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Individual Differences in Parietal and Premotor Activity During Spatial Cognition Predict Figural Creativity

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ABSTRACT

Creativity often requires envisioning novel connections and combinations among elements in space, e.g., to invent a new product or generate a work of art. A relationship between spatial cognition and creativity has been demonstrated at both the behavioral and neural levels, but the exact neurocognitive mechanisms that bridge this connection remain unclear. The present study tested whether individual differences in functional activation in spatial cognition-implicated brain regions (specifically focusing on premotor and superior parietal cortex) during mental rotation were associated with figural creativity in a composite object creation task. Functional activation in premotor and superior parietal cortex during a classical spatial task (mental rotation; MRT) has previously been causally linked with dissociable components of spatial cognition: superior parietal activity with abstract spatial representation, and premotor activity with active spatial manipulation. The present findings indicate that individual differences in functional activation of both superior parietal cortex and premotor cortex during MRT were associated with individual differences in figural creativity. The present data thus provide new evidence of a correlation between the activity in spatial cognition-implicated brain regions and figural creativity, and suggest initial insights into particular components of spatial processing (both representation and manipulation) that may be related to creative ability.

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Introduction

Creativity often requires envisioning novel connections and combinations among elements in space. For example, designing a product may require integrating new object elements into an existing spatial configuration and/or reconfiguring an existing set of components. Creating a new work of art (e.g. painting and drawing) often requires visualizing and manipulating spatial representations to turn spatial mental representations into a physically observable piece. "spatial cognition," or the ability to mentally represent and manipulate different kinds of information in space (Uttal et al, 2013), has been shown to support creative cognition in many domains (Palmiero & Srinivasan, 2015; Suh & Cho, 2020). Research has found significant behavioral associations between spatial thinking and creativity in both verbal and visual domains, however, the exact mechanism for this relationship has not been adequately identified by behavioral correlations alone (Palmiero & Srinivasan, 2015; Suh & Cho, 2020). In addition, while the neural systems underlying spatial cognition appear to support creativity in verbal contexts (Beaty, Benedek, Silvia, & Schacter, 2016; Boccia, Piccardi, Palermo, Nori, & Palmiero, 2015; Chen et al., 2015), these findings have been somewhat inconsistent and variable across different tasks (Boccia et al., 2015). In sum, the relationship between spatial cognition and creativity has been demonstrated at both the behavioral and neural levels, but the exact neurocognitive mechanisms that bridge this connection have not been adequately identified. Because the factors determining the extent of spatial brain involvement in verbal creativity are not well understood and are likely to be quite complex, investigating the relationship of the spatial brain to creativity can perhaps more straightforwardly begin within the figural domain. The present study aimed to explore this relationship by testing whether individual differences in functional activation in spatial cognition-implicated brain regions during mental rotation were differentially associated with figural creativity. We focused specifically on activity in premotor and parietal cortex based on prior evidence implicating activity in these regions in the cognitive processes of active spatial manipulation and abstract spatial representation, respectively.

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Supplemental data for this article can be accessed on the publisher's website.

Perhaps, the most widely studied measure of spatial cognition is the mental rotation task (MRT; Linn & Petersen, 1985; Terlecki, Newcombe, & Little, 2008; Zacks, 2008). Originally developed by Shepard and Metzler (1971), MRT requires participants to determine whether a pair of 3-dimensional figure images depict the same figure at different angles of rotation or depict different figures. Extensive cognitive investigation of MRT suggests that *active spatial manipulation* and *abstract spatial representation* constitute two core component processes of the task, which can be understood as the respective processes of actively moving an object vs. building and maintaining the object (Cona, Panozzo, & Semenza, 2017; Shepard & Metzler, 1971). *Active spatial manipulation* refers to the actual rotational movement of the three-dimensional object representation (e.g. rotating the first object across horizontal and vertical dimensions; Cona et al., 2017; R. Shepard & Metzler, 1971; Vingerhoets, de Lange, Vandemaele, Deblaere, & Achten, 2002; Wraga, Shephard, Church, Inati, & Kosslyn, 2005), while *abstract spatial representation* refers to the construction and maintenance of the representation, which is important for initially representing the object, ensuring the constancy of that representation as it rotates, and especially for comparing the internal representation of the mentally rotated representation to the externally presented stimulus in order to verify whether they are the same or different objects (Cona et al., 2017; Fox et al., 2005; Harris & Miniussi, 2003; Lamm, Windischberger, Moser, & Bauer, 2007; Shepard & Metzler, 1971). Neuroscientific investigations of MRT frequently reveal two brain regions, which are active during task performance: the premotor cortex and the superior parietal cortex (Cohen et al., 1996; Zacks, 2008). Given the role of the superior parietal cortex in visuo-spatial representation across domains (Colby & Duhamel, 1996; Colby, Duhamel, & Goldberg, 1995) and the role of the premotor cortex in visuo-motor movements, actions, and transformations (Graziano, Hu, & Gross, 1997; Johnston, Leek, Atherton, Thacker, & Jackson, 2004; Kakei, Hoffman, & Strick, 2001), it is reasonable to suspect that the superior parietal cortex may support *abstract spatial representation* and the premotor cortex may support *active spatial manipulation*. Indeed, recent research using transcranial magnetic stimulation (TMS; Hallett, 2000) to induce temporary lesions in different brain regions and examine the impact on different cognitive processes has provided direct causal evidence that the superior parietal cortex supports *abstract spatial representation* (Harris & Miniussi, 2003) and the premotor cortex supports *active spatial manipulation* (Cona et al., 2017). Nonetheless, these cognitive processes are undoubtedly overlapping to some degree and these brain regions are highly cooperative during MRT and other spatial tasks (Cona et al., 2017; Harris & Miniussi, 2003; Lamm et al., 2007; Milivojevic, Hamm, & Corballis, 2009; Sack et al., 2008; Wise, Boussaoud, Johnson, & Caminiti, 1997; Wraga et al., 2005; Zacks, 2008). The extensive characterization of MRT at both cognitive and neural levels of description (Linn & Petersen, 1985; S. Shepard & Metzler, 1988; Terlecki et al., 2008; Zacks, 2008) make this task a valuable reference measure to characterize individual differences in spatial cognition-related brain activity.

A promising target for investigating figural creativity is the composite object creation task developed by Finke (Finke, 1990). This task requires participants to mentally combine objects to form novel, functional composite objects (Finke, 1990, 1996; Finke & Slayton, 1988). Specifically, participants are given a set of objects to use (represented as 2-dimensional illustrations) and instructed to "mentally combine" the objects to form "an original object." They are then asked to draw the novel composite object that they envisioned (Figure 1). Participants subsequently interpret the composite object they created as an invention within a provided category (e.g., toys/games or furniture). The composite object creation task proceeds from visually inspecting the individual objects to considering how the featural properties, orientations, and positions of those objects could relate to each other (likely involving the use of *abstract spatial representation*), mentally resizing and reorienting objects in relation to each other to yield composite objects (perhaps through *active spatial manipulation*), and comparatively evaluating alternative composite objects. The demands of this task are thus likely to draw on the cognitive processes and brain regions that are engaged during MRT. It is also possible that consideration of structural and functional attributes of the objects may induce motor-related processing during this task (e.g. what acts as a handle), similar to the motor imagery (e.g. imaging utilizing one's own hand to rotate an object) that is theorized to take place during MRT (Vingerhoets et al., 2002; Wraga et al., 2005). Extant evidence suggests that these motor-related processes during MRT may be supported by the premotor cortex (Cona et al., 2017; Vingerhoets et al., 2002; Wraga et al., 2005). However, these demands are also different in several respects from the demands of MRT, including differences of kind, number, and complexity. In MRT, novelty is not relevant, resizing is not possible, and there is only one axis of rotation to consider rather than all possible axes. Critically, whereas MRT involves the rotation of isolated objects, the composite object creation task focuses on relations between multiple objects (i.e.,

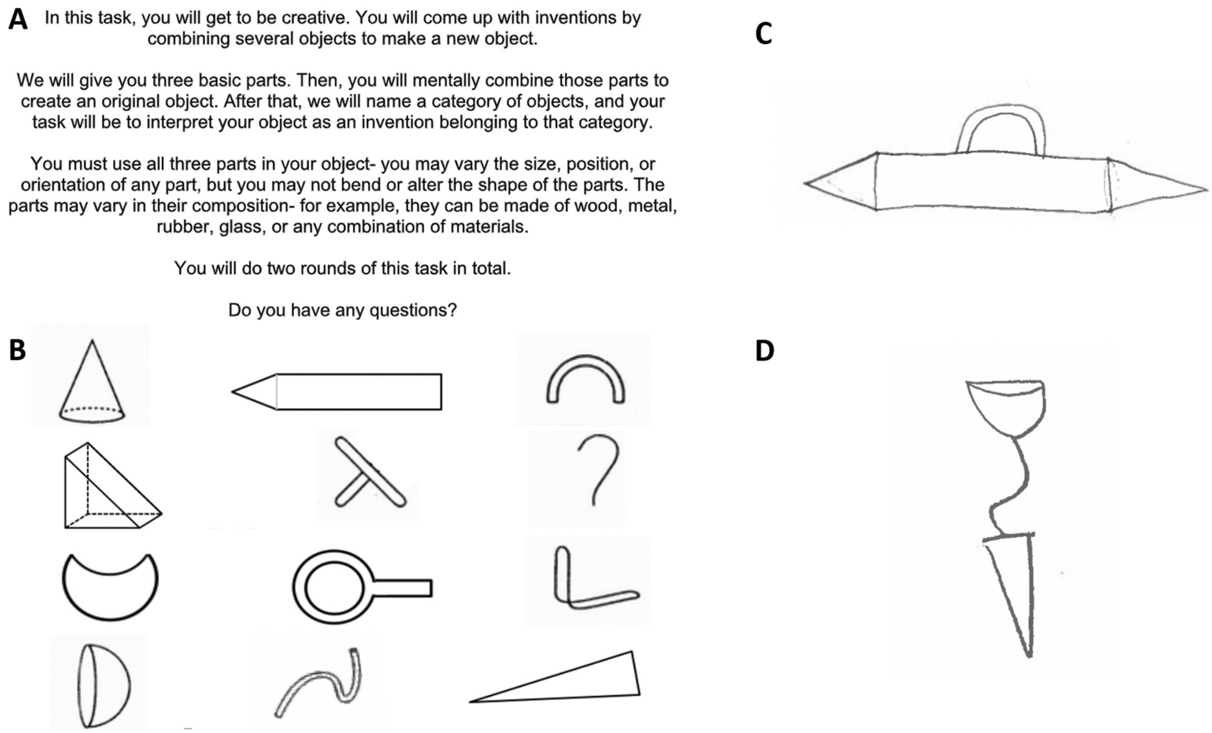

Figure 1. The composite object creation task.

how manipulating the objects leads to different ways of relating them to each other in space). Additionally, the composite object creation task is scored on creativity and the task instructions emphasize novelty and unusualness, neither of which is the case for MRT. Thus, cognitive processes that may be shared between the two tasks are nonetheless likely to be deployed somewhat differently for the differing task demands, and individual differences in brain activity related to these cognitive processes may show different relationships to the outcome measures of performance in the two tasks.

Although there are multiple distinctions between these two tasks regarding instructions, demands, and outcome measurement, both draw on core cognitive processes relevant for spatial cognition, suggesting that an assay of spatial cognition-implicated brain activity during MRT might yield neural correlates of figural creativity in the composite object creation task. Generation and comparative evaluation of different possible composite object representations could plausibly be influenced by individual differences in superior parietal activity (a marker of *abstract spatial representation*), and *active spatial manipulation* of object sizes and orientations could plausibly be influenced by individual differences in premotor activity. Beyond a role in completing this task at a level of basic competence, individual differences in such neural activity may be associated with differences in creative ability on this task. To date, one study has examined brain function related to figural creativity (Aziz-Zadeh, Liew, & Dandekar, 2013). Aziz-Zadeh and colleagues found that a modified version of the composite object creation task developed by Finke (Finke, 1990), as compared to a spatial control task, was associated with activity in both premotor cortex and superior parietal cortex, as well as visual cortex and dorsolateral prefrontal cortex. However, participants' responses on the creativity task were not scored for creativity in that study – indeed, participants were only asked to covertly combine objects and did not have to outwardly produce the composite objects – so it was not possible to relate brain activity to differences in creative performance. This leaves open the question of whether activity within spatial cognition-implicated brain regions is associated with individual differences in figural creativity.

The present study therefore examined whether individual differences in figural creativity on the composite object creation task were associated with individual differences in functional activation in spatial cognition-implicated brain regions (premotor and superior parietal cortex) during MRT. Based on the prior evidence regarding differential cognitive contributions of superior parietal cortex and premotor cortex, these cortical regions were of particular interest as MRI-based markers of engagement in indifferent aspects of spatial cognition (abstract spatial representation and active spatial manipulation, respectively) in which individual differences may be relevant to figural creativity.

Materials and methods

Participants

Fifty-one healthy, right-handed native English speakers reporting no history of mental illness or psychoactive drug use participated in the present study. Participants were recruited from [Virginia] public high schools (27 males, 24 Females; mean age = 16.67 years, SD = 0.52) as part of a larger study on spatial cognition and learning. Informed written consent was obtained for all participants prior to the experiment in accordance with the guidelines established by the [Georgetown University] IRB and the IRB of the public schools where the students attended. All participants under 18 years of age provided informed assent, with informed consent from legal guardians. Participants completed the study session (behavioral and fMRI data collection) at the [Center for Functional and Molecular Imaging at GeorgetownUniversity].

Figural creativity task

The composite object creation task (Finke, 1990) was used to assess figural creativity. In each trial, participants were presented with a set of three images of objects (Figure 1(b)), and were given 1 min in which they were instructed to "mentally combine" the objects to "create an original object." After 1 min, the participants drew the composite object with pencil on paper without any time restriction. In a subsequent phase not analyzed for the present study, the researcher provided a category, such as "furniture," "scientific instrument," or "toys and games," and participants were instructed to interpret their created object as an invention within the provided category in 1 min. Participants named their invention and provided a written description of its function. The invention and interpretation phases were conducted separately (i.e. the participants were given the category only after they had already created their original object) as Finke (1990) found that this procedure led to the greatest number of creative inventions. Each participant performed two consecutive trials of the task. Instructions can be found in Figure 1(a) and the full set of stimuli in Figure 1(b).

Participants' responses were independently scored by three trained raters for originality on a 0–4 scale. An additional un-analyzed variable of practicality was also scored. Because the present research question concerned creativity, originality scores were utilized in the present study. For the present study, analyses were conducted only on the object creation portion of the task to assess visual relational creativity performance. Raters scored only the object produced by the participant without regard to its verbal interpretation. Consistent with Finke (Finke, 1990, 1996; Finke & Slayton, 1988), raters were instructed to give higher originality scores to composite configurations that connected the given objects in atypical, unique, or non-obvious ways, as well as composites that modified the relative sizes of the objects in unexpected ways. Responses that were judged to be more commonplace/frequent within the data set were given lower originality scores. An example of a low-scoring response can be found in Figure 1(c) (very obvious combination of the presented objects), and a high-scoring example response can be found in Figure 1(d) (unique orientation and placement of presented objects). The raters performed their ratings independently, and a satisfactory interrater reliability was obtained (Cronbach's alpha = .781). Scores were averaged across all three raters, and then the scores from the two trials were averaged together for each participant, creating the final figural creativity score.

Mental rotation fMRI task

A computerized version of the mental rotation task (MRT) developed by Shepard and Metzler (1971) was administered in the fMRI scanner, using stimuli from Peters and Battista (2008). In each trial, participants saw two images of 3-dimensional objects (Figure 2) and were given up to 7 seconds to decide whether they were the same object presented at different angles of rotation or different objects. Participants pressed keys to indicate either "Yes" (the images show the same object) or "No" (the images show different objects). If participants responded before 7 seconds, the screen advanced to the next trial. Images of objects differed from each other by 50, 100, or 150 degrees. There were 24 trials of each rotation angle difference (72 trials total). Twelve trials with 0 degrees of rotation were also included as a control condition. Thus, there were a total of 84 trials. Following previous implementations of the MRT (Voyer & Hou, 2006), a 2:1 ratio of True (same object) to False (different objects) trials was used across all trial types. Jittered fixations ranging from 3 to 8 seconds were presented between trials (Figure 2). Before completing the task, participants received detailed instructions, were given opportunities and prompts to ask questions about the task, and completed 10 practice problems.

Behavioral performance on MRT was measured by rate correct score (RCS), a composite measure of accuracy and response time (Liesefeld & Janczyk, 2019; Vandierendonck, 2017; Woltz & Was, 2006). RCS is calculated as the frequency of correct responses of considered trials divided by total reaction time (RT) spent on the considered trials, and can be interpreted as

Figure 2. The mental rotation task.

number of correct responses per unit of time. RCS is appropriate where there are theoretical or empirical indications that RT and accuracy reflect a shared underlying cognitive process or processes (e.g., spatial processing that supports more accurate and faster responding on MRT (Liesefeld & Janczyk, 2019; Vandierendonck, 2017). Additionally, integrated measures, such as RCS, are most appropriate when accuracy scores are generally high (Liesefeld & Janczyk, 2019; Vandierendonck, 2017), which was the case for MRT in the present sample (average accuracy = .77, SD = .13). When the criteria for RCS are met, it is a preferable metric because it can yield an integrated effect size that reflects a larger proportion of the variance than the component measures (RT and accuracy) do on their own (Liesefeld & Janczyk, 2019; Vandierendonck, 2017).

Statistical analysis

All behavioral analyses were computed in R-studio Version 1.1.456, using the "stats" package (Verzani, 2018).

fMRI data acquisition

Imaging acquisition was performed on a 3 T Siemens Trio Tim MRI scanner. All task fMRI data were acquired from T2*-weighted echoplanar imaging sequence (37 3.0 mm transversal slices; 64 × 64 matrix; repetition time = 2000 ms; echo time = 30 ms; field of view = 192 mm; 3.0 × 3.0 × 3.0 mm voxels; flip angle = 90 degrees). In order to account for field stabilization, the first two volumes were excluded from the analysis. High-resolution T1-weighted MPRAGE images (176 1.00 mm slices; 256 × 256 matrix; repetition time = 1900 ms; echo time = 2.52 ms; field of view = 250 mm; 1.0 × 1.0 × 1.0 mm; flip angle = 9 degrees) were obtained for structural imaging and registration of functional data.

fMRI data preprocessing

All fMRI data processing was carried out using FEAT (fMRI Expert Analysis Tool) Version 5.98, part of FSL (FMRIB's Software Library). General Linear Model-based analysis in FEAT uses FSL tools including Brain Extraction Tool (BET; Smith, 2002), an affine registration tool, FMRIB's Linear Image Registration Tool (FLIRT; Jenkinson, Bannister, Brady, & Smith, 2002; Jenkinson & Smith, 2001), and a motion-correction tool based on FLIRT (MCFLIRT; Jenkinson et al., 2002). FEAT carries out standard-space registration after time-series statistics. FSL time-series statistics correct for temporal smoothness by applying pre-whitening (Woolrich, Ripley, Brady, & Smith, 2001). The following pre-statistics processing was applied: spatial smoothing using a Gaussian kernel of FWHM 5 mm; grand-mean intensity normalization of the entire 4D dataset by a single multiplicative factor; high-pass temporal filtering (Gaussian-weighted least-squares straight-line fitting, with sigma = 50.0 s). Registration to high-resolution structural and, subsequently, standard space images was performed using FLIRT.

fMRI data analysis

Whole brain parametric analysis

At the individual subject level, a design matrix was fitted to each subject's data as part of a general linear model (GLM) with each condition modeled as events with a specified duration (i.e., the time from stimulus onset to onset of the response) convolved with a canonical hemodynamic response function. A randomized, event-related design was utilized in which the duration of each trial depended on how fast the participant responded during the response period (meaning that each trial for each participant was modeled in accordance with their actual onset and duration). Following previous fMRI implementations of MRT (Voyer & Hou, 2006; Zacks, 2008) the MRT trial types of interest were Rotation True (composed of 50, 100, & 150-degree rotation trials in which both images depicted the same figure) and Control (0 Degree True trials). Both trial types of interest were modeled using the onset and duration of the entire trial. Voxelwise contrast and z-statistics images for MRT were generated for each participant using the following Rotation True > Control contrast.

Group-level analyses were conducted using FLAME, a mixed-effects model implemented in FSL (Beckmann, Jenkinson, & Smith, 2003). For the whole-brain group-level parametric analysis, participants' figural creativity performance scores were mean-centered and then entered to create a parametric regressor in the design matrix for each subject to test whether these values were predictive of increases and/or decreases in functional activation throughout the whole brain in the Rotation True > Control contrast. Cluster-based corrections for multiple comparisons used gaussian random field theory ($Z > 3.1$; cluster significance: $p < .01$, corrected).

Additional analyses

Additional exploratory analyses were conducted to query the association of structural brain differences (with voxel-based morphometry) with figural creativity and sex differences in activation during MRT (see Supplementary Information). These analyses found no significant correlations between brain structure and figural creativity, and no significant sex differences in brain activity during MRT.

Results

Behavioral

Average figural creativity performance, measured with average object originality, was 1.55, SD = .57 rated on a scale of 0–4. For MRT, performance was measured with rate correct score (RCS) averaged across all angles of rotation (50, 100, 150 degrees). Average MRT RCS was .17 correct answers per second (SD = .05); reflecting an average accuracy of .77 (SD = .13), and an average RT of 4.01 seconds (SD = .53). Figural creativity performance was not significantly associated with MRT performance ($r = -.16$, $p = .27$). The Shapiro-Wilk Normality test revealed that both variables were not significantly different from the normal distribution (both $p > .05$).

fMRI

A Rotation True > Control contrast for MRT was first conducted to identify regions engaged during mental rotation. Group-level analysis indicated activity in bilateral premotor cortex and bilateral superior parietal cortex (Table 1), consistent with previous neuroimaging studies of mental rotation (Zacks, 2008).

To examine the relationship between figural creativity performance and the recruitment of spatial brain resources during a canonical spatial task (MRT), figural creativity scores were entered as a parametric regressor in a whole-brain analyses to identify increased and/or decreased activity (within the results of the MRT Rotation True > Control contrast) associated with figural creativity score. Four clusters emerged at the whole-brain level, where figural creativity performance was associated with increased activity. These were located in right premotor cortex, right superior parietal cortex (two clusters), and left visual cortex (Figure 3; Table 2). Figural creativity performance was not significantly associated with any decreases in functional activation.

Discussion

The objective of the present study was to test whether differences in functional activation in spatial cognition-implicated brain regions (premotor and superior parietal cortex) during mental rotation were associated with differences in figural creativity in a composite object creation task. Results demonstrated that greater figural creativity was associated with increased activity during mental rotation in both right premotor cortex and right superior parietal cortex. Drawing on prior causal evidence linking neural activity during mental rotation to separate cognitive processes (Cona et al., 2017; Harris & Miniussi, 2003; Lamm et al., 2007; Milivojevic et al., 2009; Sack et al., 2008; Wise et al., 1997; Wraga et al., 2005; Zacks, 2008), these findings suggest that individual differences in functional activation within the superior parietal cortex (which putatively supports *abstract spatial representation*) and the premotor cortex (which putatively supports *active spatial manipulation*) are correlated with individual differences in figural creative ability. In addition, results showed an association of figural creativity with increased activity in the visual cortex during mental rotation. As we did not have

Table 1. Clusters of activity during mental rotation (Rotation True > Control contrast).

Hemisphere	Region	BA	Cluster size	Z-score	MNI X	MNI Y	MNI Z
Left	Superior Parietal Cortex	7	1464	5.43	−10	−64	62
Left	Premotor Cortex	6	857	5.83	−26	−4	64
Right	Superior Parietal Cortex	7	654	5.11	14	−64	60
Right	Premotor Cortex	6	536	5.81	24	−6	64

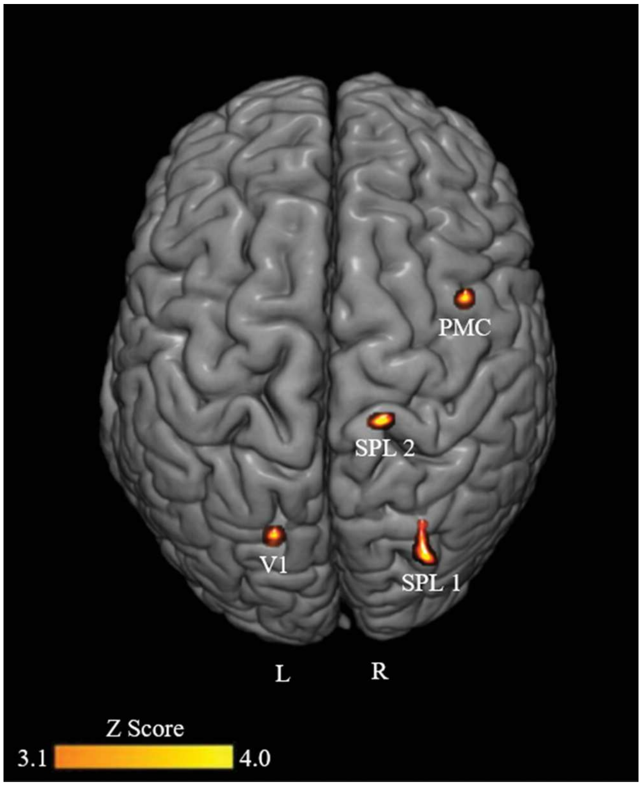

Figure 3. Brain activity during mental rotation associated with figural creativity performance.

Table 2. Clusters of activity during mental rotation associated with figural creativity performance.

						MNI		
Label	Hemisphere	Region	BA	Cluster size	Z-score	X	Y	Z
SPL 1	Right	Superior Parietal Cortex	7	31	3.7	30	−78	48
V1	Left	Visual Cortex (V1)	17	26	3.96	−18	−72	10
SPL 2	Right	Superior Parietal Cortex	5	22	4.00	16	−36	46
PMC	Right	Premotor Cortex	6	20	3.72	42	2	30

a priori hypotheses concerning the relationship between functional activation in visual cortex during MRT and figural creativity, future research should be conducted before interpreting this relationship. It should be noted that no causal conclusions can be made based on the results of the present analyses.

The brain regions that demonstrated associations between MRT-related activity and creative performance were also observed in the one previous fMRI study of figural creativity (Aziz-Zadeh et al., 2013). This provides a reasonable indication that the regions in which individual differences during MRT are associated with creativity on the composite object creation task are engaged during composite object creation. This suggests that more original figures may involve increased rotation and manipulation.

At the behavioral level, no relationship was observed between MRT performance and performance on the composite object creation task. The composite object creation task proceeds from visually inspecting the individual objects to considering how the featural properties, orientations, and positions of those objects could relate to each other, mentally resizing and reorienting objects in relation to each other to yield composite objects, and comparatively evaluating alternative composite objects. While the demands of this task are thus likely to draw on spatial resources that are engaged during MRT, these demands are also different in several respects from the demands of MRT, including differences of kind, number, and complexity. In the composite object creation task, instructions emphasize novelty and unusualness, which is not the case for MRT. In MRT, resizing objects is not possible, and there is only one axis of rotation to consider rather than all possible axes. Critically, whereas MRT involves the rotation of isolated objects, the composite object creation task focuses on relations between multiple objects (i.e., how manipulating the objects leads to different ways of relating them to each other in space). With respect to outcome measures of performance, MRT is not evaluated for creativity and the composite object creation task is only evaluated for creativity rather than extent of mental rotation. Therefore, the cognitive processes that may be shared between the two tasks are nonetheless likely to be deployed somewhat differently for the differing task demands, and individual differences in brain activity related to these processes may be differently reflected in the outcome measures of performance in the two tasks. It is thus perhaps not especially surprising that MRT performance did not predict figural creativity even if individual differences in brain activity during MRT were correlated with figural creativity. By analogy, measuring leg muscle function during jumps when athletes are playing a basketball game might reveal characteristics of jump-related leg muscle function that predict individual differences in ballet dancing ability. This would not, however, imply that the athletes who score the most points in the basketball game, or even the ones who jump the highest, are necessarily the best dancers. A main limitation of this study is that it did not include other prominent measures of creativity (e.g. Alternative Uses Test, Torrance Test of Creative Thinking), which may have shed insight on the reasons for the lack of correlation observed between MRT figural creativity scores.

Another important limitation of this study is that fMRI data was not collected during the object creation task, so individual differences in brain activity during MRT cannot be related to differences in brain activity during figural creativity. Future work examining the neural overlap between these tasks might fruitfully apply representational similarity analyses to examine the nature of similarities and differences in the ways these tasks are processed, and potentially identify where similarities between the tasks are related to figural creativity performance. Another worthwhile future direction would be to compare the structural and functional neural correlates of figural creativity to creativity in the verbal domain, and particularly whether verbal vs. figural creativity show differential relationships to individual differences in the spatial brain. Additionally, it is important to note that, because the present study only considered neural activity during MRT, creative performance could only be correlated to activity that subserves spatial cognition. Therefore, the present results should not be taken to suggest that other brain regions are not important for figural creativity. Indeed, there is substantial evidence that creativity involves diverse sets of neural regions and processes, including frontopolar activity associated with creative relational integration (Abraham et al., 2012; Brunyé et al., 2015; de Souza et al., 2010; Green, Cohen, Raab, Yedibalian, & Gray, 2015; Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010, 2012; Green et al., 2016), and the involvement of the default mode and executive control networks in verbal divergent creativity (Beaty, Benedek, Barry Kaufman, & Silvia, 2015; Beaty et al., 2016, 2014, 2018). Further investigation into figural creativity should seek to understand how individual differences in the function of spatial cognition-implicated brain regions might bear on the broader choreography of creativity-related networks.

Disclosure statement

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