

Cortical correlates of creative thinking assessed by the figural Torrance Test of Creative Thinking

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Torrance Test of Creative Thinking is the most widely used form of creativity test. Although creativity assessed using the figural form of Torrance Test of Creative Thinking has been considered non-unidimensional, the structural correlates for each separable dimension have yet to be explored. The present study investigated the underlying cortical structure of separable dimensions for creativity using the figural Torrance Test of Creative Thinking. To this end, we recruited healthy young adults and conducted a regression analysis of the figural Torrance Test of Creative Thinking scores of gray matter volume after factorizing the five subscales using exploratory factor analysis. As a result, two factors of the figural Torrance Test of Creative Thinking were identified: (1) 'FO' factor consisting of fluency and originality and (2) 'RAS' factor consisting resistance to premature closure, abstractness of titles, and sophistication/elaboration. Subsequently, the FO factor showed a positive association with cerebral volumes in the parieto-temporal regions of the left angular gyrus and the right inferior parietal lobule, inferior and middle temporal, and parahippocampal gyri, which overlapped

the default network. The RAS factor showed a positive correlation with the fronto-temporal regions including the bilateral temporal area, the left inferior parietal, and the right dorsolateral prefrontal regions representing the semantic control network. Our findings revealed the morphological substrates for the figural Torrance Test of Creative Thinking depending on two creative dimensions. The implications of the results are discussed. *NeuroReport* 30: 1289–1293 Copyright © 2019 The Author(s). Published by Wolters Kluwer Health, Inc.

NeuroReport 2019, 30:1289–1293

Keywords: creativity Torrance Tests of Creative Thinking, gray matter volume, magnetic resonance imaging, voxel-based morphometry

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Received 18 September 2019 Accepted 22 September 2019

Introduction

Creativity is characterized by an ability to generate novel and useful ideas or products and is regarded as an advantage in daily life. As creative performance benefits the society or individual life, the origins of creativity in the brain represent an area of topical interest in neuroscience. As for neuroscientific measures, a structural correlation between brain and behavior has been suggested as a promising approach for the elucidation of cerebral function in creativity [1,2]. Voxel-based morphometry is one of the methods utilized in such an investigation. Several studies explored the morphometric basis of creativity, albeit, with inconsistent findings (see Ref. 1 for a review).

Torrance Test of Creative Thinking (TTCT) [3], the most well-known and commonly used test of creative thinking. Especially, its figural form is utilized to unveil the neural substrates associated with creative thinking. Creativity index is the most utilized parameter in the figural TTCT reported in previous brain studies; it is comprised of five subscales of scores: fluency (i.e. the number of relevant

ideas), originality (i.e. the number of statistically infrequent ideas), resistance to premature closure (i.e. the degree of psychological openness), abstractness of titles (i.e. the degree beyond concrete labeling of the picture drawn), and elaboration/sophistication (i.e. the number of added ideas). However, the use of the creativity index appears to be inadequate to untangle the complexity of creativity due to the non-unidimensional nature of the subscales [4]. It will be required to categorize subscales into a homogenous group according to their characteristics to yield more consistent findings on relationships between cortical structure and creativity.

Here, we investigated the cortical morphometric correlates of creativity by separating its subdimensions as assessed by the figural TTCT. Towards this end, we performed an exploratory factor analysis to factorize five subscales of the figural TTCT, followed by regression analysis of each factor on the cortical volume.

Methods

Participants

Twenty-five right-handed participants (11 males and 14 females, mean age 19.9 ± 1.8 years) of Teachers' college at Dongguk University, Seoul, Korea, were recruited in this study. None of the participants had a history of

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neurological illness, learning disability, head trauma with loss of consciousness, current or past use of psychostimulant medications, or pregnancy. The present study was approved by the Institutional Review Board for public authority specified by the Korean ministry of health and welfare. We received a signed, written informed consent from all the volunteers after a full description of the study.

Figural Torrance Test of Creative Thinking

The figural TTCT comprises three activities, namely, picture construction, picture completion, and addition of lines in the picture. Each activity asked participants to complete a picture based on the different items provided: jellybean shape, incomplete line drawing, and a set of lines, respectively. In addition, participants were asked to assign a title for the picture completed. Ten minutes were provided to the participants to complete each activity. Each participant's performance of the figural TTCT was quantified using a creativity index based on cumulative creative strength and the average standard scores of the five subscales: fluency, originality, abstractness of titles, elaboration, and resistance to premature closure. The resulting creativity index of all the participants was 107.1 on average with a SD of 23.7.

Factor analysis on subscales of the figural Torrance Test of Creative Thinking

The five subscales of the figural TTCT were categorized via exploratory factor analysis using IBM SPSS Statistics (IBM Corp., Armonk, New York, USA). First, each subscale score was centered and scaled by the number of subjects–1, followed by calculation of Kaiser–Meyer–Olkin statistic and Bartlett's test of sphericity to determine whether or not the TTCT scores were appropriate for factor analysis. In addition, the communality was computed to identify any subscale, which does not match the factor solution. If there was a subscale with communality less than 0.4, it was excluded from the analysis. The factors were extracted using principal component analysis, and the resulting factors were rotated via the Varimax method to improve interpretability.

MRI image acquisition

For each participant, a high-resolution T1-weighted anatomical scan was obtained using a 3 Tesla Magnetom Skyra MRI scanner (Siemens, Germany) at Dongguk University Ilsan Hospital, Goyang-si, Korea. The 3-dimensional magnetization-prepared rapid gradient-echo sequence was used with the following parameters: time of repetition = 2300 ms; time of echo = 2.29 ms; field of view = 240 mm²; flip angle = 80°; and spatial resolution = 0.9 × 0.9 × 0.9 mm. Participants were instructed not to move and to avoid moving their heads during the scan.

Anatomical image preprocessing and statistical analysis

Gray matter volume (GMV) images were measured by voxel-based morphometry using the SPM12 software (Wellcome Department of Imaging Neuroscience Group, London, UK) executed in Matlab (MathWorks, Inc., Natick, Massachusetts, USA). First, the individual T1 image was segmented into different intracranial tissues such as gray matter, white matter, cerebrospinal fluid, skull in each participant's native space. The segmented images were spatially normalized into Montreal Neurological Institute space according to the SPM 12 DARTEL procedure [5] with default settings using a sample-derived template. The normalized gray matter images were modulated with the resulting Jacobian determinant maps, allowing quantitative assessment of the regional GMV. Finally, the GMV images measuring 1.5 × 1.5 × 1.5 mm were smoothed with an 8-mm full-width-at-half-maximum isotropic Gaussian kernel. As a nuisance variable for the following regression analysis, the total intracranial volume (TIV) was calculated by summing up the volumes of the gray matter, white matter, and Cerebrospinal fluid (CSF) in each subject's native space using the SPM12 software.

The smoothed images were subjected to multiple regression analysis to determine the regional GMV correlated with each factor of the TTCT. The three variables of age, gender, and TIV were fitted in the linear regression model as covariates of no interest to adjust for the confounding effects in cortical volumes as reported previously [6]. The level of significance was set at $P < 0.05$ after family-wise error correction for multiple comparisons and also set at uncorrected $P < 0.001$ for a liberal threshold. Based on the kernel size for smoothing and voxel sizes, we set a threshold of five voxels for each cluster size. The significant regions were labeled using the Yale BioImage Suite Package (<https://bioimagesuiteweb.github.io/webapp/mni2tal.html>).

Results

Two creative factors of the figural Torrance Test of Creative Thinking

The exploratory factor analysis found two factors from the five subscales of the figural TTCT. The first factor contained three subscales, namely abstractness of titles, resistance to premature closure, and sophistication/elaboration ('RAS'), whereas the second factor included the other subscales including fluency and originality ('FO'). The rotated loading factor showed that RAS factor accounted for 48.51% of the total variance in the data set and the FO factor constituted 32.86% (Table 1).

Structural basis of two-factor creative thinking

The distinct brain regions associated with creative performance depended on two factors of creativity at uncorrected $P < 0.001$, albeit it did not show when corrected P

< 0.05. The FO factor was positively correlated with the parieto-temporal regions including the left angular gyrus, the right inferior parietal lobule [Brodmann area (BA) 40; x, y, z = 38, -39, 51], inferior and middle temporal gyrus, and parahippocampal gyrus (BA 36; x, y, z = 17, -32, -15). The FO factor was negatively correlated with the fronto-parietal regions of the left precentral gyrus (BA 6; x, y, z = -53, 2, 27) and the right medial prefrontal cortex (BA 9; x, y, z = 8, 48, 29) and the left primary sensory cortex, supramarginal and lingual gyrus (Table 2 and Fig. 1a). However, the RAS factor showed a positive correlation with the fronto-temporal regions in the left superior frontal gyrus (BA 6; x, y, z = -21, -14, 57) and the right dorsolateral prefrontal cortex (BA 8; x, y, z = 33, 17, 36 and BA 9; x, y, z = 48, 26, 35). The left inferior parietal lobule, middle and inferior temporal gyri were also involved. The negative association between cortical volume and RAS factor involved only the right inferior parietal lobule (BA 40; x, y, z = 54, -45, 54) (Table 3 and Fig. 1b).

Discussion

We investigated the brain structural network engaged in two domains of creative thinking based on the assessment via figural TTCT. The two factors involved in creative thinking based on the figural TTCT were in line

with previous studies [4,7–9]. The previous studies were conducted in teenagers using confirmatory factor analysis. The present study corroborated previous findings involving college students using exploratory factor analysis. We found that resistance to premature closure loaded on one factor as shown in previous studies [7,9], although some studies reported that resistance to premature closure loaded on more than one factor [4,8]. This inconsistency requires further studies, whereas the present study suggests evidence supporting non-unidimensional creative thinking. The two factors in the subscales of the figural TTCT have been interpreted based on Kirton's theory. Kirton [10] suggested that anyone can be located on a continuum between innovative and adaptive styles of cognition. In our study, the FO factor was related to an innovative style, with a desire to perform things differently and quickly, whereas the RAS factor was associated with an adaptive style, with a preference for enhanced outcomes.

The brain structure associated with the FO factor, an innovative style, was found in the largest cluster in the left angular gyrus (BA 39) [11]. The left angular gyrus is reported to contribute to semantic process [12] and dedicate to spontaneous thinking during creative thinking as a component of default network [13]. Not only the left angular gyrus, other regions showing positive correlations with FO factor including inferior parietal lobule, inferior temporal gyrus, and parahippocampal gyrus are overlapped with the default network [14], which is consistent with a previous study showing a relationship between the default network and creativity [15]. The default network is known as a region supporting spontaneous and deliberate self-generated thought processes [16], occurring when an internal representation is required to reconstruct or imagine a situation. It is necessary during the figural TTCT test where test-takers need to imagine and generate answers. Also, the right side of inferior temporal gyrus is associated with visuospatial processing [17], suggesting that it involved in

Table 1 Two dimensions spanning the figural Torrance Test of Creative Thinking scoring revealed by exploratory factor analysis

	Factor 1 ('RAS')	Factor 2 ('FO')
Fluency	0.138	0.902
Originality	0.301	0.830
Abstractness of titles	0.881	0.170
Elaboration	0.878	0.233
Resistance to premature closure	0.877	0.237
Eigenvalue	2.426	1.643
% of variance	48.510	32.858
Cumulative % of variance	48.510	81.368

Kaiser–Meyer–Olkin = 0.778; Bartlett's chi-squared = 52.398 ($P < 0.001$); each subscale's communality score ≥ 0.4 .

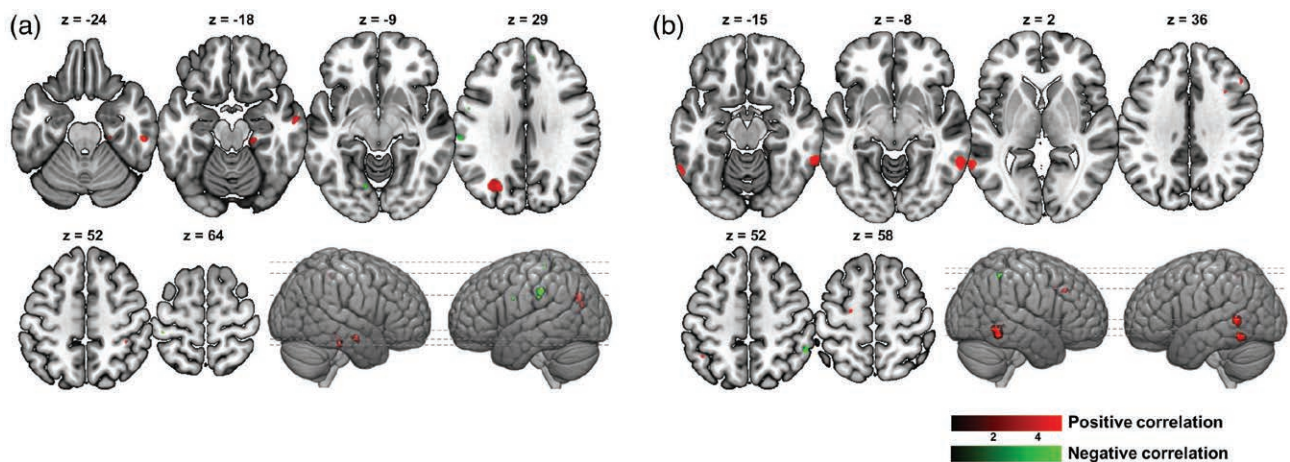
FO: total scores of fluency and originality; RAS: total scores of abstractness of the title, resistance to premature closure, and sophistication/elaboration.

Table 2 The regions showing associations between the FO factor of the figural Torrance Test of Creative Thinking and gray matter volume

L/R	Lobe	Region	BA	MNI coordinate			T-value of peak	Z-value of peak	Cluster size
				x	y	z			
Positive correlation									
L	Parietal	Angular gyrus	39	-26	-74	29	4.98	3.97	426
R	Parietal	Inferior parietal lobule	40	38	-39	51	3.89	3.32	6
	Temporal	Inferior temporal gyrus	20	54	-27	-23	5.47	4.23	63
		Middle temporal gyrus	21	60	-11	-17	4.64	3.78	66
		Parahippocampal gyrus	36	17	-32	-15	3.95	3.35	90
Negative correlation									
L	Frontal	Precentral gyrus	6	-53	2	27	3.85	3.29	11
	Occipital	Lingual gyrus	18	-12	-72	-9	3.85	3.29	13
	Parietal	Supramarginal gyrus	40	-63	-30	36	4.37	3.62	153
		Primary sensory cortex	1	-42	-33	63	4.12	3.47	9
R	Frontal	Medial prefrontal cortex	9	8	48	29	3.65	3.16	5

FO: total scores of fluency and originality; $P < 0.001$, uncorrected for multiple comparisons, cluster size ≥ 5 . BA, Brodmann area; L, left; R, right.

Fig. 1



The association between gray matter volume and the factor of creativity. (a) Brain slices and volumes depicting correlations between gray matter volume and the total scores of fluency and originality ('FO'). (b) Brain slices and volumes depicting correlations between gray matter volume and the total scores of abstractness of the title, and resistance to premature closure, and sophistication/elaboration scales ('RAS'). The figures illustrate positive (colored in red) and negative (colored in green) correlations and color bars shows t -value. $P < 0.001$, uncorrected for multiple comparisons, cluster size ≥ 5 .

Table 3 The regions showing associations between RAS factor of the figural Torrance Test of Creative Thinking and gray matter volume

L/R	Lobe	Region	BA	MNI coordinate			T-value of peak	Z-value of peak	Cluster size
				x	y	z			
Positive correlation									
L	Frontal	Superior frontal gyrus	6	-21	-14	57	3.86	3.30	10
	Parietal	Inferior parietal lobule	39/40	-44	-53	53	3.70	3.19	8
	Temporal	Inferior temporal gyrus	37	-63	-56	-15	4.44	3.66	76
		Middle temporal gyrus	21	-68	-53	5	5.41	4.20	118
R	Frontal	Dorsolateral prefrontal cortex	9	48	26	35	4.12	3.47	24
			8	33	17	36	3.77	3.24	6
	Temporal	Middle temporal gyrus	37	62	-47	-14	4.53	3.72	322
Negative correlation									
R	Parietal	Inferior parietal lobule	40	54	-45	54	4.36	3.61	34

RAS: total scores of abstractness of the title, resistance to premature closure, and sophistication/elaboration; $P < 0.001$, uncorrected for multiple comparisons, cluster size ≥ 5 .

BA, Brodmann area; L, left; R, right.

the creation of figures. On the other hand, the negative correlation with the FO factor was found in the largest cluster in the left supramarginal gyrus known for contribution to phonological process and motor attention [18], also in small clusters of sensorimotor regions including precentral, primary sensory, and lingual gyri. These findings suggested that sensory input is attenuated to prevent internal train of thought from external interference during a creativity task.

As for the RAS, an adaptive style of creativity, showed correlations with the largest cluster in the right middle temporal region (BA 37). This right posterior middle temporal region is associated with creativity trait, especially openness to experience [11], which corresponds to the resistance to premature closure, keeping open-minded long enough to prevent premature closure. The second biggest cluster was in the left posterior middle

temporal regions (BA 21), which is reported to contribute to semantic processing [12] and to semantic control [19]. In addition, the RAS has positive correlation with the right dorsolateral prefrontal regions (BA 8 and 9). The ventral part of the middle frontal gyrus (BA 8) is known to be involved in regulation of attention [20], reflecting visual processing essential for conducting the figural TTCT. The mid-dorsolateral part of prefrontal region (BA 9) is known for monitoring of information in working memory [20]. With the left inferior parietal region (BA 39/40), these prefrontal regions and the posterior middle temporal region are overlapped with the semantic control network [21]. Semantic control is task-driven retrieval and selection of memories and integrates these representations with external stimulus and goals [21], which is correspond to the RAS factor requiring mental retention and integration of ideas or words to develop a story along with an appropriate title.

Taken together, we found consistency with brain functional studies in that the default network and semantic control network were revealed as previous studies [13,15], suggesting a neural backbone for the functional and structural basis of creativity in common. In addition, each brain networks are spanning in different styles of creative thinking as assessed by the figural TTCT. For future study, a multimodal analysis of the interaction between functional and structural brain underpinning for creativity will be of help for further investigation on the neural framework of creativity.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (NRF-2013S1A3A2042899 and NRF-2017R1A6A3A11036413).

J.H. wrote the manuscript, analyzed the data, and discussed the results; K.K.K. wrote the manuscript, discussed the results, designed the study and collected the data; S.H.P. discussed the results, designed the study and collected the data.

Conflicts of interest

There are no conflicts of interest.

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