default mode network is important in creative idea generation, future research should investigate whether these findings also account for different domains of creativity.

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