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To create or to recall? Neural mechanisms underlying the generation of creative new ideas ☆

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ABSTRACT

This fMRI study investigated brain activation during creative idea generation using a novel approach allowing spontaneous self-paced generation and expression of ideas. Specifically, we addressed the fundamental question of what brain processes are relevant for the generation of genuinely new creative ideas, in contrast to the mere recollection of old ideas from memory. In general, creative idea generation (i.e., divergent thinking) was associated with extended activations in the left prefrontal cortex and the right medial temporal lobe, and with deactivation of the right temporoparietal junction. The generation of new ideas, as opposed to the retrieval of old ideas, was associated with stronger activation in the left inferior parietal cortex which is known to be involved in mental simulation, imagining, and future thought. Moreover, brain activation in the orbital part of the inferior frontal gyrus was found to increase as a function of the creativity (i.e., originality and appropriateness) of ideas pointing to the role of executive processes for overcoming dominant but uncreative responses. We conclude that the process of idea generation can be generally understood as a state of focused internally-directed attention involving controlled semantic retrieval. Moreover, left inferior parietal cortex and left prefrontal regions may subserve the flexible integration of previous knowledge for the construction of new and creative ideas.

Introduction

The basis of all innovation is a creative idea. The neuroscientific investigation of creativity hence strives to unveil the specific neural processes leading to creative thought. Relevant research has revealed valuable insights into the brain activation related to divergent thinking by contrasting tasks involving higher and lower creative task demands (Abraham et al., 2012; Chrysikou and Thompson-Schill, 2011; Ellamil et al., 2012; Fink et al., 2007, 2009a; Vartanian et al., 2013). So far, however, research has not investigated the brain activity patterns specifically related to ideas of varying levels of quality. Specifically, the process of idea generation usually involves two types of ideas: ideas being recalled from memory and ideas newly created during the task (Gilhooly et al., 2007). The present study hence aims at determining the brain activation specifically related to generation of new and creative ideas in contrast to ideas recalled from memory during the spontaneous process of idea generation.

Over the last few years there has been an increasing interest in the investigation of the neural correlates of creativity, resulting in a considerable number of studies using a variety of tasks and neuroscientific methods. Recent efforts to integrate the available findings, however, reported difficulties in detecting consistent findings across studies, and identifying the most relevant brain areas involved in creative thought (Arden et al., 2010; Dietrich and Kanso, 2010; Fink and Benedek, 2013, in press). One assumed reason for these inconsistent findings may be related to the large variety of conceptual approaches employed in the field. Studies that investigated creativity employed divergent thinking tasks, verbal and figural insight tasks, mental imagery, or the generation of creative stories, paintings, or melodies (e.g., Aziz-Zadeh et al., 2012; Berkowitz and Ansari, 2010; Ellamil et al., 2012; Fink et al., 2009a; Goel and Vartanian, 2005; Howard-Jones et al., 2005; Jung-Beeman et al., 2004). Given this diversity of approaches it may become understandable that a variety of cognitive processes were found to be involved.

The present study focuses on divergent thinking which can be described as the process or ability to generate new and creative ideas to given open problems (Flaherty, 2005; Sternberg and Lubart, 1996). Divergent thinking ability is conceived of as a useful estimate for the potential of creative thought (Runco and Acar, 2012), and has reasonable predictive validity (Plucker, 1999). A common example task is the alternate uses task, which requires thinking about creative uses for common objects such as a car tire. The process of divergent thinking corresponds

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to the general concept of creative idea generation. There are many possible responses to this task and people differ in the fluency and originality/creativity of their responses (Guilford, 1950; Runco and Acar, 2012). Divergent thinking is thought to rely on cognitive processes such as "the retrieval of existing knowledge from memory and the combination of various aspects of existing knowledge into novel ideas" (Paulu and Brown, 2007, p. 252; see also, Mednick, 1962). Moreover, there is increasing evidence that the ability to generate highly creative responses is related to effective executive functions and intelligence (Beaty and Silvia, 2012; Benedek et al., 2012a; Benedek and Neubauer, 2013; Gilhooly et al., 2007; Jauk et al., 2013, in press; Nusbaum and Silvia, 2011).

The brain activation associated with divergent thinking has been examined with different methods including EEG and fMRI. Concerning EEG, there is robust evidence that divergent thinking is associated with increases in alpha band power especially at frontal sites and parietal regions of the right hemisphere (Fink and Benedek, 2013, in press). Moreover, the EEG alpha band was found to be sensitive to creativity-related demands of tasks (Fink et al., 2007; Jauk et al., 2012; Jaušovec, 1997), originality of ideas (Fink and Neubauer, 2006; Grabner et al., 2007), and to individual differences in creativity (Fink et al., 2009b; Jaušovec, 2000; Martindale and Hasenfus, 1978). Increases in alpha power presumably reflect increased internal attention demands and the prevalence of top-down control due to the intensive memory search during idea generation (Benedek et al., 2011; cf., Klimesch, 2012). Fink et al. (2009a) examined the brain activation related to a set of four divergent thinking tasks varying in the amount of creative task demands by means of EEG and fMRI. They found that divergent thinking generally involved strong BOLD increases in frontal regions of the left hemisphere including the inferior frontal gyrus, anterior cingulate and precentral gyrus corresponding to increased alpha activity in the EEG assessment. Divergent thinking with high creative task demands (i.e., finding creative alternate uses for objects) specifically involved higher activation of the left angular gyrus and lower activation of the right inferior parietal cortex as compared with a divergent thinking task involving low creative task demands (i.e., generating typical object characteristics). Subsequent studies investigated the effect of cognitive stimulation on creativity of ideas and brain activation pointing at the specific role of temporo-parietal regions for controlling attention to stimulation or memory cues (Fink et al., 2009a, 2010, 2012).

Abraham et al. (2012) also compared divergent thinking tasks with higher and lower creative demands (i.e., alternate uses task vs. object location task) and found that the former was related to stronger activations in the inferior and middle frontal gyri of the left hemisphere but also the left inferior parietal cortex. Divergent thinking was also contrasted to the convergent n-back revealing diverse differences across the brain including a higher involvement of the hippocampal formation during divergent thinking. Chrysikou and Thompson-Schill (2011) employed a figural version of the alternate uses task and compared conditions asking for common or uncommon uses in a between-subject design. Both divergent thinking conditions elicited activations of the left frontal cortex and of occipital brain regions; thinking about uncommon uses was found to lead to stronger occipital activations possibly related to cognitive strategies applied to the visually depicted object.

This study aims to address an important conceptual issue that has not been considered in the literature so far. Ideas arising during divergent thinking are usually defined as creative when they are unusual and appropriate (Runco, 2012; Sternberg and Lubart, 1996). This, however, does not necessarily imply that these ideas are the result of a genuinely creative process. A detailed analysis of the responses given in divergent thinking tasks revealed that people can retrieve a substantial amount of unusual ideas from memory without actually having created them (Gilhooly et al., 2007). For example, thinking about alternate uses for a car tire may elicit responses such as "swing" and "crash barrier", which conform to the task instructions but which are not new to most people. The distinction between *old* and *new* ideas concerns a vital point of creative idea generation. Only new ideas are the result of a genuinely creative act in which previously unrelated frames of thought become associated in a new and meaningful way (Koestler, 1964). In contrast, old (i.e., known) ideas result from successful retrieval from long-term memory and thus do not involve a creative process. Therefore, this study aims to uncover the specific brain processes related to the generation of new and hence genuinely creative ideas. This is achieved by contrasting brain activation associated with the generation of new and old ideas in an event-related design. This study employs a novel experimental paradigm allowing self-paced generation and expression of ideas. This approach ensures a natural and valid condition for idea generation, paying tribute to the spontaneous nature of creative thought (Dietrich, 2004; Finke, 1996). Although research has not yet addressed this specific research question, one might expect stronger involvement of the medial temporal lobe during generation of old ideas, given its central role for declarative memory (e.g., Squire et al., 2004). We also aim at analyzing the brain activation related to high creativity of ideas which goes beyond novelty. Considering that the literature suggests that intelligence and executive processes play an important role for the generation of creative ideas, we expect that creativity of ideas should be related to activation in brain regions supporting executive functions (e.g., left prefrontal cortex; Barbey et al., 2012).

Materials and methods

Participants

The sample consisted of 35 healthy adults (24 female, 11 male; mean age: 22.7 years, age range: 18–29) after excluding seven participants; three due to technical problems with audio recording of responses, one for excessive head movements (>1 mm), and three who did not meet the performance criterion (see below). All participants were right-handed, had normal or corrected-to-normal vision, and reported no history of CNS-affecting drugs, mental or neurological diseases. They gave written informed consent and were paid for participation in the fMRI session. The study was approved by the local ethics committee of the Medical University of Graz, Austria.

Experimental task and procedure

Participants performed the alternate uses task, which is a divergent thinking task that is commonly used in the behavioral and neuroscientific study of creative idea generation (Fink and Benedek, 2013, in press; Fink et al., 2007). This task requires generating creative uses for given common objects (e.g., "car tire"). Participants were asked to name all the unusual and creative uses they could think of and to vocalize their ideas as soon as they came to their mind. This mode of self-paced responding was chosen in order to capture the process of spontaneous idea generation in a natural and valid way (Birn et al., 2010; Long et al., 2010). The data was acquired in a single run consisting of 15 task blocks and 16 fixation blocks. The session started with a fixation block (25 s) followed by 15 task blocks which were separated by randomly jittered fixation null epochs (20–22 s; see Fig. 1). Each task block consisted of an idea generation period (60 s) presenting different items taken from previous studies (Fink et al., 2012). Participants' overt verbal responses were recorded by means of a funnel and a plastic tube (20 mm diameter) leading to a microphone placed outside the scanning room (Barch et al., 1999). A coworker monitored the task with headphones and immediately transcribed all responses.

The key experimental variation of this study capitalized on the fact that ideas during divergent thinking are either retrieved from long-term memory or created at that very moment (Gilhooly et al., 2007). Participants hence were asked to review all their responses right after the scanning session and to indicate for each single idea whether it represented an *old idea* or a *new idea*. This was done following a brief instruction defining an old idea as an idea that was previously known to