

Gender differences in creative thinking: behavioral and fMRI findings

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Abstract Gender differences in creativity have been widely studied in behavioral investigations, but this topic has rarely been the focus of neuroscientific research. The current paper presents follow-up analyses of a previous fMRI study (Abraham et al., *Neuropsychologia* 50(8):1906–1917, 2012b), in which behavioral and brain function during creative conceptual expansion as well as general divergent thinking were explored. Here, we focus on gender differences within the same sample. Conceptual expansion was assessed with the alternate uses task relative to the object location task, whereas divergent thinking was assessed in terms of responses across both the alternate uses and object location tasks relative to n-back working memory tasks. While men and women were indistinguishable in terms of behavioral performance across all tasks, the pattern of brain activity while engaged in the tasks in question was indicative of strategy differences between the genders. Brain areas related to semantic cognition, rule learning and decision making were preferentially engaged in men during conceptual expansion, whereas women displayed higher activity in regions related to speech processing and social perception. During divergent thinking, declarative memory related regions were strongly activated in men, while regions involved in theory of mind and self-referential processing were more engaged in women. The implications of gender differences in adopted strategies or cognitive style when faced with generative tasks are discussed.

Keywords Sex differences · Creative cognition · Neuroimaging · Semantic cognition · Divergent thinking · Cognitive style · Cognitive strategy · Conceptual expansion

Introduction

Creative thinking is synonymous with the capacity to generate new ideas, devise novel solutions, or express oneself in a unique manner Abraham (2013). Although the potential to be creative exists within everyone, individuals differ a great deal with regard to actual creative output over their lifetimes. Empirical investigations of creativity routinely seek to identify variables that have an impact on creative performance. Gender differences in creative thinking is one avenue that has been intensively explored in behavioral studies, but has rarely been the subject of neuroscientific investigations.

Behavioral studies on gender differences in creative potential have been inconclusive thus far with half the investigations reporting no significant differences while the other half are characterized by mixed findings that, on average, favor females (for a review, see Pagnani 2011). This may be attributable to the fact that most of the tasks were not designed to distinguish between different cognitive processes underlying creativity. Overall, this suggests that gender cannot be considered a singular factor that significantly contributes to individual differences in creative potential. What is undoubtedly noteworthy though is the continued dominance of men over women in the degree of associated creative accomplishment or eminence across different professions from politics and commerce to the arts and sciences. This dissociation between creative potential and creative accomplishment with regard to gender has been attributed to socio-cultural and environmental factors, such as gender inequality in society and differing levels of social support accorded to each gender (Baer and Kaufman 2008; Pagnani 2011; Runco et al. 2010).

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Neuroscientific investigations on gender differences in creative thinking are rare. No neuroimaging studies have been reported on this topic so far, and only one published EEG study has directly addressed this issue (Razumnikova 2004), the results of which indicated differences in hemispheric organization between men and women during creative thinking. The past decade has witnessed a surge of interest in gender differences in terms of brain structure and function (Cahill 2006; Gong et al. 2011; McCarthy et al. 2012). Structural brain differences (after adjusting for differences in brain size) include greater cortical thickness in anterior temporal and orbitofrontal areas in men, and greater cortical convolution and complexity across the neocortex in women (Luders and Toga 2010). Functional gender-dependant brain differences have been widely explored in the field of emotion, where enhanced left amygdala activity is demonstrated in response to negative emotion in women but positive emotion in men (Stevens and Hamann 2012). As such gender-based brain differences are no longer considered to be trivial, we sought to investigate the impact of gender on creative thinking in terms of behavioral responses as well as brain activity.

This investigation constitutes an extension of a previously reported study (Abraham et al. 2012b) where creative conceptual expansion was assessed in healthy male and female volunteers. Conceptual expansion is an operation that is particularly critical when formulating new ideas and refers to the ability to widen the conceptual boundaries of acquired concepts to include novel elements (Ward 1994). This process is assessed in the alternate uses task, a widely employed task of creative thinking (Abraham and Windmann 2007; Wallach and Kogan 1965), where participants are required to generate multiple uses for common objects, (e.g., shoe). The originality of any response is assessed by the infrequency or uniqueness of the generated use. To take the example of a shoe, a highly unusual or original response would be to use a shoe as an ashtray. So here the concept of a shoe has been vitally expanded beyond the customary use of foot protection.

Abraham et al. (2012b) distinguished between brain regions that are activated as a function of creative conceptual expansion as opposed to those that are generally involved in divergent thought (thinking in an open-ended manner). The brain regions which were activated as a function of greater conceptual expansion were uncovered by contrasting participants' performances when carrying out a highly demanding divergent thinking task (like the alternate uses task) that necessitates conceptual expansion, relative to an undemanding divergent thinking task which does not, such as an object location task where participants are required to report objects that are commonly found in a particular location (e.g., office).

Both are divergent tasks in that they involve open-ended responses. But the divergent thought processes in the alternate uses task necessitate the expansion of one's conceptual structures as novel associations have to be forged between

unrelated concepts (e.g., shoe as an ashtray). This is not so in the object-location task as it merely involves generating generic associations to concepts (e.g., office: desk, chair).

In order to control for differences in cognitive demand between both the divergent thinking tasks that are problematic when interpreting within-group findings associated with creative thinking, Abraham et al. (2012b) included n-back tasks as control tasks¹. The n-back is a well-established paradigm in the investigation of working memory, which refers to the capacity to actively monitor and manipulate information in the mind in service of a goal (for a recent review, see Baddeley 2012). Comparison of the divergent thinking tasks to n-back tasks allowed for the characterization of the brain response during open-ended or divergent thinking relative to cognitively demanding non-divergent control tasks.

Given the absence of previous work on the neurocognition of gender differences in creative thinking, the present study is necessarily explorative in nature. The goal of this study was to explore the brain basis of gender differences in creativity in order to build a repository of information from which future data-driven hypotheses can be formulated about the basis of potential differences between men and women in creative thinking. The objectives of this investigation are two-fold. The first is to assess the effect of gender differences on behavioral performance across tasks that differ with regard to the involved cognitive processes, i.e. creative conceptual expansion as opposed to thinking in a divergent manner. The second is to assess the impact of gender differences on brain activity in two contrasts that assess creative conceptual expansion and general divergent thinking. The former contrast specifically assesses brain activity associated with creative thinking, whereas the latter contrast assesses brain activation associated with thinking in an open-ended or divergent manner.

Abraham et al. (2012b) reported that creative conceptual expansion was associated with activity in brain regions such as the left anterior inferior frontal gyrus, lateral frontopolar cortex and temporal pole, which are known to play a critical role in the retention, retrieval and integration of semantic information. Divergent thinking was associated with activation in these and other structures that are relevant for declarative memory, language processing, hypothetical reasoning, and evaluative judgement, such as the hippocampal formation, amygdala, posterior cingulate cortex, medial prefrontal cortex and angular gyrus.

The current investigation will explore whether differences as a function of gender, if any, will arise within the same network of brain regions in question (quantitative differences)

¹ Please refer to Abraham et al. (2012b) for a details regarding the rationale behind the original paradigm where inclusive masked contrasts were carried out in the within-subjects analyses. As the male and female groups in the current sample performed comparably on all behavioral measures during the fMRI session, direct between-group comparisons were carried out for all relevant contrasts.

or whether previously uninvolved areas would be recruited (qualitative differences).

Materials and methods

Participants

The final sample included 28² right-handed healthy social science undergraduates (14 female; Mean±SD age: 22.79±3.17; mean laterality index: 0.88). All were native German speakers with no reported history of neurological or psychiatric illness and none were taking medication at the time of measurement. All gave informed consent before participation and received either payment (EUR 20) or course credits for their participation. The experimental standards of the study were approved by the Ethics Commission of the German Psychological Society (DGPs).

The participants were divided into two groups based on gender (Table 1). Both groups were matched on the handedness index ($t_{26}=1.385, p=.18$) and on the vocabulary scale of the Hamburg Wechsler Intelligence Test for Adults ($t_{26}=0.71, p=.49$). There was a significant difference between the groups in terms of age ($t_{26}=2.47, p=.024$). The differing age range across groups (male age range: 19–30, female age range: 20–25) is likely to have contributed to this difference.

Experimental design

The MRI session followed a behavioral practice session on a laptop where subjects familiarized themselves with experimental set-up and trial events, and were given a few examples of each trial type. The fMRI experimental design and procedure was identical to that reported in Abraham et al. (2012b) (please see Fig. 1 for details). A 2×2 design was employed with Task (divergent, control) and Cognitive Demand (high, low) as the factors. The experiment included 20 trials per condition and 8 resting baseline trials. All stimuli were presented visually in a pseudo-randomised order³. With a trial length of 25 s and total of 88 trials, the fMRI Session lasted approximately 38 min. The participants responded via a

² The sample size in the current analyses is larger than that of Abraham et al. (2012b) as all participants who performed above chance on the control tasks and registered movement less than 3 mm were included in the present sample. The same brain regions that were involved in all the within-group contrasts ($n=19$) as reported in Abraham et al. (2012b) were also found engaged in the within-group contrasts using the present sample ($n=28$).

³ The word “pseudo-randomized” here means that strict control was exerted over the randomization rules such that (a) all trial transition types were presented equally often, (b) the presentation of trial types was balanced throughout the experiment, etc. In this way, the randomizations of the trial order was consistent and comparable across all participants.

Table 1 Descriptive data (mean, standard deviation) for the behavioral measures (ConH convergent-high 2-back task, ConL convergent-low 1-back task, DivH divergent-high alternate uses task, DivL divergent-low object location task, FB Feedback Session, HAWIE Hamburg Wechsler Intelligence Test for Adults)

	Males ($n=14$)		Females ($n=14$)	
	Mean	SD	Mean	SD
Age *	24.14	3.76	21.43	1.65
Handedness Index	0.85	0.14	0.91	0.09
HAWIE Vocabulary Scale	12.36	1.82	11.79	2.42
DivH - Mean Originality	10.31	1.62	10.62	2.07
ConH - Response Accuracy %	76.88	10.49	81.07	7.12
ConL - Response Accuracy %	98.17	2.07	97.77	2.13
DivH - Mean responses/trial	4.16	1.02	4.20	1.27
DivL - Mean responses/trial	7.45	1.82	9.10	2.68
ConH - Mean responses/trial	3.84	0.59	4.13	0.65
ConL - Mean responses/trial	8.04	0.21	8.04	0.11
DivH - Mean responses/trial (FB)	3.87	1.27	3.62	0.96
DivL - Mean responses/trial (FB) *	6.67	1.43	8.18	2.27
DivH - Difficulty Rating	3.93	1.49	3.57	1.45
DivL - Difficulty Rating	5.64	1.01	5.57	1.34
ConH - Difficulty Rating	2.21	1.05	1.93	0.83
ConL - Difficulty Rating	5.71	0.91	5.57	1.02

*Significant group difference ($P<.05$)

button press in the scanner every time they generated a new use in the alternate uses task (DivH: divergent-high) or a new object in the object location task (DivL: divergent-low) or indicated a hit in the case of the 2-back (Con-H: convergent-high) or 1-back tasks (Con-L: convergent-low). They verbally reported the uses and objects they generated during a post-fMRI Feedback Session. Participants also completed a difficulty rating scale during the feedback session to indicate the

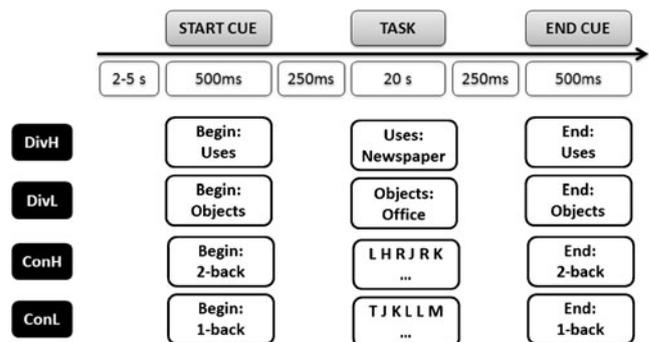


Fig. 1 Each trial began with a jittered pause (blank screen) of 2–5 s, followed by a “Start Cue” which indicated the commencement of the experimental task. The cue “Uses” correspond to the alternate uses task (DivH), “Objects” to the object-location task (DivL), “2-back” to the 2-back task (ConH), and “1-back” to the 1-back task (ConL). Following a brief pause (250 ms), the experimental task was presented during which the participants responded using a button press. After another brief pause (250 ms), the “End Cue” was presented to indicate the end of the trial

level of task difficulty they experienced during each of the tasks (1: extremely difficult to 7: extremely easy). To obtain an index of intellectual ability, all participants completed the vocabulary scale of the Hamburg Wechsler Intelligence Test for Adults (HAWIE; Tewes 1994).

Experimental tasks

- (a) **Divergent-high (DivH):** The Alternate Uses task was employed here and each trial began with the trial start cue “Start Uses”, followed by the task cue “Uses → Object” and ended with the trial end cue “End Uses”. The task cue indicated for which particular object different uses need to be generated in that trial (e.g., Uses → Shoe). Participants pressed a response key as soon as they generated a new use. The recorded measures included the average number of uses generated per trial (fluency) in the fMRI Experimental Session and in the post-fMRI Feedback Session, as well as the average degree of originality of the uses. Each generated use is assigned an originality index, which is inversely proportional to the number of subjects who generated that use. The higher the number of participants who generated a particular use, the lower the originality index associated with that use.
- (b) **Divergent-low (DivL):** The Object-Location task was employed and each trial began with the trial start cue “Start Objects”, was followed the by the task cue, and ended with the trial end cue “End Objects”. The task cue indicated for which particular location different objects would have to be generated (e.g., Objects → Office). Participants pressed a response key as soon as they generated a new object. The recorded measures included the average number of objects generated per trial (fluency) in the fMRI Experimental Session and in the post-fMRI Feedback Session.
- (c) **Control-high (ConH):** The 2-back task was employed and each trial began with the trial start cue “Start 2-back” and ended with the trial end cue “End 2-back”. The trial start cue was followed by presentation of single letters over the entire duration of the trial. Participants pressed the response button every time the current letter was the same as the one presented 2 letters before. The recorded measures included the average number of responses per trial and the percentage of correct responses.
- (d) **Control-low (ConL):** The 1-back task was employed and each trial began with the trial start cue “Start 1-back” and ended with the trial end cue “End 1-back”. The trial start cue was followed by presentation of single letters over the entire duration of the trial. Participants pressed the response button every time the current letter was the same as the one presented 1 letter before. The recorded measures included the average number of responses per trial and the percentage of correct responses.

MRI scanning procedure & fMRI data analysis

The MRI procedure was identical to that reported in Abraham et al. (2012b). Functional and anatomical imaging was carried out using a 1.5 Tesla whole-body tomography system (Siemens Symphony) with a standard head coil. Participants lay in a supine position in the MRI scanner with their right index finger positioned on the response button of a response box. The participants’ hands were stabilized and form-fitting cushions were employed to prevent head, arm and hand movements. Ear plugs were also provided to attenuate the scanner noise. The stimuli were visually projected onto a screen at the end of the scanner (visual field = 18°) using an LCD projector (EPSON EMP-7250). They were viewed by participants through a mirror mounted on the head coil. Presentation software (www.neurobs.com) was used to present the stimuli (resolution: 800×600).

The structural image acquisition consisted of 160 T1-weighted sagittal images (MPRAGE, 1 mm slice thickness). One run of functional imaging was carried out with a total of 902 volumes which were recorded using a T2*-weighted gradient echo-planar imaging sequence (EPI) with 25 slices covering the whole brain (slice thickness=5 mm; gap=1 mm; descending slice order; TA=100 ms; TE=55 ms; TR=2.5 s; flip angle=90°; field of view =192 mm×192 mm; matrix size=64×64). The orientation of the axial slices was tilted to parallel the OFC tissue–bone transition to keep susceptibility artefacts to a minimum.

The fMRI data were processed using the LIPSIA software package (Lohmann et al. 2001)⁴. This freeware contains tools for preprocessing, registration, statistical evaluation and presentation of fMRI data. Functional data were first motion-corrected using a matching metric based on linear correlation. To correct for the temporal offset between the slices acquired in one scan, a sinc-interpolation based on the Nyquist–Shannon–Theorem was applied. Low frequency signal changes and baseline drifts were removed using a temporal high pass filter with a cut-off frequency of 1/150 Hz. Spatial smoothing was performed with a Gaussian filter of 8 mm FWHM. The functional data were registered to the anatomical data via a rigid linear registration with 6° of freedom (3 rotational, 3 translational) and were then normalized to the Talairach standard space. The normalized parameters were then used to transform the functional slices using trilinear interpolation, generating output data with a spatial resolution of 3 mm×3 mm×3 mm (voxel size: 27 cubic mm).

The statistical evaluation was based on a least-squares estimation using the general linear model for serially autocorrelated observations (Friston et al. 1995; Worsley and Friston 1995). The design matrix used for modelling the data consisted of onset

⁴ <http://www.cbs.mpg.de/institute/software/lipsia/index.html>

vectors for each of the four experimental conditions with an additional onset vector for baseline trials. The design matrix was generated with a box-car function, convolved with the hemodynamic response function. Brain activations were analyzed in an event-related design, time-locked to 1 s before the responses. The model equation, including the observation data, the design matrix, and the error term, was convolved with a Gaussian kernel dispersion of 4 s FWHM to account for the temporal autocorrelation (Worsley & Friston 1995).

The single-subject contrast images were entered into a second-level Bayesian statistical analysis for each of the contrasts (Neumann and Lohmann 2003). The parameter estimates obtained from the general linear model for single subjects are used to calculate posterior probability maps and maps of the effect size for the contrasts of interest. This Bayesian statistical method is more robust against outliers in comparison to conventional analyses based on *t* statistics as the influence of individual subjects on group statistics is weighted by the within-subject variability. As this technique has been shown to be highly reliable when applied to different groups of subjects (Thirion et al. 2007), it has been commonly employed in studies where between-group comparisons are the focus (e.g., Abraham et al. 2012a; Albrecht et al. 2011; Klein et al. 2007). It provides estimates for, not only the size of an effect of interest, but also the probability for that effect to occur in the population. It also overcomes some of the common problems of null hypothesis significance tests such as the need to correct for multiple comparisons (Neumann and Lohmann 2003). The output of the Bayesian second-level analysis is a probability map which shows the probability that the contrast is greater than zero.

Group differences on the basis of gender were carried out using Bayesian analyses. The Bayesian second-level probability maps for the two groups were used as the input. The output of this between-groups analysis is a probability map which shows the probability for that particular contrast to be larger in one group relative to the other group. Group differences were analyzed for the following contrasts: (a) Conceptual expansion: Divergent-High (DivH) > Divergent-Low (DivL), (b) Divergent thinking : Divergent (DivH & DivL) > Control (ConH & ConL). For the contrasts related to each group, inclusive masks were employed to limit the regions of activation to those specific to that gender. So, for instance, in the female > male between-subjects contrast of DivH > DivL, the female within-group contrast (female: DivH > DivL) was used as an inclusive mask, whereas in the male > female between-subjects contrast of DivH > DivL, the male within-group contrast (male: DivH > DivL) was used as an inclusive mask.

There are no standard “thresholds” that indicate the significance of a result within the framework of Bayesian statistics⁵. As values of over 99 % are held to indicate a high

probability of activation, a significance threshold of 99.5 % was applied in the current study with a minimum cluster size of more than 10 voxels (270 cubic mm).

Results

Behavioral findings

Descriptive data (Mean, Standard Deviation) across groups are indicated for all behavioral variables in Table 1. A MANOVA revealed no significant gender differences in the degree of originality within the DivH alternate uses task ($F_{1,26}=0.20$, $p=.66$), response accuracy on the ConH 2-back task ($F_{1,26}=1.53$, $p=.23$), or response accuracy on the ConL 1-back task ($F_{1,26}=0.26$, $p=.62$). This signifies that men and women demonstrated comparable behavioral performance across all four conditions.

In addition, no significant gender differences were found in repeated measures analyses (Task type, Cognitive demand, Group) of the mean number of responses generated per trial during the experiment within the DivH alternate uses task ($F_{1,26}=0.01$, $p=.94$), DivL object location task ($F_{1,26}=3.64$, $p=.07$), ConH 2-back task ($F_{1,26}=1.49$, $p=.23$), or ConL 1-back task ($F_{1,26}=0.01$, $p=.91$). While men and women were undifferentiated in the numbers of uses they reported in the post-fMRI feedback session for the DivH alternate uses task ($F_{1,26}=0.35$, $p=.56$), women were more successful than men at remembering and reporting objects in the post-fMRI feedback session for the DivL object-location task ($F_{1,26}=4.44$, $p=.045$, $h_2p=0.15$).

A repeated measures ANOVA (Task type, Cognitive demand, Group) on the difficulty ratings revealed no significant main effect for Group ($F_{1,26}=1.29$, $p=.48$) nor significant group-related interaction effects (all $F_{1,26}<0.32$, all $p>.57$). So men and women were not distinguishable in terms of the task difficulty they experienced during each of the tasks.

All in all, the behavioral findings suggest comparable performance between men and women in virtually all variables. Women only displayed an advantage compared to men in reporting more generated objects for the DivL object location task during the post-fMRI feedback session.

fMRI findings

Conceptual expansion (contrast: DivH alternate uses task > DivL object location task)

Comparing the brain activity elicited by men and women when engaged in conceptual expansion revealed predominantly left hemisphere activity for both genders, but in different regions of the brain (Table 2, Fig. 2). Men displayed significantly stronger activity in areas such as the left inferior

⁵ <http://static.cbs.mpg.de/lipsia/vbays/index.html>

Table 2 Gender differences during creative conceptual expansion (contrast: DivH alternate uses task > DivL object location task)

Area	x	y	z	BA	mm3	Prob
MALES > FEMALES : Conceptual Expansion						
Middle/inferior frontal gyrus (anterior)	-44	40	0	10, 47	918	99.77
Orbitofrontal cortex	-23	28	-12	11	594	99.84
Inferior frontal gyrus (posterior)	-41	1	21	44, 6, 8	2457	99.93
Middle/inferior temporal gyrus (posterior)	-50	-65	9	37	2673	99.90
Inferior parietal lobule	-29	-41	39		837	99.84
Postcentral gyrus	-41	-29	36		1431	99.84
Fusiform gyrus	-39	-44	-9	37	486	99.78
Cuneus	25	-92	3	18	2511	99.85
FEMALES > MALES: Conceptual Expansion						
Superior temporal gyrus (anterior)	-53	2	3	22	945	99.88
Superior temporal gyrus (posterior)	-50	-49	27	40	756	99.82
Middle temporal gyrus (mid)	-53	-46	0	21	999	99.84
Superior parietal lobule	-38	-70	45	7	378	99.76

Anatomical area specification, Talairach coordinates, mean probability (Prob) and volume (mm³) of the significantly activated areas. The minimum threshold was set at 99.5 % probability (Bayesian) with a minimum cluster size more than 10 voxels (270 cubic mm)

frontal gyrus, orbitofrontal cortex and inferior parietal lobule compared to women. Women, on the other hand, activated regions such as the anterior and posterior superior temporal gyrus, as well as the superior parietal lobule, more strongly than men.

Divergent thinking (contrast: DivH and DivL tasks > ConH and ConL n-back tasks)

Assessing gender differences in divergent thinking revealed a strikingly different network of regions engaged for men and women relative to one another (Table 3, Fig. 3). Men demonstrated stronger activity in brain areas such as the hippocampal formation, amygdala, retrosplenial cortex, orbitofrontal cortex, and the inferior frontal gyrus. Women activated brain regions in the dorsal and ventral medial prefrontal cortex, temporal poles, temporoparietal junction, and the posterior cingulate.

General discussion

The objective of the present fMRI study was to assess gender differences in creative thinking. This was implemented by conducting follow-up analyses on the data reported by Abraham et al. (2012b) where the brain correlates of creative conceptual expansion – as opposed to general divergent thinking, working memory or cognitive load – was assessed. Gender differences were explored in the present paper with reference to creative conceptual expansion and general divergent thinking.

Conceptual expansion

Gender differences in conceptual expansion was first assessed in terms of behavioral performance on the alternate uses task. The findings revealed that men and women were undifferentiated in terms of the degree of originality associated with the

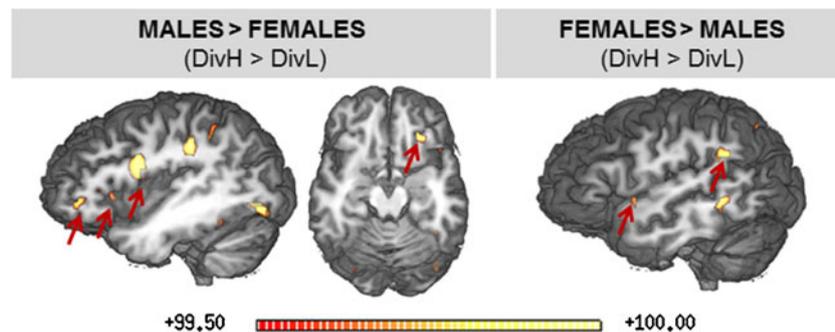


Fig. 2 Conceptual expansion: Gender differences in the brain regions activated as a function of conceptual expansion (DivH alternate uses divergent-high task > DivL object location divergent-low task) include the anterior, mid and posterior regions along the left inferior frontal gyrus

(left image) as well as the orbitofrontal cortex in men (middle image), in contrast to regions along the left anterior and posterior superior temporal gyrus in women (right image)

Table 3 Gender differences during divergent thinking (contrast: DivH alternate uses task and DivL object location task > ConH 2-back and ConL 1-back tasks)

Area	x	y	z	BA	mm3	Prob
MALES > FEMALES : Divergent Thinking						
Orbitofrontal cortex	7	37	-12	11	702	99.90
Angular gyrus, inferior parietal lobule	-38	-65	36	39	3537	99.93
Hippocampal formation, Amygdala	31	-15	-15		l.m.	100
Hippocampal formation, Amygdala	-26	-38	-3		l.m.	100
Retrosplenial cortex (bilateral)	-8	-47	9	29, 30	l.m.	100
Precuneus, Posterior Cingulate	-11	-41	39	7, 31	2349	99.90
Inferior frontal gyrus, orbitofrontal cortex	-35	25	-12	45, 47, 11	15444	99.95
Inferior/Middle frontal gyri	31	34	-12	47, 11	2349	99.92
Inferior frontal sulcus	-41	4	21	6	459	99.85
Insula (posterior)	40	-14	21		1863	99.83
Cingulate Gyrus (caudal)	1	-2	27	24	2484	99.84
Precentral gyrus	-23	-26	54	4	2619	99.87
Cerebellum, Fusiform & Middle occipital gyri	28	-77	-15	18, 19	63099	99.93
Insula (posterior)	-32	-17	15		l.m.	100
Superior& Middle temporal gyri	-50	-32	3	21, 22	l.m.	100
Superior& Middle temporal gyri	-53	-56	6	37, 39	l.m.	100
Fusiform and Middle occipital gyri	-20	-80	-6	18, 19	1215	99.91
FEMALES>MALES: Divergent Thinking						
Dorsal medial prefrontal cortex (posterior)	1	23	54	8	5670	99.90
Dorsal & ventral medial prefrontal cortex	-5	47	12	10, 9, 24, 32	20493	99.93
Posterior Cingulate	-11	-55	33	31	2673	99.94
Temporoparietal junction	-53	-58	21	39	5967	99.96
Cerebellum	-26	-40	-24		69012	99.94
Temporal Pole	-38	23	-21	38	l.m.	100
Middle & Inferior temporal gyrus (anterior)	52	-13	-21	20, 21	351	99.88
Insula (anterior)	-29	8	18		2457	99.85
Cuneus	7	-94	33	19	1485	99.88
Caudate Nucleus	-14	-25	20		945	99.80
Thalamus	-5	-25	3		810	99.89
Lingual & Fusiform Gyrus	31	-58	-3		351	99.81
Globus Pallidus	-14	2	-3		513	99.90
Cerebellum	1	-64	-39		567	99.76

Anatomical area specification, Talairach coordinates, mean probability (Prob) and volume (mm3) of the significantly activated areas (l.m.: local maxima within each volume). The minimum threshold was set at 99.5 % probability (Bayesian) with a minimum cluster size more than 10 voxels (270 cubic mm)

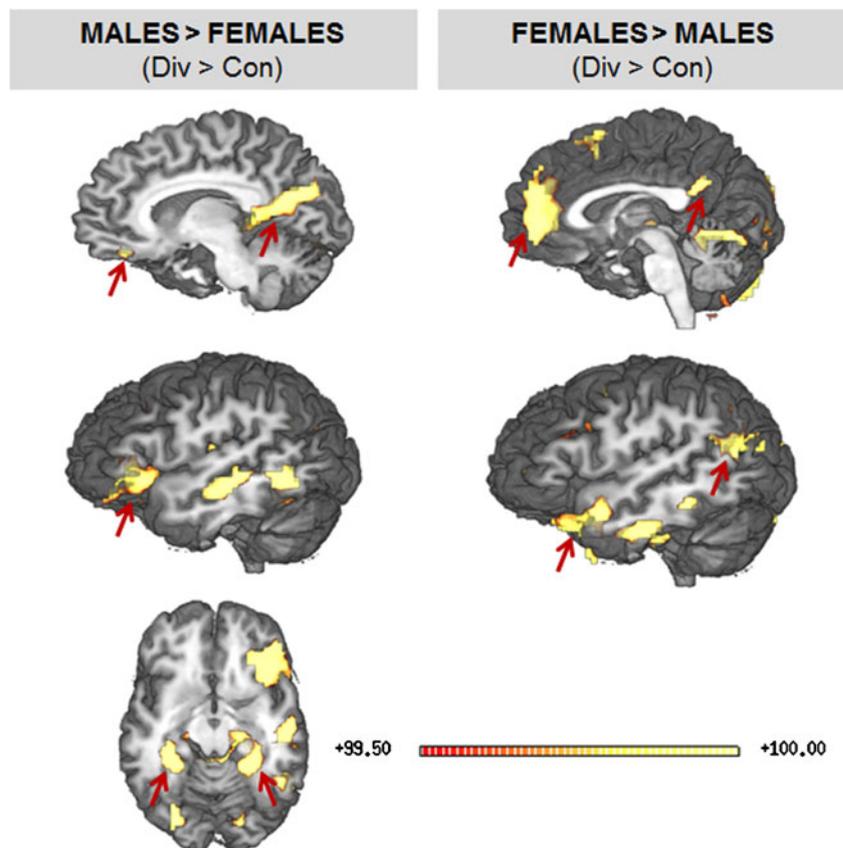
generated uses, as well as the degree of fluency or the number of uses generated while engaged in the alternate uses task. These findings fit with the large body of behavioral research that indicates no ostensible gender differences in creative performance (Baer and Kaufman 2008; Pagnani 2011).

McCarthy et al. (2012) recently proposed that gender differences in cognition and behavior may not necessarily be instantiated in actual behavioral output, but may instead be observed in terms of employed strategy differences when performing a task. This striking observation was made in the context of gender differences in rats when the animals were faced with a spatial learning problem (McCarthy et al. 2012). Potential gender-specific strategy differences have also been proposed to explain gender differences in other aspects of cognition, behavior and brain function (e.g., Hugdahl et al.

2006; Jordan and Wüstenberg 2010; Lipp et al. 2012; Moriguchi et al. 2013). For instance, on basis of the pattern of brain activation differences during affective experiences, Moriguchi et al. (2013) proposed that women are more self-focused whereas men are more world-focused. Hugdahl et al. (2006) differentially classified women as adopting a serial, categorical processing approach during mental rotation while men adopt a coordinate processing approach.

Children's drawing behavior, a field which is highly relevant to creativity, has also been discussed in terms of gender-based strategy differences. A study of 5–6 year old children in the motifs they generated during free drawings showed stark gender differences (Iijima et al. 2001). Boys (96.4 %) drew moving objects such as vehicles, trains and aircraft significantly more often than girls (4.6 %), whereas

Fig. 3 Divergent thinking: Gender differences in the brain regions activated as a function of divergent thinking (Div: Divergent alternate uses and object location tasks > Con: Control 2-back and 1-back tasks). In men (*left panel*), these brain regions include orbitofrontal cortex and retrosplenial cortex (*top image*), inferior frontal gyrus (*middle image*), hippocampal formation and amygdala (*bottom image*). In women (*right panel*), these brain regions include the dorsal and ventral medial prefrontal cortex as well as the posterior cingulate (*top image*), alongside the temporal pole and temporoparietal junction (*bottom image*)



girls drew persons (96.6 %) and flowers (57 %) more than boys (26.5 % and 7.2 % respectively). Evidence that these strategies are likely to be biologically determined come from comparing drawings generated by unaffected boys and girls to drawings generated by girls with congenital adrenal hyperplasia (CAH). CAH is a genetic disorder that is marked by an overproduction of adrenal androgen. Girls with CAH customarily exhibit masculine-typical play behavior and play with boy-preferred toys (Jordan-Young 2012). CAH girls have been reported to have smaller amygdalae than controls (Giedd et al. 2006) and are found to activate the amygdala more than control females, but not more than control males, during a face viewing task (Ernst et al. 2007). Iijima and colleagues found that drawings by CAH girls contained significantly more masculine characteristics compared to those of unaffected girls, and were not significantly differentiable from drawings of unaffected boys (Iijima et al. 2001). Such findings speak for biologically determined gender-based strategy differences when engaged in generative tasks.

It is therefore possible that, within the current study, although men and women exhibit ostensibly undifferentiated performance on behavioral measures of creativity, they may have employed different strategies when performing the same task. One means to uncover potential strategy differences

would be to study gender differences in brain activity during creative thinking.

When assessing the patterns of brain activity in men versus women when engaged in creative conceptual expansion during the alternate uses task compared to the object location task, it was found that both genders preferentially engaged different brain regions within the left hemisphere. Among others, brain areas along the anterior and posterior extents of the inferior frontal gyrus, lateral orbitofrontal cortex, and posterior middle/inferior temporal gyrus were more strongly engaged in men compared to women. These findings suggest that when expanding boundaries of acquired concepts with the objective of generating novel uses for common objects, men preferentially activated brain networks associated with semantic memory operations (Binder and Desai 2011), rule learning (Bunge 2004) and outcome-based decision making (Rudebeck and Murray 2011), more than women.

In contrast, no frontal lobe regions were selectively more activated in women relative to men when engaged in conceptual expansion. The brain activity associated with women was largely limited to the anterior and posterior regions in the superior temporal gyrus. Superior temporal regions have been associated with a range of functions particularly in relation to spoken language production and comprehension (Price 2010). Anterior superior temporal regions are held to be involved in

speech processing, whereas cognitive operations related to theory of mind, social cue perception (faces, biological motion) and audio-visual comprehension engage posterior superior temporal regions (Hein and Knight 2008).

So, in summary, while men preferentially engaged brain areas related to semantic cognition, rule learning and decision making during conceptual expansion, women preferentially engaged brain regions related to speech processing and social perception instead.

As some of these regions (e.g., inferior frontal and temporal lobe structures in men) were implicated in neural correlates of conceptual expansion across genders (Abraham et al. 2012b), the preferential engagement of these regions in men relative to women implicate quantitative differences in brain activity. However, as brain structures that were previously unrelated to conceptual expansion (e.g., orbitofrontal cortex in men, superior temporal regions in women) were more strongly engaged for either gender, there were also qualitative differences in the brain structures recruited during conceptual expansion as a function of gender.

Divergent thinking

Gender differences were then assessed with regard to divergent or open ended thinking in general relative to the control tasks. Creative thinking is commonly held to be synonymous with divergent thinking as it usually involves generating open ended responses or subjective responses. While most of the creative thinking tasks employed in research are divergent thinking tasks, not all tasks that are divergent in nature (such as those involving hypothetical reasoning, future thinking, fluency, etc.) necessarily involve creative thinking (Abraham 2012; Abraham et al. 2012b). In order to investigate gender differences in general divergent thinking, the brain activity elicited when performing the previously discussed alternate uses (high demand divergent thinking) task and the object location (low demand divergent thinking) task was compared to the brain activity when performing the 1-back and 2-back tasks which were the low and high demand control tasks.

First, behavioral performances across all measures were assessed. Just as in the case of the alternate uses task, the findings revealed that men and women performed comparably on virtually all measures. There were no significant differences between the genders in the degree of fluency (number of responses) associated with the object location task, working memory capacity on the n-back tasks, or the ratings of difficulty associated with all four experimental and control tasks.

The only measure on which significant gender differences surfaced was in the self-report of generated objects in the object location task during the post-fMRI feedback session. Here, women were significantly better than men at recalling objects that they generated during the imaging session of the object location task. This finding is in line with several

strands of research that have implicated better verbal and declarative memory skills in women compared to men (Andreano and Cahill 2009; De Frias et al. 2006). It is important to note though that this advantage on the post-fMRI feedback session was only specific to the object location (divergent low demand) task and did not extend to the alternate uses (divergent high demand) task, which is the condition that necessitates creative conceptual expansion.

A comparison of the gender differences in brain activity during divergent thinking tasks compared to the control task revealed a dissociation in the network of structures preferentially engaged by men versus women. Men activated regions in the bilateral hippocampal formation, amygdala, retrosplenial cortex, inferior frontal gyrus, orbitofrontal cortex, alongside the left angular gyrus and mid-to-posterior regions in the superior and middle temporal gyri. Women, on the other hand, activated regions in the medial prefrontal cortex (ventral and dorsal), posterior cingulate, temporoparietal junction, temporal poles, as well as subcortical and cerebellar structures.

Many of these preferentially engaged brain regions in the case of both men and women have been commonly implicated across many mental operations, including future thinking, prospection or mental time travel (Buckner and Carroll 2007), and are considered core structures of the default mode of the brain (Abraham and von Cramon 2009; Buckner et al. 2008; Spreng et al. 2009).

However, regions like the hippocampal formation, amygdala, inferior frontal gyrus and retrosplenial cortex, which were more strongly engaged in men, are more specific to processes involved in autobiographical, episodic, semantic and spatial memory (Abraham et al. 2008a; Binder et al. 2009; Cabeza and St Jacques 2007; Spiers and Maguire 2007; Svoboda et al. 2006; Wagner et al. 2005). In contrast, regions like the dorsal and ventral medial prefrontal cortices, the posterior cingulate, the temporoparietal junction and temporal poles, which were more strongly engaged in women, are more specifically implicated during self-referential processing and theory of mind or mental state reasoning (Abraham et al. 2008b; Frith and Frith 2006; Northoff et al. 2006; Saxe et al. 2004).

This dissociation between the pattern of activity associated with each gender suggests that when generating responses under divergent thinking conditions, men more strongly draw on information in their declarative memory stores, whereas women more strongly engage in self and other referential mental state or metacognitive reasoning. It is unclear whether participants explicitly used or were even aware of the type of strategies they employed as such behavioral data were not collected within the present investigation. Such strategy differences could be focus of important future work on potential gender-related biases in information processing related to creative thinking.

The idea that the adopted cognitive strategy in a given situation or the cognitive style of a person is influenced by

gender is not new (Lin et al. 2012). For instance, according to the empathizing-systemizing (E-S) theory of sex differences in cognitive style, males are generally characterized by a stronger systemizing or analytical cognitive style, whereas females generally have a stronger empathizing cognitive style (Baron-Cohen et al. 2005). Lin et al. (2012) in fact reported gender differences in creative thinking such that women performed better on a divergent thinking task (which was positively correlated with openness in personality), whereas men performed better on insight problem solving tasks (which was negatively correlated with emotionality in personality).

Other literature that directly speaks to this issue of gender related strategy differences in divergent response production comes from the field of music therapy. Baker et al. (2005), for instance, conducted research on patients with traumatic brain injury where their task was to generate lyrics to songs. The results showed that while men and women referred commonly to themes of significant others and self-reflection, the differences between the two were that, compared to those of women, lyrics composed by men expressed adversity and concern for the future. Women, on the other hand, focused on their relationships with others in their lyrics more than men (Baker et al. 2005). Such work is indicative of general strategy based differences between the genders when faced with generative task contexts. Indeed, such strategy differences in generative or open ended situations could translate to be advantageous or disadvantageous in some contexts for one gender over the other. This issue of potential gender-based strategy differences is one that has scarcely received any focus in the information processing of individual differences in creative thinking and is one that deserves far more scrutiny.

Finally, just as in the case of the conceptual expansion contrast, some of brain regions that were previously reported to be activated during divergent thinking across genders (Abraham et al. 2012b), were preferentially engaged by men relative to women (e.g., inferior frontal regions, hippocampal formation, amygdala, retrosplenial cortex) and by women relative to men (e.g., dorsal and ventral medial prefrontal cortex, posterior cingulate). Such findings imply quantitative differences in brain activity as a function of gender when engaged in divergent thinking. However, as brain structures that were previously unrelated to divergent thinking (e.g., orbitofrontal cortex in men, temporal pole and temporoparietal junction in women) were also more strongly engaged for either gender, there were also qualitative differences in the brain structures recruited during divergent thinking as a function of gender.

Limitations of the investigation

As the strengths and limitations of the employed paradigm have been discussed in detail within a previous paper (Abraham et al.

2012b), this section will only focus on the limitations of the current analysis in relation to gender differences.

The chief limitation of the present investigation is that it was explorative in nature, which means that there was an absence of a priori hypotheses. The discussion of the findings is therefore necessarily ad hoc in nature and should be noted as such. This situation was unavoidable as no prior neuroimaging study investigated gender differences in creative thinking, and few studies have explored this issue from an electrophysiological or neuropsychological perspective (Razumnikova 2004). The findings of current investigation will therefore be part of the foundation on which future neurocognitive and behavioral research on gender differences in creative thinking can be explored.

As participants were not required to systematically report the strategies they relied on when engaged in the alternate uses and object location tasks, a weakness of the current analysis is that it is not possible to determine whether the strategy differences that we postulate here to explain the gender differences in brain activity were explicit (that the participants were aware of the strategies they used) or implicit (that the participants were unaware of the strategies they employed). Neuroscientific investigations that explore strategy differences in cognition and behavior in relation to brain function form a slowly burgeoning field (Hugdahl et al. 2006; Wolfensteller and von Cramon 2010, 2011). Potential strategy differences in creativity provide a promising area for future exploration in this light.

Another limitation of the study is the sample size. Although a sample size of 14 participants per group could be considered low, such sample sizes are not unusual in the functional neuroimaging of gender differences in cognition and behavior (e.g., Kohn et al. 2011; Kret et al. 2011; Marchewka et al. 2012), and are due to the exorbitant costs that accompany fMRI research. To safeguard against potential biases in the data that can result from such issues, stringent cut-off criteria to determine significance levels was applied in the data analysis of the current functional imaging data (Bayesian probability threshold of 99.5 % with minimum cluster of over 10 voxels).

Although the groups were comparable in terms of handedness, vocabulary and educational background, they differed significantly in terms of age. As the average age of both groups were very close (men = 24.14 years, women = 21.43 years), the impact of this difference is difficult to interpret in the current context. It must nonetheless be kept in mind when interpreting the findings that the groups were not perfectly matched.

A conceptual issue that arises in the context of these findings is whether these gender differences in brain activity patterns reflects strategy differences in creative cognition or alternatively more domain-general differences in how men and women use their brains. As the current study was not devised to test these assumptions, our discussion of this result can only be limited to this particular context of creative cognition. This is, however an important issue that needs to be taken into consideration when

considering these results especially given the many reports of gender-related structural and functional brain differences (e.g., Cosgrove et al. 2007; Gong et al. 2011; Luders and Toga 2010; Stevens and Hamann 2012). Indeed, even from a wider perspective, it is important to understand why men and women recruit different brain regions and evolve different strategies when faced with generative and other complex situations.

Conclusions and implications

It is important to note that these findings of qualitative and quantitative differences between genders in brain activity during creative conceptual expansion and divergent thinking are relative and are specific to the current context. Caution must be therefore exerted when generalizing the findings of gender differences in the current explorative neuroimaging investigation to the wider context as potential misunderstandings can be easily perpetuated as a result (Eliot 2011; Fine 2010).

The findings suggest that while men and women are not differentiated in terms of creative or divergent thinking performance as assessed by behavioral measures, the differences in the recruited brain areas when engaged in such tasks as a function of gender are indicative of strategy differences when faced with situations that call for creative or generative responses. These findings point to novel avenues that beg further exploration in the field of gender differences in higher-order cognition where the crucial question is not whether the ostensible differences between the genders lie in gross or manifest intellectual abilities, but instead in the employed strategies, functional task approach or cognitive style adopted by each gender under specific conditions.

As the current interpretations of the findings are necessarily ad hoc and as strategy differences have been rarely explored in the creativity research, further research is necessary to verify the manner and the degree to which gender-based strategy differences explain variations in creative performance. One means by which this avenue can be explored would be to have participants report what kind of strategies they were aware of using during the creative idea generation phase. These responses can then be classified as belonging to different categories (self-focused, other-focused, past-oriented, present-oriented, future-oriented, use of analogy, use of metaphor, etc.) and group differences could be assessed across categories. However, this kind of approach would be limited to the assessment of conscious or explicit strategies, and not implicit strategies.

As it is possible that participants may be unaware of some of the strategies they used as they are implicit in nature, it would be worthwhile to assess the consistency of such brain-based findings by evaluating gender differences in brain correlates of creative thinking across different kinds of creativity tasks. If a consistent pattern surfaces which shows a dissociation in the network of brain regions implicated as a function of gender, then

one possibility would be to devise creativity tasks with context based differences (social versus hypothetical future context) and to assess whether behavioral differences support the idea of gender-based advantages in one context over the other.

Strategy-based gender differences in creative cognition may partly explain the mixed picture regarding the behavioral findings associated with gender differences in creativity (Pagnani 2011; Runco et al. 2010). Creativity tasks are rarely systematically compared to one another in terms of the underlying similarities and differences in the information processing mechanisms that they evoke. It may well be the case that cognitive strategies typically employed by men versus women in generativity-inducing contexts would selectively abet performance on specific creativity tasks.

Interesting implications for potential strategy-based findings may also extend to applied domains, such as in education, industry and politics, particularly in situations where creativity and innovation are necessary. If men and women employ different strategies when engaging in creative and divergent thinking, it may be vital to ensure that there is a balanced representation of men and women in such work spaces to ensure that the full spectrum of the solution space is optimally explored.

These are only tentative proposals concerning the implications of strategy-based gender differences in creative cognition, but they are indicative of some of the many potential directions for investigation with reference to this topic.

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