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Creativity meets neuroscience: Experimental tasks for the neuroscientific study of creative thinking

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Abstract

The psychometric assessment of different facets of creative abilities as well as the availability of experimental tasks for the neuroscientific study of creative thinking has replaced the view of creativity as an unsearchable trait. In this article we provide a brief overview of contemporary methodologies used for the operationalization of creative thinking in a neuroscientific context. Empirical studies are reported which measured brain activity (by means of EEG, fMRI, NIRS or PET) during the performance of different experimental tasks. These tasks, along with creative idea generation tasks used in our laboratory, constitute useful tools in uncovering possible brain correlates of creative thinking. Nevertheless, much more work is needed in order to establish reliable and valid measures of creative thinking, in particular measures of novelty or originality of creative insights.

Keywords: Human cognition; Creativity; Creative thinking; Divergent thinking; Neuroscience

1. Introduction

Creativity is definitely a complex field of research. On the one hand, it pervades almost all areas of our everyday life: It is important in the pedagogical, cultural, and in the scientific domain. Likewise, creativity is advantageous in economy and in the job. On the other hand, no conclusive definition of this mental ability construct has been achieved yet. Most researchers agree that creativity is the ability to produce work that is novel (original, unique), useful and generative [1]. Accordingly, creativity is regarded as a performance or ability trait, preferably manifested in original, valuable, and socially accepted ideas, products, or works of art. This view is also reflected in the presumption that the creativity level of an individual can be assessed by means of performance measures derived from creative thinking tasks or psychometric tests. But what kind of measures are these?

As originally suggested by Guilford, creative talent or creative ability can be assessed by a number of variables such as ideational fluency (i.e., number of ideas), the degree of novelty (or uniqueness/originality) of ideas, or the flexibility of the mind (i.e., the ability to produce different types of ideas, as opposed to rigidity) [2]. Influenced by Guilford's suggestions many creativity measures have been developed, among the most influential are the Torrance Tests of Creative Thinking (TTCT; [3]), Mednick's Remote Associates Test [4], or Guilford's divergent production tests [5].

The availability of creativity measures as well as the availability of experimental tasks for the study of creative thinking has also motivated other scientific disciplines to enter into this complex mental ability domain. Recent research efforts in the field of cognitive sciences and particularly in the field of neurosciences have expanded our knowledge about creativity to a considerable extent. Different frameworks and theories about possible mechanisms underlying creative thinking have been proposed [6,7]. Basically, theoretical and empirical advances in these disciplines have—along with psychometric approaches—displaced the viewpoint of creativity as an unsearchable phenomenon. This is nicely illustrated in Ward et al.'s concept of creative cognition which is considered as an extension of recent

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work in cognitive psychology or cognitive science to the domain of creative thinking [8]. Concepts, theories, and methods that have already been employed in many noncreative research fields of cognitive psychology are adapted for the study of creative thought. Among the most prominent examples of the creative cognition approach are, as outlined in Ward et al., the study of insightful problem solving, creative imagery, extending concepts (or conceptual expansion, respectively), or the study whether creative products are the result of recently activated knowledge (e.g., previously seen examples). Likewise, Weisberg's knowledge theory of creativity has also contributed to a better understanding of this complex mental ability domain [9]. He emphasizes the role of domain-specific knowledge as an important prerequisite for creative functioning. Along the same lines, other researchers pay attention to intellectual ability as a key variable in creative thinking [10].

The viewpoint of creativity as performance or ability oriented trait has been further underpinned by Dietrich who provides a comprehensive review of contemporary research in the field of cognitive science and neuroscience [6]. Dietrich argues that creativity requires a variety of classic (frontal lobe demanding) cognitive abilities such as working memory, sustained attention, or cognitive flexibility. Creative thinking involves, among others, the ability to break conventional rules of thinking or to develop new strategies. Moreover, producing novel ideas by combining already stored knowledge elements [6] presumably also involves working memory, which is conceptualized as the ability to temporarily maintain information in mind upon which concurrent information processing takes place.

Recent advances in the development of brain imaging techniques like the quantification of task- or event-related (de)synchronization of brain activity in the electroencephalogram (EEG), the measurement of regional cerebral blood flow (rCBF) via positron emission tomography (PET), or functional magnetic resonance imaging (fMRI) techniques allow us to look at the brain when engaged in creative thinking [see also 11]. However, presumably due to difficulties in operationalizing creative performance during EEG, PET, or fMRI measurements, neuroscientific studies that aim at identifying possible brain mechanisms related to creative thinking are comparatively rare at the present time. In the following we provide a brief overview of existing methodologies used for the operationalization of creative thinking in a neuroscientific context.

1.1. Operationalization of creativity in neuroscientific research

Table 1 summarizes empirical studies which measured brain activity during the performance of different experimental tasks. The employed tasks cover different aspects of creative thinking ranging from creative story generation, over mental imagery, to mental composition of music. Petsche, for instance, used verbal, visual, and musical tasks [12]. Bhattacharya and Petsche asked their participants to mentally compose a drawing [13]. In other studies participants were requested to solve match problems [14] or to generate a story with given stimulus words [15,16]. Most of the tasks presented in this table were adapted from, or at least influenced by Torrance', Mednick's or Guilford's tests of creative thinking [3–5]. For example, Jung-Beeman et al. [17; see also 18] studied neural activity during the performance of compound remote associate problems which were adapted from Mednick's Remote Associates Test [4]. In this task, Jung-Beeman et al. present three stimulus words (e.g., *pine*, *crab*, *sauce*) and instruct their participants to produce a single solution word (*apple*) that represents a compound with each of the three stimulus words (*pineapple*, *crab apple*, *applesauce*). Carlsson et al., Folley and Park, and Mölle et al. employed modified versions of the well-known unusual uses task (see TTCT), which requires participants to name as many alternative or unusual uses of a common object as possible [19–21].

An issue directly related to the experimental tasks reviewed here is the experimental design that should allow conclusions on the neuronal bases of creative thinking. Near infrared spectroscopy (NIRS), fMRI, and PET measure brain activity indirectly by hemodynamic (in PET also metabolic) parameters. The observed changes in brain activity (e.g., from a baseline condition to an activation interval) occur rather slowly (e.g., the BOLD signal in fMRI reaches its maximum at 4–6 s and needs about 15 s to decline) which considerably limits the investigation of the time-course of creative cognition. With respect to fMRI, perhaps the most important question is how to design different task conditions that can be used to isolate the brain areas involved in creative cognition by means of the subtraction method [22,23]. The mere comparison of a creative thinking task with a resting period seems to be unsatisfactory as it is not known which cognitive processes take place in the resting condition. Binder et al., for instance, found that language regions are active during a resting period which was attributed to "mental soliloquizing" of the participants [24]. A more appropriate approach is the comparison of tasks or conditions requiring creative thinking to a different extent. In this vein, Jung-Beeman et al. contrasted brain activity during problem solving with vs. without insight as indicated by the participants [17]. Howard-Jones et al., in contrast, varied the extent of creative engagement via the instruction to generate either creative or uncreative stories [15].

While fMRI enables insights into the neuroanatomical bases of creative cognition with high spatial accuracy, the primary advantage of EEG lies in its high temporal resolution (in the range of milliseconds) and the availability of different parameters. All EEG studies presented in Table 1 analyzed oscillatory EEG activity which is associated with functional network formation and dynamic interactions within and between brain structures during cognitive information processing [25–27]. In light of the complexity of creative thinking, presumably requiring a highly coordinated interplay of different neural networks, the analysis of