Neuropsychologia 50 (2012) 1906–1917

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Creativity and the brain: Uncovering the neural signature of conceptual expansion

Anna Abraham[a,*], Karoline Pieritz[a], Kristin Thybusch[a], Barbara Rutter[a], Sören Kröger[a], Jan Schweckendiek[b], Rudolf Stark[b], Sabine Windmann[c], Christiane Hermann[a]

[a] Department of Clinical Psychology, Justus Liebig University of Giessen, Otto-Behagel-Strasse 10F, D-35394 Giessen, Germany
[b] Bender Institute of Neuroimaging, Justus-Liebig-University of Giessen, Germany
[c] Institute of Psychology, University of Frankfurt, Germany

ARTICLE INFO

Article history:
Received 15 September 2011
Received in revised form
21 March 2012
Accepted 16 April 2012
Available online 30 April 2012

Keywords:
Creative cognition
fMRI
Semantic cognition
Working memory
Higher-order cognition
Divergent thinking

ABSTRACT

Neurophysiological studies of creativity thus far have not allowed for clear conclusions to be made regarding the specific neural underpinnings of such complex cognition due to overgeneralizations concerning the creativity construct, heterogeneity in the type of creativity tasks used, and the questionable efficacy of the employed comparison tasks. A novel experimental design was developed in the present fMRI study which rendered it possible to investigate a critical facet of creative cognition – that of conceptual expansion – as distinct from general divergent thinking, working memory, or cognitive load. Brain regions involved in the retention, retrieval and integration of conceptual knowledge such as the anterior inferior frontal gyrus, the temporal poles and the lateral frontopolar cortex were found to be selectively involved during conceptual expansion. The findings go against generic ideas that argue for the dominance of the right hemisphere during creative thinking and indicate the necessity to reconsider the functions of regions such as the anterior cingulate cortex to include more abstract facets of cognitive control. This study represents a new direction in the investigation of creativity in that it highlights the necessity to adopt a process based perspective in which the multifaceted nature of creativity can be truly grasped.

1. Introduction

Our fundamental capacity to be creative is a subject of much fascination to scientists and lay people alike. Although several efforts in the field of psychology and neuroscience have been levelled at dispelling the aura of inscrutability surrounding this complex ability, far more conceptual and empirical work is necessary to develop a thorough understanding of this multifaceted construct (Dietrich, 2007; Dietrich & Kanso, 2010).

While psychological investigations of creativity are challenging for several reasons, the neuroscientific study of creative thinking is especially problematic because of implementation difficulties associated with adapting common creativity tasks when using almost any method (Abraham & Windmann, 2007). For instance, most creativity tasks do not have an objective yes/no answer (e.g., Carlsson, Wendt, & Risberg, 2000) and often require drawing or verbal responses (e.g., Jung-Beeman et al., 2004), which can lead to movement related artefacts in brain data. Many tasks are also untimed or of long duration or consist of very few trials (e.g., Chavez-Eakle, Graff-Guerrero, Garcia-Reyna, Vaugier, & Cruz-Fuentes, 2007)—in both these cases what is compromised is the possibility of having a large enough number of trials to ensure a good average response. There are also conceptual problems that are difficult to overcome (Dietrich & Kanso, 2010) such as not being able to prompt creativity volitionally or predictably as well as being unable to often define the actual time point at which a person produced a creative response within an extended trial (e.g., Fink et al., 2009).

Another severe problem in most neuroimaging studies of creativity is that the comparison control task is usually less difficult or cognitively demanding than the creative task (e.g., Bechtereva et al., 2004; Fink et al., 2009; Starchenko, Bekhtereva, Pakhomov, & Medvedev, 2003; Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005). For instance, Howard-Jones and colleagues (2005) used a paradigm where the task was to generate a story from three unrelated words (e.g., flea, sing, sword) or from three related words (e.g., magician, trick, rabbit). Piecing together a story from unrelated words predictably led to more creative responses than doing the same for related words. However, it is undeniably also more cognitively demanding to build a story from unrelated words compared to related words.

* Corresponding author. Tel.: +49 641 99 26083; fax: +49 641 99 26099.
E-mail addresses: annaabr@gmail.com, anna.abraham@psychol.uni-giessen.de (A. Abraham).

0028-3932/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.neuropsychologia.2012.04.015

So, in this case, mental operations both specific and unspecific to creativity would influence the pattern of brain activity that was generated.

A further problem is that creativity has generally been investigated in the neurosciences as a unitary and coherent construct (Dietrich, 2004; Dietrich & Kanso, 2010). For instance, many studies erroneously equate creative thinking with divergent thinking despite the fact that convergent thinking also clearly leads to creative thinking, such as during insight problem solving (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Moreover, there are tasks that would qualify as divergent thinking tasks, such as those of future thinking where responses are open-ended and subjective (e.g., Abraham, Schubotz, & von Cramon, 2008), but these principally assess hypothetical thinking and not creative thinking. Such issues highlight the need to study specific operations underlying creativity. Apart from the process of insight (e.g., Jung-Beeman et al., 2004), few other specific creative cognitive operations have been targeted.

Given the manifestly multifaceted nature of creativity, the necessity of adopting a process-driven approach while investigating creativity has been stressed by many researchers (Dietrich, 2004; Smith, Ward, & Finke, 1992). Several candidate cognitive processes have been outlined and investigated by examining normative cognitive processes under explicitly generative conditions (Finke, Ward, & Smith, 1992; Smith, Ward, & Finke, 1995). One such operation is "conceptual expansion" which refers to the ability to widen the conceptual structures of acquired concepts, a process that is especially critical in the formulation of novel ideas (Ward, 1994). The original conceptual expansion task required participants to imagine and draw an animal that lives on an alien planet. What was commonly found was that generic features of Earth animals posed considerable limitations on the capacity to create a new type of animal. This overwhelming tendency to resort to the cognitively least demanding route reflects the most commonly employed "path-of-least-resistance" strategy when faced with generative tasks (Ward, 1994; Ward, Patterson, Sifonis, Dodds, & Saunders, 2002). Evidence of this strategy can also be gleaned from the findings of the aforementioned study on story generation (Howard-Jones et al., 2005). Regardless of whether subjects were instructed to "be creative" or "be uncreative", stories generated from unrelated words were more creative than those generated from related words, which is revealing in that it is easier to give in to the path-of-least-resistance in the latter case.

The process of conceptual expansion is also assessed in the alternate uses task, a widely employed task of creative thinking (Abraham & Windmann, 2007; Wallach & Kogan, 1965) where participants are asked to generate multiple uses for common objects, such as a shoe. The originality of the responses is assessed by the infrequency or uniqueness of the generated uses. To take the example of a shoe, a highly unusual response would be to use a shoe as a flowerpot. So here the concept of a shoe has been vitally expanded beyond the customary use of foot protection to be associated with a far less common use. Which regions of the brain are activated as a function of greater conceptual expansion will be possible to uncover by contrasting participants' performances when carrying out a difficult divergent thinking task like the Alternative Uses task (AU) relative to a simple divergent thinking task,[1] such as an Object-Location (OL) task where participants are required to report objects that are commonly found in a particular location. The path of least resistance strategy would be more readily employed in the OL task compared to the AU task because it is more cognitively demanding to forge novel associations between unrelated concepts (e.g., shoe as a plant pot) than it is to recall generic associations to concepts (e.g., office: desk, chair, computer, table lamp). Due to the greater associative strength between concepts in the latter case of the OL task, they are easier to access and retrieve from our semantic knowledge stores (e.g., Tse, 2009). This difference between the two divergent thinking tasks should be demonstrated by significantly more items generated during the OL task than the AU task. While the divergent thinking processes in the case of the alternate uses task necessitate the expansion of one's conceptual structures, this is not so in the case of the divergent thinking processes in the object-location task. Other creative cognitive processes, such as imagery and overcoming the constraints posed by recently activated knowledge (Abraham & Windmann, 2007), will be expected to play a less significant role as they are likely to be involved in both divergent thinking tasks (imagery) or are irrelevant to the situation at hand (recently activated knowledge).

In the current study, we sought to rectify some of the problems associated with the neuroscientific study of creative thinking with four objectives in mind. First, a novel experimental design was developed that enables uncovering not only what brain areas are associated with divergent thinking in general but, more significantly, what regions of the brain are specifically associated with the process of conceptual expansion in creative thinking. Second, the design was optimized so as to make the trial events comparable across conditions (e.g., trial length, comparable number of button presses, etc.). Third, a cognitively demanding control task was included which allows overruling the argument that any of the relevant regions are activated solely as a function of task difficulty. Fourth, by having the participants explicitly indicate every time an idea is generated during the experiment, it is possible to assess which brain regions are involved at the actual time point of the creative idea generation.

To control for the differences in levels of cognitive demand associated with the divergent thinking tasks, two *n*-back tasks (1-back and 2-back) were employed as control tasks in the current study. The *n*-back task is a highly established task in the investigation of working memory (Cohen et al., 1997), which refers to the capacity to actively monitor and manipulate information in mind in service of a goal (e.g., Baddeley, 2010). Participants are presented with a sequence of stimuli in an *n*-back task and are required to respond when the current stimulus is identical to the stimulus that was displayed just prior to it (1-back task), two stimuli before (2-back task), and so on. The further back the comparison stimulus is, the greater the working memory load. By including these conditions, it is possible to carry out fMRI statistical analyses such that the effects of the cognitive demand differences between the two divergent thinking conditions are partialled out (see Section 2). To be able to claim this, the 2-back control condition must be perceived by the participants to be more cognitive demanding than the other conditions. The experimental design of the current fMRI study (Fig. 1) was therefore a repeated measures design with factors Task Type (divergent, control) and Cognitive Demand (high, low).

Using this design, the aim of the current study was to uncover which brain regions are specifically activated as a function of conceptual expansion as distinct from regions that are generally active as a function of divergent thinking, working memory, or high cognitive demand. It was predicted that Conceptual Expansion would lead to activations in select brain regions such as the left anterior inferior frontal gyrus (BA 45/47), temporal poles (BA 38), and lateral frontopolar cortex (BA 10). These regions are known to play key roles in semantic retrieval, semantic memory

[1] The Object Location task is a novel task that was devised for the current study. It can be classified as a divergent thinking task as it necessitates the generation of multiple solutions to a problem and thereby involves cognitive operations related to divergent production. This is is in accordance with J. P. Guilford's conceptualization of divergent thinking (Guilford, 1967).