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Neural basis underlying the association between openness/intellect and scientific creativity achievement: the mediation role of the inferior frontal gyrus

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Abstract

Scientific creativity is vital for cultivating higher-order thinking skills and preparing students for a rapidly evolving world. Research consistently highlights Intellect as a key driver of scientific creativity. However, the neural mechanisms underlying scientific creativity and the pathways through which Intellect contributes to it remain underexplored. This study utilized voxel-based morphometry (VBM) in a large sample to investigate the neural correlates of scientific creativity and explored the neural mechanisms linking Intellect to scientific creativity. Behavioral analyses revealed positive associations between scientific creativity and openness to experience, particularly its facet of Intellect. VBM analyses showed that core regions of the executive control network (ECN) and the default mode network (DMN) were positively correlated with scientific creative achievement. In addition, mediation analysis demonstrated that gray matter volume (GMV) in the left inferior frontal gyrus (IFG) partially mediated the relationship between Intellect and scientific creative achievement. These findings suggest that the IFG, which plays a crucial role in information retrieval and selection, facilitates the link between Intellect and scientific creativity. This research provides valuable insights into the relationship between openness to experience and scientific creativity, offering potential avenues for developing training programs aimed at enhancing students' scientific creative abilities.

Keywords Scientific creative achievement, Openness to experience, Intellect, Gray matter volume, Inferior frontal gyrus (IFG)

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Introduction

Creativity, defined as the ability to generate novel and appropriate ideas or solutions, is crucial for success across science, technology, engineering, and mathematics (STEM) fields [33, 37, 49]. Furthermore, creativity has consistently facilitated our ability to consider diverse aspects of phenomena, generate innovative ideas, and develop problem-solving approaches in everyday life [34, 38, 71]. It also promotes overall psychological well-being and imbues life with meaning [19]. While the debate over whether creativity is domain-specific or general remains ongoing, much of the research on domain-specific creativity has focused on artistic creativity [7, 11, 21, 73, 74], leaving scientific creativity relatively underexplored [1, 35, 72]. Yet, scientific creativity is crucial for students to thrive in an increasingly technological and globalized world. It empowers them to adapt to rapid changes, think critically, and develop innovative solutions to emerging challenges [22]. Therefore, examining the factors that influence scientific creativity is of considerable educational and practical significance.

Intellect and scientific creativity

General intelligence and personality traits are key predictors of scientific creativity [61]. Among the Big Five personality traits, openness to experience consistently correlates with creative achievements and engagement in creative pursuits [9, 20, 32, 33, 43, 48, 58]. It is also recognized as a significant factor influencing scientific creativity [39, 41, 47, 58]. Openness to experience, a composite personality trait, consists of two distinct subtraits: Openness and Intellect [25, 28]. Intellect reflects cognitive engagement with abstract and semantic information through reasoning, while Openness emphasizes cognitive engagement with perception, fantasy, aesthetics, and emotions [26]. Using the Big Five Aspect Scales [28], Kaufman et al. (2016) demonstrated that Openness predicted artistic creativity, while Intellect predicted scientific creativity. They proposed that Openness facilitates implicit learning, aiding in the detection of correlational patterns in sensory experiences, whereas Intellect supports working memory, crucial for analyzing causal and logical patterns [25, 40]. However, these findings were largely based on Western samples, and their applicability in non-Western contexts, such as China, remains uncertain [22]. Furthermore, much of the existing research has relied on the Creative Achievement Questionnaire (CAQ), which emphasizes publicly recognized accomplishments. This limits its utility in "Little-C" or "Pro-C" contexts, where such public achievements may be less common. In reality, creativity exists on a spectrum, ranging from personal to public achievements [56]. While public recognition is often emphasized, studying personal achievements is equally crucial. Major accomplishments rarely arise spontaneously; instead, they tend to emerge from the gradual accumulation of smaller, incremental creative efforts over time [56, 65]. The Inventory of Creative Activities and Achievements (ICAA) provides a broader and more ecologically valid measure of creativity by capturing a wider range of creative achievements, including those at the lower end of the achievement continuum [30]. The ICAA's Creative activities (CAct) scale is conceptually similar to the Creative Behavior Inventory (CBI), assessing the frequency of specific creative activities over the past 10 years. The creative achievements (CAch) scale of the ICAA, while resembling Carson et al.'s (2005) CAQ, uses uniform achievement levels for each domain. It also captures more non-publicly recognized achievements and measures lower-tier creative accomplishments, such as Pro-C creativity. By covering a broader spectrum of creative achievements, the ICAA offers a more inclusive and ecologically valid assessment of scientific creativity [30]. In addition, the university students represent a crucial developmental period for the emergence of scientific problem-solving, domain-specific engagement, and early creative expression. Previous research suggested that individual differences in personality traits such as Intellect are already predictive of scientific creative potential and early achievements even in this age group [41]. Thus, in this study, we employed the ICAA to measure scientific creativity achievements among Chinese university students, aiming to gain a more nuanced understanding of the relationship between Intellect and scientific creativity.

The neural mechanisms between intellect and scientific creativity

Neuroimaging research on the neural mechanisms of scientific creativity is relatively scarce compared to the extensive literature on domain-general creativity [13, 44, 57, 72]. Beaty et al.(2023) used a scientific hypothesis generation task and found scientific creative thinking involves hubs of the default, salience, and semantic control networks. Other studies have investigated the structural brain correlates of scientific creative achievement, identifying regions associated with the executive control network (ECN) and the default mode network (DMN) [27, 29, 66]. For instance, Wertz and colleagues (2020) reported a negative correlation between the surface area of the right superior frontal gyrus and scientific creative achievement, as assessed by the Creative Achievement Questionnaire (CAQ). Similarly, Shi et al. (2017) found that gray matter volume (GMV) in the left middle frontal gyrus, a core region of the ECN, was positively correlated with scientific creativity measured by the CAQ. Previous research on the structural brain correlates of scientific creativity has primarily focused on Big-C creativity, typically assessed using the Creative Achievement

Questionnaire (CAQ). The ICAA provides a more comprehensive measure of creative output by including both personal and public achievements [30]. Using the ICAA to assess scientific creativity achievement would provide a more nuanced understanding of the neurocognitive mechanisms underlying scientific creative achievement.

According to DeYoung's Cybernetic Big Five Theory (CB5T), personality traits reflect the operation of evolved neural systems for goal-directed information processing [24]. Specifically, Intellect—the cognitive facet of openness to experience—is posited to be supported by individual differences in neural systems involved in executive functioning, abstract reasoning, and semantic integration, primarily subserved by the prefrontal cortex [23, 27, 29]. Within this broader prefrontal network, the inferior frontal gyrus (IFG) has consistently been associated with working memory, attentional control, and scientific reasoning—cognitive functions that are closely linked to both Intellect and scientific creativity [13, 45, 67]. To our knowledge, no study explore the neural mechanism between the intellect and scientific creativity. Based on the brief review of the existing literature, we hypothesize that the IFG may serve as a neurocognitive mediator linking trait Intellect to individual differences in scientific creative achievement.

The present study

In sum, the first aim of this study was to re-examine the relationship between scientific creativity and Intellect in a large sample of Chinese subjects. Given that both intelligence and divergent thinking are predictors of creative performance [16], we sought to determine whether the connection between Intellect and scientific creativity remains significant after controlling for their influence on creativity. Inspired by Kaufman et al. (2016), we employed a regression analysis with Intellect and Openness as simultaneous predictors to assess their independent contributions to creative achievements. To further validate these findings, we included all Big Five personality traits in our analyses, following Kaufman et al. (2016), to examine whether Openness and Intellect can independently predict creative output beyond the influence of other personality dimensions. Second, voxel-based morphometry (VBM) enables analysis of brain structure at the voxel level, facilitating the identification of regional GMV differences that may account for individual variations in cognitive functions, personality traits, and behaviors [6], so we utilized VBM analysis to investigate the GMV associated with scientific creative achievement. Finally, a mediation analysis was conducted to explore the neural mechanisms linking Intellect to scientific creative achievement. Previous research has demonstrated a strong association between scientific creativity and the frontal lobes, particularly the IFG [2, 3, 13]. The IFG is closely associated with key cognitive functions such as working memory, inhibitory control, and controlled semantic retrieval, while Intellect reflects abstract information processing and intellectual engagement. We hypothesized that the IFG may mediate the association between Intellect and scientific creative achievement.

Method

Participants

A total of 1,345 (896 females; mean age: 18.75 years old; SD: 1.07) healthy college students from Southwest University participated in this study. The participants in this dataset were recruited from the previous database [46, 70]. All participants were native Chinese speakers without any history of neurological or psychiatric disorders. All participants received some payment upon completion of the experiment. The study was conducted in accordance with the principles of the Helsinki Declaration. The research protocol was approved by the ethics committee of the review committee of the Brain Imaging Center of Southwest University.

Inventory of creative activities and achievements

The ICAA provides a comprehensive assessment of individual differences in real-life creativity. The CAct scale and the CAch scale are measured through self-reported evaluations across eight domains: literature, sports, arts and crafts, performing arts, music, visual arts, creative cooking, and science and engineering. The CAct scale captures the frequency of an individual's creative activities, such as writing short stories. The CAch scale evaluates the level of achievement an individual has attained in a creative domain, such as having works exhibited or holding patents. For scientific creative achievement, we followed Diedrich et al. (2018), summing the scores from the science and engineering domain of the CAch scale to obtain the scientific creative achievement score. Similarly, for the artistic creative achievement score, we aggregated the scores across five artistic domains: music, arts and crafts, literature, visual arts, and performing arts. The Cronbach's α was 0.81 for the CAct scale and 0.72 for the CAch scale in this study.

Big five aspect scales (BFAS)

DeYoung et al. (2007) developed the Big Five Aspect Scales (BFAS), an instrument that measures two aspects of each of the Big Five domains. Within the Openness/Intellect (O/I) framework, openness to experience is further subdivided into two interrelated dimensions: Openness and Intellect. The Openness dimension reflects a propensity for engaging with sensory and aesthetic experiences, encompassing imaginative and perceptual domains. In contrast, the Intellect dimension captures a tendency to engage with abstract and intellectual stimuli,

emphasizing analytical thinking and cognitive exploration. The correlation between Openness and Intellect typically ranges from 0.3 to 0.5. The Cronbach's α for openness to experience was 0.69.

General cognitive ability (g) and divergent thinking (DT)

Additionally, research has demonstrated strong associations between both General Cognitive Ability (g) and Divergent Thinking (DT) with openness and intellect [26]. To examine the extent to which openness and intellect independently predict individual scientific creative achievement, we also assessed two key cognitive abilities: General Cognitive Ability and Divergent Thinking. General cognitive ability was measured using the R-type Advanced Raven's Progressive Matrices and divergent thinking was measured using the Alternate Uses Task (AUT). In the AUT, participants were instructed to "list all the novel uses you can think of for bricks/cans" within three-minute. Four previously trained graduate students independently assessed the AUT responses. An analysis of rater agreement revealed robust inter-rater reliability, ranging from 0.728 to 0.984. Participants' answers were rated on three dimensions: Originality: Measured the novelty of each answer on a 5-point scale (1 = not at all creative to 5 = highly creative). Flexibility: Quantified the diversity of response categories generated by participants. Fluency: Assessed the quantity of ideas generated for each item. These scores were then standardized and averaged to obtain individual DT score.

Data acquisition

Functional and structural imaging data were acquired on a Siemens 3T Trio scanner (Siemens Medical Systems, Erlangen, Germany). High-resolution, three-dimensional T1-weighted structural images were captured using a magnetization-prepared rapid acquisition gradient-echo (MPRAGE) sequence with the following specifications: repetition time (TR) = 2530 ms, echo time (TE) = 2.98 ms, flip angle (FA) = 7°, field of view (FOV) = 224 × 256 mm^2, slice thickness = 1.0 mm, inversion time = 1100 ms, and voxel resolution = 0.5 × 0.5 × 1 mm^3.

Preprocessing of T1-weighted images was carried out using Statistical Parametric Mapping (SPM) software (Yan & Zang, 2010). The initial 10 functional images were discarded to stabilize the magnetic field and allow participants to acclimate to the scanning environment. Slice timing correction and realignment were then applied to the remaining volumes. Functional images were subsequently normalized to the Montreal Neurological Institute (MNI) template and resampled to a voxel size of 3 × 3 × 3 mm^3. To control for nuisance signals, including those from white matter, cerebrospinal fluid, and head motion parameters along with their derivatives, the Friston 24-parameter model was used. Additionally, a temporal band-pass filter (0.01–0.1 Hz) was implemented to reduce high-frequency physiological noise.

Voxel-based morphometry analysis

In whole-brain analysis, we employed multiple regression analysis to explore the relationship between GMV and scientific creative achievement. The GMV of each voxel in the whole brain was considered the independent variable, and scientific creative achievement was considered the dependent variable. The age, sex, DT, g, and total GMV were included as covariates in the regression model. In this analysis, the absolute threshold masking was set to 0.2 to exclude gray matter and white matter from edge effects [5]. This strategy mitigated the potential for false negatives arising from excessively stringent masking, as it could lead to the exclusion of voxels of potential interest from the statistical analysis. For all analyses, statistical significance was established at a threshold of $p < 0.05$, corrected using non-stationary cluster correction with a voxel-level significance set at $p < 0.001$ [35].

Mediation analysis

To investigate the neural mechanisms linking Intellect to scientific creative achievement, we utilized a mediation model. In this framework, the Intellect score assessed by the BFAS was treated as the predictor variable (X), scientific creative achievement measured by the ICAA as the outcome variable (Y), and the previously identified GMV associated with scientific creative achievement as the mediator variable (M). Sex, age, DT, g, and total GMV were included as covariates to control for potential confounding effects. The mediation model followed the structure outlined by Hayes and Scharkow (2013), defining the total effect of X on Y as path c. This total effect was decomposed into the indirect effect of X on Y, represented by the product of path a (X's effect on M) and path b (M's effect on Y), and the direct effect of X on Y, referred to as path c' [36]. To test the statistical significance of the indirect effects, a bootstrapping procedure with 5000 resampled iterations was employed to generate 95% confidence intervals (CIs). An indirect effect was considered significant if the CI excluded zero ($p < 0.05$), ensuring robust inference.

Results

In this study, preliminary descriptive statistics were conducted on the measurements of the ICAA. Table 1 provided distributional insights into the key variables of interest for our hypotheses. CAch scores were skewed, consistent with theoretical predictions and prior research [41, 59]. We also reported descriptive statistics, including the mean, median, kurtosis, and skewness, to provide a comprehensive overview of the data distribution.

Table 1 Distributional information for creative achievements

	M	Mdn	Sk	Ku
CAch total	19.24	10.00	2.12	7.16
CAch sciences	1.16	0.00	5.54	39.95
CAch arts	15.46	8.00	2.12	6.71

Note: CAch = creative achievements; Mdn = median; Sk = skewness; Ku = kurtosis

Table 2 described the correlation of BFAS, g and DT with individual creative achievements. For creative achievements in the arts and the sciences, Openness/Intellect is the most relevant factor to creative achievements. The findings revealed that the relationship between Openness and creative achievements was significantly stronger in the arts than in the sciences. Conversely, Intellect exhibited a stronger correlation with creative achievements in the sciences as opposed to the arts.

Table 3 summarized the regression analyses predicting creative achievements in the arts and sciences. The first block of variables included age, sex, Intellect, and Openness, aligning with the study's primary aim of evaluating their influence on artistic and scientific creative achievement. In the second block, additional Big Five traits—Agreeableness, Neuroticism, Extraversion, and Conscientiousness—were introduced to examine their contributions beyond Openness/Intellect. Lastly, the third block incorporated g and DT to assess the stability of Intellect and Openness as predictors when controlling for cognitive ability factors.

The regression analysis revealed distinct patterns of predictors for creative achievement in the arts and sciences. Sex was negatively associated with scientific creative achievement but positively linked to artistic creative achievement. Openness emerged as a strong predictor of creative achievement in the arts, while Intellect was a significant predictor of scientific creative achievement. Agreeableness independently predicted creative achievement in the arts (when the Big Five personality traits and g, DT were included in the regression). Furthermore, divergent thinking was a significant positive predictor of creative achievements in both domains. This finding suggested the importance of divergent thinking in contributing to scientific creative achievement.

We investigated the relationship between GMV and scientific creative achievement after regressing out age, gender, g, DT and total GMV of individual brains using multiple linear regression analysis. Table 4 presented statistical information on brain regions that positively and negatively correlated with scientific creative achievement scores.

Mediation results

Mediation analysis was conducted in SPSS 26.0 using the plug-in process v3.3 developed by Andrew F. Hayes [55]. We used Intellect as an independent variable, GMV related to creative achievement in science as a mediator variable, and scientific creative achievement as the dependent variable.

As illustrated in Fig. 1, the indirect path from Intellect to scientific creative achievement through GMV in the left IFG was statistically significant (0.0056, $p < 0.001$). Additionally, the direct effect of Intellect on scientific creative achievement was also significant (0.1138, $p < 0.001$). These findings suggested that GMV in the left IFG partially mediates the relationship between Intellect and scientific creative achievement. Specifically, Intellect directly influences scientific creative achievement while also exerting an indirect effect through its impact on GMV within the left IFG.

Discussion

This study aimed to investigate the relationship between Intellect and scientific creative achievement, as well as the neural mechanisms underlying this connection. The findings confirmed that Intellect is a significant personality predictor of scientific creative achievement among Chinese college students. Furthermore, mediation analysis indicated that the association between Intellect and scientific creative achievement was mediated by the GMV of the left IFG. This provided preliminary support for a neurocognitive pathway through which personality traits may influence scientific creativity.

The positive relationship between Intellect and scientific creative achievement aligned with the findings of previous studies [40, 41]. Intellect is linked to cognitive processes such as working memory, which facilitate the analysis of causal and logical patterns [32]. Specifically, Intellectual Engagement, a subcomponent of Intellect, has been associated with goal-directed behavior and enhanced working memory capacity [40]. Individuals with higher levels of intellectual ability often demonstrate superior inhibitory control, allowing them to suppress irrelevant or distracting information and select appropriate responses [15, 42]. Numerous studies have also demonstrated that working memory and inhibitory control, which are critical components of executive functioning, play a pivotal role in the generation and evaluation of creative ideas [12, 17, 69]. This study offered two significant innovations that build upon the work of Kaufman et al. (2016). While Kaufman et al. (2016) assessed creative achievements using the CAQ, which emphasizes publicly recognized accomplishments such as winning awards or selling works, this approach may not effectively differentiate creativity in Little-C samples, where such achievements are uncommon. As a result, their findings may not fully generalize to personal creative achievements that do not result in public recognition [41]. In contrast, the current study utilized the achievement scale from the ICAA,

Table 2 Relations among predictor variables and creative achievements

	g	DT	Lit	Music	A&C	CC	Sports	VA	PA	S&E	CAch_S	CAch_A
g	—	−0.030	0.003	−0.020	−0.039	−0.046	−0.011	−0.060*	−0.052	−0.044	−0.044	−0.043
DT	−0.030	—	0.202**	0.108**	0.163**	0.174**	0.054*	0.156**	0.155**	0.066*	0.066*	0.237**
Neoo	−0.067*	0.142**	0.258**	0.176**	0.153**	0.102**	0.021	0.183**	0.156**	0.080**	0.080**	0.283**
Oi	−0.067*	0.078**	0.122**	0.099**	0.083**	0.088**	0.056*	0.069*	0.098**	0.149**	0.149**	0.140**
Oo	−0.039	0.133**	0.247**	0.169**	0.163**	0.096**	0.007	0.199**	0.144**	0.052*	0.052*	0.281**
Neon	−0.010	0.045	−0.004	−0.012	0.014	−0.002	−0.026	0.008	0.046	−0.035	−0.035	0.016
Nv	−0.018	0.046	0.032	0.004	0.010	0.023	0.010	−0.026	0.074**	−0.019	−0.019	0.028
Nw	−0.017	0.035	0.005	−0.010	0.004	0.008	−0.033	0.020	0.032	−0.012	−0.012	0.015
Neoa	0.041	−0.042	−0.111**	−0.053*	−0.060*	−0.049	−0.097**	−0.095**	−0.078**	−0.054*	−0.054*	−0.123**
Ac	0.006	0.022	0.070**	0.067*	0.086**	0.106**	0.006	−0.017	0.094**	0.040	0.040	0.084**
Ap	0.027	−0.012	−0.144**	−0.086**	−0.082**	−0.093**	−0.099**	−0.111**	−0.123**	−0.073**	−0.073**	−0.166**
Neoc	−0.010	0.041	0.099**	0.061*	0.087**	0.112**	0.062*	0.012	0.035	0.053*	0.053*	0.090**
Ci	0.007	0.026	0.058*	0.031	0.069*	0.097**	0.052	−0.008	0.005	0.033	0.033	0.048
Co	−0.007	−0.006	0.056*	0.024	0.073**	0.087**	0.023	−0.008	0.031	0.043	0.043	0.053*
Neoe	0.013	0.070**	0.087**	0.066*	0.063*	0.097**	0.082**	−0.008	0.119**	0.038	0.038	0.094**
Ee	0.021	0.025	0.049	0.033	0.035	0.056*	0.028	−0.021	0.060*	−0.011	−0.011	0.046
Ea	−0.019	0.104**	0.172**	0.103**	0.090**	0.118**	0.097**	0.055*	0.155**	0.086**	0.086**	0.175**

Note: g = general cognitive ability; DT = Divergent Thinking; CAch = Creative achievements; Neoo = Openness/Intellect; Oi = Intellect; Oo = openness; Neon = Neuroticism; Nv = volatility; Nw = withdrawal; Neoa = Agreeableness; Ac = compassion; Ap = politeness; Neoc = Conscientiousness; Ci = Industriousness; Co = Orderliness;. Neoe = Extraversion; Ee = enthusiasm; Ea = assertiveness. CAch_S = scientific creative achievement; CAch_A = artistic creative achievement; Correlations with the CAch are Spearman's rho; all others are Pearson correlations; *$p < 0.05$; **$p < 0.01$

Table 3 Robust Poisson regression predicting creative achievement in the arts and sciences

	arts					sciences				
	b	**SE**	**95%CI**	**Wald x^2**	***p***	**b**	**SE**	**95%CI**	**Wald x^2**	***p***
Block 1										
Age	0.004	0.0300	[-0.054, -0.063]	0.022	0.881	**0.118**	**0.0595**	**[0.002, 0.235]**	**3.942**	**0.047**
Sex	**0.433**	**0.0770**	**[0.282, 0.584]**	**31.584**	**0.000**	**-0.794**	**0.1670**	**[-1.121, -0.466]**	**22.594**	**0.000**
Intellect	**0.020**	**0.0096**	**[0.001, 0.039]**	**4.430**	**0.035**	**0.097**	**0.0233**	**[0.051, 0.143]**	**17.345**	**0.000**
Openness	**0.049**	**0.0059**	**[0.038, 0.061]**	**69.388**	**0.000**	0.008	0.0150	[-0.022, 0.037]	0.250	0.617
Block 2										
Age	0.014	0.0298	[-0.044, 0.073]	0.227	0.634	**0.117**	**0.0590**	**[0.001, 0.232]**	**3.909**	**0.048**
Sex	**0.443**	**0.0780**	**[0.290, 0.596]**	**32.299**	**0.000**	**-0.784**	**0.1728**	**[-1.123, -0.446]**	**20.601**	**0.000**
Intellect	0.006	0.0107	[-0.015, 0.026]	0.273	0.602	**0.090**	**0.0260**	**[0.039, 0.141]**	**12.089**	**0.001**
Openness	**0.050**	**0.0058**	**[0.039, 0.062]**	**73.566**	**0.000**	0.009	0.0158	[-0.023, 0.040]	0.288	0.591
Neuroticism	0.000	0.0020	[-0.004, 0.004]	0.000	0.998	0.000	0.0043	[-0.008, 0.009]	0.010	0.919
Agreeableness	**-0.013**	**0.0020**	**[-0.017, -0.009]**	**41.922**	**0.000**	-0.009	0.0065	[-0.021, 0.004]	1.718	0.190
Conscientiousness	0.003	0.0020	[-0.001, 0.007]	2.778	0.096	0.002	0.0042	[-0.007, 0.010]	0.144	0.704
Extraversion	0.003	0.0019	[0.000, 0.007]	3.051	0.081	0.002	0.0047	[-0.008, 0.011]	0.123	0.726
Block 3										
Age	0.007	0.0293	[-0.050, 0.065]	0.065	0.798	0.109	0.0615	[-0.011, 0.230]	3.145	0.076
Sex	**0.390**	**0.0765**	**[0.240, 0.540]**	**26.011**	**0.000**	**-0.833**	**0.1776**	**[-1.181, -0.485]**	**21.990**	**0.000**
Intellect	0.002	0.0107	[-0.019, 0.023]	0.031	0.861	**0.086**	**0.0259**	**[0.035, 0.137]**	**10.965**	**0.001**
Openness	**0.048**	**0.0059**	**[0.036, 0.059]**	**65.685**	**0.000**	0.006	0.0159	[-0.025, 0.037]	0.149	0.700
Neuroticism	-0.001	0.0020	[-0.005, 0.003]	0.172	0.678	0.000	0.0043	[-0.009, 0.008]	0.010	0.920
Agreeableness	**-0.012**	**0.0020**	**[-0.016, -0.008]**	**37.346**	**0.000**	-0.008	0.0063	[-0.020, 0.004]	1.562	0.211
Conscientiousness	0.003	0.0020	[-0.001, 0.007]	2.151	0.142	0.002	0.0041	[-0.006, 0.010]	0.193	0.661
Extraversion	0.002	0.0019	[-0.001, 0.006]	1.776	0.183	0.000	0.0047	[-0.009, 0.009]	0.005	0.945
g	-0.004	0.0049	[-0.014, 0.006]	0.627	0.428	-0.012	0.0136	[-0.039, 0.015]	0.768	0.381
DT	**0.214**	**0.0318**	**[0.152, 0.276]**	**45.273**	**0.000**	**0.208**	**0.0836**	**[0.045, 0.372]**	**6.225**	**0.013**

Note: SE = standard error; CI = confidence interval. Significant effects ($p < 0.05$) are in boldface

Table 4 Gray matter volume correlated with creative achievement in the science

Regions	**Cerebral hemisphere**	**Peak MNI coordinate**			**Voxels**	**Peak T score**
		x	**y**	**z**		
Positive correlation						
Cerebelum_8	R	32	-60	-44	16	3.6057
Temporal_Pole_Mid	R	54	6	-24	59	3.7728
Temporal_Inf	R	54	-21	-24	23	4.0375
Frontal_Inf_Orb	R	49	39	-15	22	3.7324
Frontal_Inf_Tri	R	51	29	14	156	4.954
Frontal_Inf_Tri	R	50	16	21	15	3.488
Frontal_Inf_Oper	L	-47	5	11	140	3.9811
Postcentral	L	-63	-16	27	35	3.6223
Temporal_Sup	L	-59	-16	1	49	3.8318
Frontal_Inf_Orb	L	-46	36	-9	93	4.0119
Temporal_Mid	L	-51	6	-23	31	3.4306
Negative correlation						
Temporal_Inf	R	48	-26	-26	30	-3.6292
Rectus	R	7	39	-18	15	-3.5506
Supp_Motor_Area	R	3	21	57	58	-4.1101
Precentral	R	24	-27	69	19	-3.6341
Precentral	L	-45	4	50	87	-3.8895
Cerebelum_6	L	-39	-39	-28	31	-3.573

Note: MNI, Montreal Neurological Institute. All T-scores reflect a VBM threshold of $p < 0.001$ (non-stationary cluster corrected) and a minimum cluster size (k) of 15 contiguous voxels

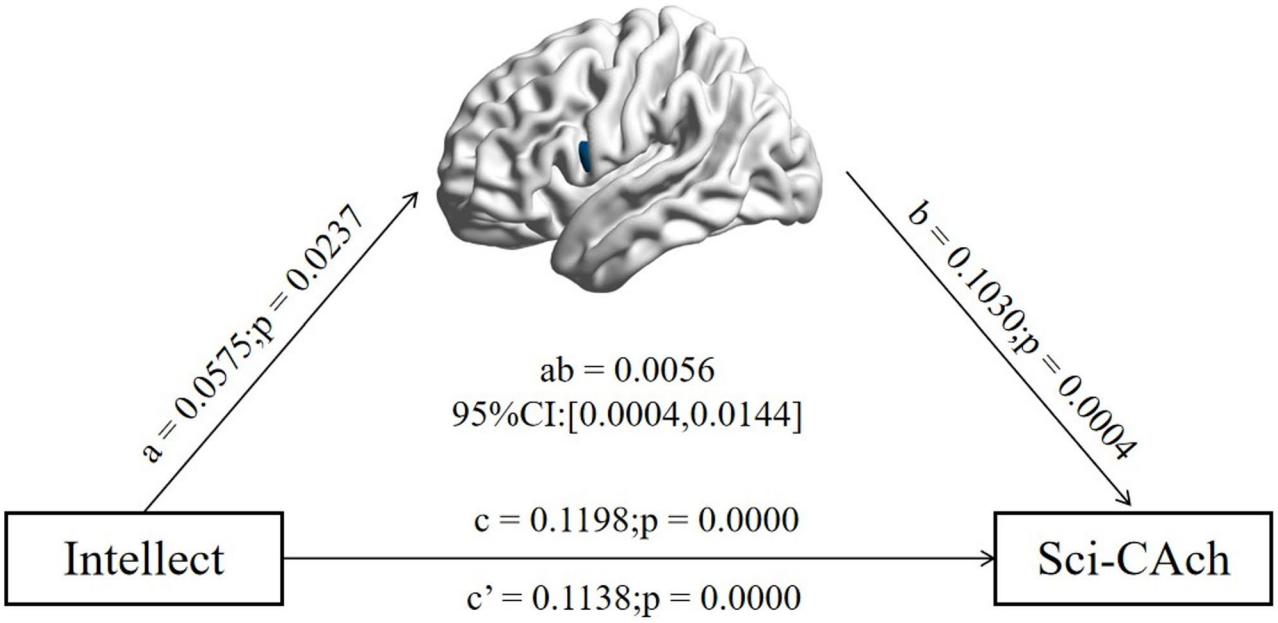


Fig. 1 Left Inferior frontal gyrus mediates the association between Intellect and scientific creative achievement. The mediator is the Inferior Frontal Gyrus (IFG), which is the blue part of the brain region in the figure. Sci-CAch = Scientific Creative Achievement

which encompasses both public and personal achievements, providing a more comprehensive evaluation of creative accomplishments [56, 61, 65]. This study extends previous research by demonstrating that the correlation between Intellect and high-level scientific creativity can also be generalized to personal scientific creativity achievement. Furthermore, from a cross-cultural perspective, utilizing a substantial sample of Chinese undergraduate students, our study demonstrated the existence of the association between Intellect and scientific creativity in this population, thereby underscoring the cross-cultural robustness of this personality-creativity linkage.

Our findings demonstrated a significant positive correlation between GMV of bilateral IFG, left Superior Temporal Gyrus (STG), left Middle Temporal Gyrus (MTG), left postcentral gyrus, and scientific creative achievement. Notably, the MTG and STG are integral components of the DMN, while the IFG is a key node in the ECN [49, 51]. The left MTG is involved in forming distant semantic associations and integrating semantic information [11, 18]. This region not only facilitates the retrieval of stored information but also supports the formation of novel, atypical semantic connections, both of which are essential for generating highly creative ideas. Additionally, the left STG may contribute to interpreting emotional context and the processing of non-textual information, further enhancing creative thinking. Our findings align with previous research [14] indicating a significant positive correlation between bilateral IFG GMV and scientific creative achievement, suggesting that individuals with greater IFG GMV are more predisposed to excel in scientific creativity. The IFG is essential for cognitive functions such as information retrieval and semantic memory flexibility, which underpin the generation of novel and innovative ideas [45, 67]. These cognitive mechanisms enhance the quality of creative outputs, reinforcing the IFG's predictive value for future creative achievements. In addition, the IFG's role in attentional control enables efficient allocation of cognitive resources to working memory tasks. By filtering out irrelevant information, it supports the sustained maintenance and processing of pertinent information, thereby optimizing working memory performance and fostering creative problem-solving [4, 64]. This study utilized the ICAA, a more comprehensive measure of creative output that encompasses both personal and public achievements, to assess individual scientific creativity. They also revealed that individual differences in GMV within regions associated with the DMN (e.g., MTG, STG) and ECN (e.g., IFG) were linked to scientific creativity. This pattern underscores the structural importance of these two large-scale brain systems in supporting scientific creative achievement across varying levels of expression. Although VBM cannot directly assess functional connectivity or network interactions, the involvement of both DMN- and ECN-related regions aligns with prior functional accounts emphasizing the complementary roles of generative and controlled processes in creative cognition [10, 53]. Beaty et al. (2016) proposed, scientific creative thinking likely depends on coordinated contributions from the default and control networks. Our structural findings extend this theoretical framework by showing that the GMV of

regions within these systems is also relevant for scientific creativity.

An interesting finding of this study is that the mediation analysis revealed the left IFG as a mediator in the relationship between Intellect and scientific creative achievement. Intellect may engage the executive control network, with fluid intelligence and working memory being key components associated with Intellect. Previous research has demonstrated that Intellect is linked to activation in the left prefrontal and medial prefrontal cortices during working memory tasks [29]. Specifically, the mediating role of the left IFG in this relationship can be attributed to its function as a neural substrate supporting the cognitive processes of working memory. Intellect influences scientific creative achievement through this working memory pathway, which allows for the retention and manipulation of information critical for higher-order cognitive functions. Moreover, the IFG plays a critical role in inhibitory control, which facilitates goal-directed creative thinking by suppressing automatic responses and filtering out distractions. These processes enhance the generation of high-quality creative ideas, further highlighting the IFG's significance in scientific creativity. However, as GMV reflects brain structure rather than function, our findings cannot directly confirm the cognitive processes underlying the mediation effect. Structural differences in the IFG may reflect accumulated engagement in functions like working memory or inhibition over time [31, 50]. Nevertheless, this interpretation remains speculative. Future studies using task fMRI are necessary to test whether the executive functions or semantic control processes of IFG mediate the link between Intellect and scientific creativity.

Theoretical and practical implications

Theoretically, by identifying the GMV of the IFG as a potential intermediary, this study provided preliminary support for a neuroanatomical pathway through which Intellect might influence scientific creativity. This result aligned broadly with dual pathway models of creativity [52], which posit that both controlled and spontaneous processes contribute to creative output. Intellect, which is associated with working memory and abstract reasoning [10, 24], may enhance creativity by facilitating controlled cognitive strategies such as hypothesis generation, semantic integration, and focused problem solving. The IFG, as part of the executive control network, is well suited to support such processes [13]. However, as our design is cross-sectional, these conclusions remain preliminary and should be tested further using longitudinal and experimental designs to establish causality. By focusing on scientific creativity—a relatively underexplored yet socially important domain—our study also responds to calls for domain-specific investigations of the neural basis of creativity [1].

From a practical perspective, our findings offer tentative guidance for educational efforts aimed at fostering scientific creativity. For instance, training programs that target executive function skills—such as reasoning, semantic association, or cognitive control—may support the development of scientific thinking in students [8]. Moreover, personality-informed approaches to education could help identify learners with high Intellect traits and nurture their strengths, such as curiosity about abstract concepts or engagement with complex problem-solving tasks [62, 63]. That said, applying findings from personality neuroscience to educational practice must be approached with caution. The translation from brain-based research to pedagogical intervention remains a developing area [54], and creative achievements are influenced by a constellation of interacting factors, including environment, motivation, and learning opportunities [60]. Any educational applications should therefore consider the broader ecological and individual contexts of learners.

Limitations and future directions

Several limitations of the present study should be acknowledged. First, the neural basis of the relationship between scientific creativity and Intellect has been primarily investigated using VBM analysis. The VBM analysis primarily identifies differences between groups by comparing static metrics of brain structure, such as gray matter density or volume. While this method exhibits high sensitivity in detecting localized structural abnormalities, it remains inherently a static structural analysis technique. Consequently, it fails to capture the dynamic interactions and functional coupling between different brain regions [5, 6]. Future studies could benefit from incorporating functional connectivity analysis to gain a more dynamic understanding of the brain networks involved. Additionally, although our focus on the IFG was informed by prior literature, other brain regions may also play a mediating role and should be examined in future studies using exploratory or data-driven approaches.

Second, the development of creative achievements and domain-specific expertise is a gradual process that evolves over time with age [16]. This study focused on a sample of college students. Yet the limited age range within our cohort of young adults may have led to reduced variability in brain region volumes, potentially contributing to a weaker significant relationship between GMV in the region of interest and scientific creative achievement. Therefore, expanding the subject pool to include individuals from a broader range of age groups could provide a more comprehensive understanding of the relationship between brain structure

and achievement, offering deeper insights into the neural mechanisms underlying scientific creative achievement. Furthermore, although we employed the CAch scale from ICAA to assess Pro-C creativity, it must be acknowledged that participants were not genuine experts in their respective fields. These achievements cannot fully capture Pro-C creativity. Therefore, future research could examine how Intellect influences creativity among actual domain experts in scientific fields.

Third, while self-report tools such as the BFAS and the ICAA are widely used and psychometrically validated, they are not without shortcomings, such as social desirability or shared method variance [68]. Similarly, self-assessments of creative achievements—particularly those involving retrospective recall—may be vulnerable to memory distortions and the overestimation or underestimation of one's accomplishments [54, 59]. Notably, while the ICAA provides a broad and ecologically valid measure of creative achievements, its assessment of scientific creative achievement may not fully distinguish between general participation in science-related activities and high-level scientific innovation. Future studies should consider using multi-method approaches—including behavioral tasks, or objective creativity assessments—to complement self-report instruments and reduce shared method variance. It is also necessary to incorporate domain-specific, performance-based assessments to complement self-report tools, in order to better capture the construct of scientific creativity.

Finally, implementing a longitudinal research design would enable a more rigorous validation of the findings and provide valuable insights into the temporal dynamics of the relationship between Intellect and scientific creativity. Such an approach would facilitate a deeper understanding of the directional changes driven by the passage of time and the cumulative development of experience. These dynamic changes may, in turn, contribute to the individual differences observed in scientific creative abilities.

Conclusion

In conclusion, this study provides empirical evidence for the relationship between Intellect and scientific creative achievement within the Chinese cultural context and further explores the underlying neural mechanisms. The behavioral findings revealed a positive correlation between Intellect and scientific creative achievement. Moreover, this relationship was partially mediated by the GMV of the IFG, a critical neural substrate for scientific creativity. These findings offer novel insights into the cognitive and neural basis of scientific creativity and have important implications for the development of training programs designed to enhance students' scientific creative achievement.

Author contributions

Yi Wan: Conceptualization, Methodology, Writing – review & editing. Titanwei Xu: Conceptualization, Writing-review & editing, Project administration. Wenlong Zhou: Conceptualization, Project administration.Lei Fu: Conceptualization, Methodology. Peiduo Liu: Conceptualization, Investigation, review & editing, Project administration. Jiang Qiu: Conceptualization, Methodology, Project administration. Wenjing Yang: Conceptualization, Writing – review & editing, Resources, Project administration.

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Data availability

The data supporting the findings of this study are not publicly available as they are part of an ongoing database development. However, deidentified and anonymized individual data can be obtained from the corresponding author upon reasonable request.

Declarations

Ethical approval

This study involving human participants was approved by the Institutional Review Board of Southwest University, Chongqing, China. All participants provided informed consent prior to participation and were informed that their data might be included in the published results.

Consent for publication

Written informed consent for the publication of data was obtained from all participants in this study.

Competing interests

The authors declare no competing interests.

Clinical trial number

Not applicable.

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