Differences in brain morphometry associated with creative performance in high- and average-creative achievers.

Evangelia G Chrysikou  
Drexel University, USA

Christopher Wertz  
University of New Mexico, USA

David B Yaden  
University of Pennsylvania, USA

Scott Barry Kaufman  
Columbia University, USA

Donna Bacon  
University of New Mexico, USA

Follow this and additional works at: https://jdc.jefferson.edu/medfp

Let us know how access to this document benefits you

Recommended Citation

Chrysikou, Evangelia G; Wertz, Christopher; Yaden, David B; Kaufman, Scott Barry; Bacon, Donna; Wintering, Nancy; Jung, Rex E; and Newberg, MD, Andrew B., "Differences in brain morphometry associated with creative performance in high- and average-creative achievers." (2020).  
Department of Medicine Faculty Papers. Paper 268.  
https://jdc.jefferson.edu/medfp/268

This Article is brought to you for free and open access by the Jefferson Digital Commons. The Jefferson Digital Commons is a service of Thomas Jefferson University's Center for Teaching and Learning (CTL). The Commons is a showcase for Jefferson books and journals, peer-reviewed scholarly publications, unique historical collections from the University archives, and teaching tools. The Jefferson Digital Commons allows researchers and interested readers anywhere in the world to learn about and keep up to date with Jefferson scholarship. This article has been accepted for inclusion in Department of Medicine Faculty Papers by an authorized administrator of the Jefferson Digital Commons. For more information, please contact: JeffersonDigitalCommons@jefferson.edu.
Differences in brain morphometry associated with creative performance in high- and average-creative achievers

Evangelia G. Chrysikou,*, Christopher Wertzb, David B. Yaden, Scott Barry Kaufmand, Donna Baconb, Nancy A. Winteringe, Rex E. Jungb, Andrew B. Newberge

a Drexel University, USA
b University of New Mexico, USA
c University of Pennsylvania, USA
d Columbia University, USA
e Department of Integrative Medicine and Nutritional Sciences, Thomas Jefferson University, USA

ARTICLE INFO

Keywords:
Creativity
Divergent thinking
Magnetic resonance imaging
Brain structure
Brain morphometry
Individual differences
Creative achievement

ABSTRACT

Nearly everyone has the ability for creative thought. Yet, certain individuals create works that propel their fields, challenge paradigms, and advance the world. What are the neurobiological factors that might underlie such prominent creative achievement? In this study, we focus on morphometric differences in brain structure between high creative achievers from diverse fields of expertise and a ‘smart’ comparison group of age-, intelligence-, and education-matched average creative achievers. Participants underwent a high-resolution structural brain imaging scan and completed a series of intelligence, creative thinking, personality, and creative achievement measures. We examined whether high and average creative achievers could be distinguished based on the relationship between morphometric brain measures (cortical area and thickness) and behavioral measures. Although participants’ performance on the behavioral measures did not differ between the two groups aside from creative achievement, the relationship between posterior parietal cortex morphometry and creativity, intelligence, and personality measures depended on group membership. These results suggest that extraordinary creativity may be associated with measurable structural brain differences, especially within parietal cortex.

1. Introduction

What are the cognitive and neural processes underlying extraordinary creative achievement? Within the burgeoning field of the neuroscience of creativity, much recent research has examined the brain mechanisms enabling creative thought (Beatty et al., 2015a, 2018; Kounios and Beeman, 2014; Maysel et al., 2015; Pinho et al., 2016). This growing body of work supports the view that creativity—the ability to produce ideas deemed both novel and useful (Simonton, 2012)—involves ordinary cognitive processes such as memory (Abraham, 2014; Abraham and Bubic, 2015; Abraham et al., 2012; Chrysikou and Thompson-Schill, 2011; Kenett, 2014), attention (Benedek et al., 2014; Zabelina, 2018) and executive function (Chrysikou, 2019; Chrysikou et al., 2014; Gonev-Yaacovi et al., 2013; Maysel et al., 2014; Maysel and Shamay-Tsoory, 2015; Zabelina and Gani, 2018). On the other hand, it remains unclear whether these same ordinary cognitive and neural mechanisms are engaged in similar ways in support of extraordinary creativity. Only a handful of investigations to date have focused on the possible neural differences between exceptional (sometimes referred to as ‘big C’) creativity and everyday (sometimes referred to as ‘little c’) creativity (Kaufman and Beghetto, 2009) and their potential importance for our understanding of creative thought.

One of the first studies exploring this question focused on possible neural differences in brain activation among exceptionally creative participants (4 artists and 3 scientists) while they performed a free word association task during functional magnetic resonance imaging (fMRI; the Iowa Study of Creative Genius; Andreasen and Ramchandran, 2012). Notwithstanding the small sample sizes, the results suggested no significant differences between the two exceptionally creative groups, with the task eliciting predominantly left hemisphere activity. An influential study of professional jazz musicians during improvisation showed that relative to well-practiced music sequences, expert jazz musicians showed a transient hypofrontal neural profile during improvisation, compared to novice participants (Limb and Braun, 2008), and these results have been
The most comprehensive study of extraordinary creativity to date pertains to the Big-C project at the University of California Los Angeles. The goal of this ambitious project is to examine the neural substrates of creative thought in exceptionally creative individuals within the visual arts and the sciences, using well-established creativity measures. Studies conducted within the Big-C project hold strong potential to advance our understanding of exceptional creativity because they have employed larger sample sizes than previous work and, importantly, a ‘smart’ comparison group of well-accomplished, but not notably creative, individuals—matched to the exceptionally creative subjects in age, gender, intelligence, and parental education background (Japardi et al., 2018). The Big-C project has elicited a recent set of interesting functional neuroimaging findings, according to which, despite lack of differences in divergent thinking task performance, significant neural differences among the groups were reported, with Big-C creators showing less activation in frontal and occipital regions relative to the smart comparison group. This study was the first to provide evidence in favor of the proposition that exceptional creativity might be associated with functionally less engagement of task-positive brain networks (Japardi et al., 2018), a finding that has recently been extended in creative experts from the domains of art and entertainment (Meyer et al., 2019), and which tracks the ‘neural efficiency hypothesis’ from intelligence research (Neubauer and Fink, 2009).

A question that remains following these seminal intriguing studies pertains to whether differences in brain morphology might additionally be linked to extraordinary creativity. Previous studies have implicated brain morphometry in the expression of important cognitive constructs including intelligence (Basten et al., 2015), creativity (see Jung et al., 2013 for review), and personality (Owens et al., 2019). Combinations of intelligence, creativity, and personality variables have been hypothesized to underlie exceptional ability, including extremely high creative achievement (aka. the study of genius; Jung and Haier, 2013). As high creative achievers are seen to reside at the extremes of the ranges of intelligence, creativity, and certain personality traits (e.g., openness), it is plausible that such individuals’ brain morphometry would also lie at structural extremes, at least in certain brain regions within which brain-behavior relationships have been demonstrated in normal samples. Thus, we sought to focus our study on structural correlates of high creative achievement. The study of the potential association between brain structure measures and creative thought has been much more limited relative to studies employing functional neuroimaging measures, although these structural measures are highly reliable and elicit more pronounced differences in brain morphometry (i.e., cortical volume and thickness) in high creative achievers, and 2) decreased prefrontal gray matter within prefrontal regions would be associated with CAQ scores in high creative achievers compared to average-creative achievers, and 2) decreased prefrontal gray matter within prefrontal regions would be associated with CAQ scores in high creative achievers compared to average-creative achievers.

2. Material & methods

2.1. Participants

We recruited 19 highly creative achievers (Mage = 49.89, SD = 14.22; 10 males) who had extremely high creative achievement in one of several creative domains (psychology/neuroscience, education, writing, comedy, law, design, music, business, and politics). Across several different creative domains, a prominent (or ‘magnet’) individual was identified who was then asked to nominate individuals with a reputation for creativity in their field. Other criteria complemented this process, such as an examination of publication records and awards, in order to verify the nominations. Both the magnet and nominated individuals were then invited to participate in this study. A group of 13 individuals matched to the eminent group in age and IQ, but who did not have any specific achievement in any particular creative domain were recruited to serve as a ‘smart’ comparison group (Mage = 47.92, SD = 10.32; 8 males). Verification of high or average creative achievement was based on the CAQ (see Materials), with eminent creators determined as having a higher CAQ score than the mean reported score on the scale (Carson et al., 2005). The CAQ does not fully capture all of the creative domains represented by the eminent group in this study, so the CAQ difference between the groups is slightly suppressed—thus providing a conservative test of differences between the groups. All participants were from the continental United States, met all inclusion criteria for magnetic resonance imaging, and were not diagnosed with any neurological or psychiatric condition that might have affected brain structure or function. Participants provided informed consent and were paid for their participation. The study was approved by the Thomas Jefferson University Institutional Review Board.

2.2. Materials

Participants were administered a battery of screening and behavioral measures including: the Structured Interview of Cognition and Personality and the MINI International Neuropsychiatric Interview to verify study eligibility and neuropsychiatric health; the CAQ (Carson et al., 2005) as a measure of creative achievement; the NEO Five Factor Personality Questionnaire for assessment of Openness to Experience; the Raven’s progressive Matrices as a measure of fluid intelligence; and the
vocabulary scale from the Wechsler Adult Intelligence Scales (4th ed.) along with the mental rotations test (Peters et al., 1995) as a measure of general intelligence (Johnson and Bouchard, 2005). These measures were administered following standard neuropsychological procedures in individually administered sessions. The two items comprising the divergent thinking measure were adapted from the Torrance Tests of Creative Thinking: participants were given 5 min to produce (a) as many possible outcomes the could think of if people could fly and (b) as many creative uses as they could think of for a common object (brick). A composite measure of ideational fluency was created following summarization of the number of ideas generated for each of the two divergent thinking task components. We used fluency as our standalone indicator of divergent thinking because fluency is often so highly correlated with other dimensions of divergent thinking, such as originality and flexibility (e.g., Hocevar, 1979); indeed, recent research has defined the divergent aspect of creative potential in terms of fluency (e.g., Lubart et al., 2011; cf. Forthmann et al., 2020; Runco, 2010; Runco and Acar, 2012).

2.3. Study procedures

Following informed consent procedures, all participants underwent a semi-structured interview which was conducted by a trained study coordinator using the screening measures specified above. These interviews lasted approximately 2 h. All participants then completed the behavioral and personality measures battery that lasted on average 1 h. Finally, participants underwent a high-resolution structural brain imaging scan that lasted approximately 10 min.

2.4. MRI data acquisition

Structural imaging was obtained at a 3 T Magnetom Biograph mMR scanner using a 12-channel head coil to obtain a T1 sagittal MPRAGE sequence (TE = 2.46 ms; TR = 1600 ms; voxel size = 1.0 × 1.0 × 1.0 mm³; FOV = 252 mm; slices = 176; acquisition time = 7:26s). For all scans, each T1 was reviewed for image quality. Cortical reconstruction and volumetric segmentation were performed with the FreeSurfer v6.0 image analysis suite. The methodology for FreeSurfer is described in full in several papers (Fischl et al., 2002, 2004a; Segonne et al., 2007). Briefly, this process includes automated Talairach transformation and segmentation of the subcortical white matter and deep gray matter volumetric structures, (Fischl et al., 2002, 2004a). Segmented data were then parceled into units based on gyral and sulcal structure, resulting in values for cortical thickness, surface area, and volume (Desikan et al., 2006 and Fischl et al., 2004). The results of the automatic segmentations were quality controlled, and any errors were manually corrected. Volume measures represented a combination of thickness (a one-dimensional measure) and area (a two dimensional measure) across 33 measures per hemisphere (i.e., 66 across the surface of the brain) as well as seven subcortical volumes per hemisphere (i.e., 14 across the brain) including bilateral caudate, putamen, globus pallidus, nucleus accumbens, thalamus, amygdala, and hippocampus (Fischl et al., 2002).

2.5. MRI data processing and analysis

We used multivariate generalized linear models (Nelder and Wedderburn, 1972; Alhusaini et al., 2013) to assess whether the high- and average-creative achievement groups differed on the relationship between cortical area and thickness measurements and participants’ total score on the CAQ, the Five-Factor Openness to Experience subscale, the Raven’s progressive matrices, the Vocabulary and Mental Rotation scores, and the composite Divergent Thinking measure. Each design matrix consisted of either the CAQ, the Five- Factor Openness to Experience subscale, the Raven’s progressive matrices total score, the Vocabulary and Mental Rotation scores, or the composite Divergent Thinking raw scores as the dependent variable, using group as a between subjects factor, assessing 33 ROIs left and right (66 total) hemisphere separately, corrected by Bonferroni correction for false positives at p < 0.05. Data were modeled with either negative binomial, gamma, poisson, or normal distributions (cf. Alhusaini et al., 2013). We used SPSS version 24 for Mac for all behavioral statistical analyses, which are reported at a p < 0.05 (2-tailed).

3. Results

3.1. Performance on behavioral measures

Descriptive statistics across all demographic and behavioral measures are presented in Table 1. Data from one participant in the high-creative achievement group were incomplete, and two participants in the average-creative achievement group were lost due to a computer error. Four participants in the high-creative achievement and one participant in the average-creative achievement group did not complete the personality measures. Six participants in the high-creative achievement group and two participants in the average-creative achievement group did not complete the mental rotation measures. There were no significant differences between the high- and average-creative achievement groups on age (t[50] = 0.43, p = 0.67, d = 0.002) or gender (χ²[1] = 0.62, p = 0.43). Data across all other measures violated normality assumptions; thus, non-parametric Mann-Whitney U tests were employed to examine the presence of statistically significant differences in the distributions of scores between the high- and average-creative achievement groups. Exact significance was used to account for the relatively small sample size per group. As predicted, high-creative achievers had higher scores on the CAQ than average-creative achievers (U = 59.00, p = 0.039, r = −0.40). High- and average-creative achievers did not differ in openness to experience (U = 63.00, p = 0.71, r = −0.07), mental rotation (U = 35.5, p = 0.19, r = −0.27), Raven’s progressive matrices (U = 50.0, r = 0.38, r = −0.20), divergent thinking total score (U = 68.0, p = 0.31, r = −0.20), and vocabulary scores (U = 34.5, p = 0.06, r = −0.40). Thus, in line with our predictions, the high- and average-creative achievement groups did not differ on the personality, intelligence, divergent thinking or other demographic measures, beyond their significant differences in their CAQ score that determined group membership.

Table 1

<table>
<thead>
<tr>
<th>Behavioral Measure (N)</th>
<th>Average-Creative Achievement Group Mean (SD)</th>
<th>High-Creative Achievement Group Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (N = 32)</td>
<td>47.92 (10.32)</td>
<td>49.89 (14.22)</td>
</tr>
<tr>
<td>Gender (N = 32)</td>
<td>38% male</td>
<td>53% male</td>
</tr>
<tr>
<td>CAQ (N = 32)</td>
<td>16.54 (18.58)</td>
<td>36.83 (31.5)</td>
</tr>
<tr>
<td>Openness to Experience (N = 24)</td>
<td>4.17 (0.71)</td>
<td>4.11 (0.52)</td>
</tr>
<tr>
<td>Divergent Total (N = 28)</td>
<td>17.20 (5.31)</td>
<td>20.22 (7.24)</td>
</tr>
<tr>
<td>Mental Rotation (N = 21)</td>
<td>6.00 (2.95)</td>
<td>10.83 (7.57)</td>
</tr>
<tr>
<td>Raven’s Matrices (N = 23)</td>
<td>7.30 (1.16)</td>
<td>7.77 (1.09)</td>
</tr>
<tr>
<td>Vocabulary (N = 23)</td>
<td>34.09 (1.76)</td>
<td>35.77 (2.71)</td>
</tr>
</tbody>
</table>
3.2. Morphometry results

We examined the relationships between the behavioral and morphometric measures separately for the high- and average-creative achievement groups. Significant main effects of group were observed (Wald-$\chi^2 = 5.61; p = 0.018$) for CAQ scores, with the high-creative achievement group having significantly greater surface area in the right postcentral gyrus (Wald-$\chi^2 = 4.54; p = 0.033$), and bilateral superior parietal area (Wald-$\chi^2 = 8.97; p = 0.003$). The high-creative achievement group had significantly greater surface area in the left (Wald-$\chi^2 = 7.44; p = 0.006$) and right (Wald-$\chi^2 = 5.75; p = 0.017$) superior parietal gyri than the average-creative achievement group (Fig. 1).

Significant main effects of group were observed (Wald-$\chi^2 = 7.51; p = 0.006$) with the high-creative achievement group having significantly greater thickness in the right caudal anterior cingulate gyrus (Wald-$\chi^2 = 8.51; p = 0.004$), and the banks of the superior temporal sulcus thickness (Wald-$\chi^2 = 4.03; p = 0.045$). The high-creative achievement group had significantly greater thickness in the left banks of the superior temporal sulcus (Wald-$\chi^2 = 7.19; p = 0.007$) in relation to mental rotation scores (Fig. 2). Additionally, a significant main effect of group (Wald-$\chi^2 = 4.62; p = 0.032$) was found, with the high-creative achievement group’s divergent thinking scores being related to less surface area in the left (Wald-$\chi^2 = 7.42; Wald-$\chi^2 = 0.006$) and right (Wald-$\chi^2 = 5.91; p = 0.015$) transverse temporal gyrus (Fig. 3). Lastly, significant main effect of group was observed (Wald-$\chi^2 = 4.15; p = 0.042$) with the high-creative achievement group’s Raven’s total score being related to less surface area (compared to the average-creative achievement group) in the left (Wald-$\chi^2 = 5.12; p = 0.24$) and right (Wald-$\chi^2 = 4.41; p = 0.36$) paracentral gyrus (Fig. 4). The openness to experience and vocabulary total generalized linear models were not significant, all $p$’s > 0.1.

4. Discussion

The ability for creative thought is broadly considered a hallmark of human cognition. Yet, a considerable number of innovative ideas that have changed the world are attributed to a small group of exceptionally creative individuals. Few cognitive neuroscience studies have examined the neurobiological processes that might be associated with extraordinarily high creative achievement and no work to date has explored morphometric variation with regards to exceptional creativity. To address this research gap, we examined morphometric differences in brain structure between high-creative achievers (as determined by their CAQ score) from diverse fields of expertise and a ‘smart’ comparison group of age-, intelligence-, and education-matched average-creative achievers. In line with past literature on particularly prominent creators in the arts and sciences (e.g., Andreasen and Ramchandran, 2012; Andiasen and Rush, 2012; Andreasen, 1997; Takahashi et al., 2009).
we did not find behavioral differences between the high- and average-creative achievement groups on any of the intelligence, personality, and divergent thinking measures. In contrast, despite our modest sample size, high- and average-creative achievers could be distinguished based on the relationship between morphometric brain measures (cortical area and thickness) and behavioral measures. Specifically, high-creative achievers had significantly greater cortical surface area in the bilateral superior parietal gyrus and in the right postcentral gyrus in relation to CAQ scores relative to average-creative achievers, whereas they had significantly smaller cortical surface area in the left and right transverse temporal gyrus in relation to divergent thinking total scores than the average-creative achievement group. With regards to mental rotation and reasoning performance, the high-creative achievers showed increased cortical thickness in the left bank of the superior temporal sulcus and in the right caudal anterior cingulate gyrus in relation to mental rotation scores, whereas they showed smaller cortical surface area in the paracentral gyrus bilaterally in relation to Raven’s progressive matrices scores.

These results suggest that extraordinary creativity might be manifested in measurable structural brain differences between high- and average-creative achievers, especially within posterior parietal and superior temporal cortex. Indeed, the relationship between neuroanatomical characteristics and extraordinary creative accomplishments appears to track—to an extent—similar relationships observed in the general population. Past studies examining morphometric differences in association to creative achievement in typical young student samples have shown that individuals with higher CAQ scores exhibited lower cortical thickness in the left lateral orbitofrontal gyrus and higher cortical thickness in the right angular gyrus (Jung et al., 2010). Increased scores on the CAQ have further been associated with increased cortical volume in the superior frontal gyrus and ventromedial prefrontal cortex and decreased volume in the anterior cingulate cortex (Chen et al., 2014), relationships that have been shown to vary by field of expertise (e.g., Shi et al., 2017). Here, we used the CAQ to determine the creative achievement status of our participants, and subsequently examined morphometric differences in association to behavioral performance in a series of intelligence, creativity, and personality measures. Our results showed increased cortical thickness in posterior parietal cortex with increased creative achievement, as measured by CAQ scores. Further, our analysis revealed that when brain morphometry is directly related to task performance (relative to self-reports of creative achievement as in past studies) smaller cortical surface area in superior temporal cortex bilaterally was linked to higher divergent thinking scores in the high-creative achievement group. Our findings are partially aligned with past studies with different samples that have generally shown higher cortical thickness in posterior parietal cortex and lower cortical thickness in medial frontal areas in association to self-report creativity measures (e.g., Jung et al., 2016; Wertz et al., in press), although the lower cortical surface area effect in the present study was in transverse temporal (not frontal) cortex. We interpret the increased cortical thickness in the posterior...
parietal cortex areas we observed in relation to higher scores on the CAQ to reflect the consistent and continuous engagement of these posterior networks (typically considered key regions within the DMN) in the service of extraordinary creative achievement (cf., Beaty et al., 2017; Jung et al., 2013). We note that some of the variability in these results may be attributed to differences between behavioral assessments of divergent thinking that are dynamic measures of performance, as opposed to static checklists of factual accomplishments like the CAQ. These results might have further been impacted by the relatively modest sample size and the difference in total number of participants between the two groups, which is attributed to the difficulties of conducting a complex neuroimaging experiment in a special population. We further note that our participants in the present study were significantly older relative to the samples tested in past work that have mainly included healthy young adults (e.g., Wertz et al., in press). Age has been shown to be a factor that influences brain morphometry and may well have interacted with high-creative achievement in the present study (e.g., Menari et al., 2013). Future studies could explore further this possibility by examining highly creative achievers who are younger and resemble the characteristics of samples used in past work.

We speculate that the increased cortical surface area observed in relation to mental rotation scores for the high-relative to the average-creative achievement group might suggest the potential contribution of visuospatial thinking processes to exceptional creative performance, although much additional work is required to explore further this potential relationship. In contrast, our results showed that higher Raven's progressive matrices total scores were associated with less cortical surface area in the paracentral gyrus bilaterally in the high-creative achievement group. The negative correlations between brain morphometry and reasoning measures in the high-creative achievement group, notwithstanding the absence of behavioral effects, could reflect higher efficiency in the employment of neural resources with attendant lower plasticity in that group (e.g., Jung et al., 2010), although future research is invited to examine this relationship further with a broader set of measures and larger sample sizes. Again, research regarding potential overlap between neural networks supporting intellectual and creative efficiency is required to determine whether these are isomorphic and/or interact in meaningful ways within creative cohorts (Neubauer and Fink, 2009; Jung et al., 2010).

5. Conclusions

This study is the first to examine morphometric brain differences in exceptionally high creativity.

We investigated relationships between neuroanatomy and performance in a series of behavioral measures, including divergent thinking, personality, and intelligence assessments in a group of high-creative achievers from diverse fields of expertise, who were compared to an intelligence-matched control group. Despite the absence of behavioral differences between the high- and average-creative achievement groups, increased cortical thickness in posterior parietal cortex and decreased surface area in superior temporal cortex were positively associated with creative achievement and divergent thinking scores. These results point to the potential of structural neuroimaging studies to further elucidate...
Fig. 4. Statistical maps showing the high-creative achievement group with significantly less cortical surface area than the average-creative achievement group in the (A) left and (B) right paracentral gyrus in relation to Raven’s progressive matrices total scores; L = left, R = right.

the neural underpinnings of creative thought.

Acknowledgements

This research was supported by a grant to A.B.N. and D.B.Y from the John Templeton Foundation through the Imagination Institute.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuroimage.2020.116921.

References
