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Review

EEG alpha power and creative ideation

Andreas Fink*, Mathias Benedek

Institute of Psychology, University of Graz, Austria

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Neuroscientific studies revealed first insights into neural mechanisms underlying creativity, but existing findings are highly variegated and often inconsistent. Despite the disappointing picture on the neuroscience of creativity drawn in recent reviews, there appears to be robust evidence that EEG alpha power is particularly sensitive to various creativity-related demands involved in creative ideation. Alpha power varies as a function of creativity-related task demands and the originality of ideas, is positively related to an individuals' creativity level, and has been observed to increase as a result of creativity interventions. Alpha increases during creative ideation could reflect more internally oriented attention that is characterized by the absence of external bottom-up stimulation and, thus, a form of top-down activity. Moreover, they could indicate the involvement of specific memory processes such as the efficient (re-)combination of unrelated semantic information. We conclude that increased alpha power during creative ideation is among the most consistent findings in neuroscientific research on creativity and discuss possible future directions to better understand the manifold brain mechanisms involved in creativity.

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1. Introduction

1.1. Creativity and neuroscience: the status quo

Creativity is commonly defined as the ability to produce work that is both novel (original, unique) and useful within a social

* Corresponding author at: University of Graz, Institute of Psychology, Biological Psychology Section, Universitaetsplatz 2/III, A-8010 Graz, Austria.
Tel.: +43 316 380 8482.
E-mail address: andreas.fink@uni-graz.at (A. Fink).
URL: http://www.uni-graz.at/biologicalpsychology/ (A. Fink).

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context (e.g., Flaherty, 2005; Stein, 1953; Sternberg and Lubart, 1996). Besides other classic mental ability constructs such as intelligence,[1] creativity appears to be crucial or even indispensable in many areas of our everyday lives, leading some authors to conclude that creativity is "...a good attribute for people to possess..." (Simonton, 2000, p. 151). It is sorely needed in culture, science and education, likewise in the economical or industrial domain. As a matter of fact, creativity is becoming increasingly attractive not only in the popular domain but also across a broad variety of different scientific disciplines. Meanwhile it has been approached in the cognitive sciences (e.g., Smith et al., 1995; Ward, 2007), in pedagogy or in the educational domain (e.g., Sawyer, 2006), from the perspective of social psychology (e.g., Amabile, 1983; Hennessey and Amabile, 2010), in the context of mental illness (e.g., Kaufman, 2005; Fink et al., 2011b) and most recently also in the field of neurosciences (see e.g., Arden et al., 2010; Dietrich, 2004, 2007; Dietrich and Kanso, 2010; Fink et al., 2007; Jung et al., 2010a,b). Though relevant research in this burgeoning field is rapidly growing it seems nevertheless noteworthy that, compared to other mental ability constructs such as intelligence, this field is only at the beginning of a long search for potential cognitive and neural mechanisms underlying this multifaceted mental ability domain. Up to the present, a comparatively low number of approx. 550 scientific publications is available which deal with brain correlates of creativity (Source: Thomson Reuters © WEB of KNOWLEDGE; Topic: "*Creativity*" AND "*Brain*"), while there are approx. 19.300 published papers dealing with the brain-intelligence relationship (ibid.).

This article attempts to show how neuroscientific studies on creative ideation using human electroencephalography (EEG) can help us to learn more about the manifold ways of how creative thought might be manifested in our brains. Motivated by the increasing availability of new neuroscientific methodologies, creativity has become increasingly attractive in the neurosciences, and in the meanwhile a considerable number of studies has been published in this emerging field. These studies investigated brain activity during a broad range of different creativity-related tasks (ranging from divergent thinking, over insightful problem solving to artistic or musical creativity) by means of a variety of different neuroimaging methods. Taken together, these studies have produced a large diversity of findings and existing review articles on the neuroscience of creativity (e.g., Arden et al., 2010; Dietrich and Kanso, 2010; Sawyer, 2011) draw rather disappointing conclusions. For instance, in reviewing EEG, ERP and neuroimaging studies of creativity and insight, Dietrich and Kanso (2010) recently came to the conclusion that "... creative thinking does not appear to critically depend on any single mental process or brain region, and it is not especially associated with right brains, defocused attention, low arousal, or alpha synchronization, as sometimes hypothesized ..." (p. 822). In a similar vein, Arden et al. (2010) found "little clear evidence of overlap" (p. 143) in the findings obtained in different neuroimaging studies of creative cognition. These two reviews have covered a large amount of studies involving a variety of creativity tasks investigated by means of a variety of different neurophysiological methods. At this, it should be noted that creativity is usually not considered as prime example of a homogeneous construct. Creativity can be variably defined either as a cognitive state or event, as a cognitive potential or personality disposition, by creative expertise, or even by life time creative achievement (e.g., Kaufman and Beghetto, 2009).

In addition, a large number of tasks have been conceived which are thought to capture relevant cognitive processes related to creativity. They include such different tasks as creative ideation tasks asking participants to come up with original ideas for open problems (e.g., alternate uses task), insight tasks involving misleading problem representations which need to be restructured (e.g., matchstick problems), remote associates problems which require loose associations to find non-obvious semantic relations, or the production of creative stories, metaphors, paintings, or melodies (Arden et al., 2010; Dietrich and Kanso, 2010). Moreover, there are so many different ways such tasks can be realized, particularly with respect to task instructions (e.g., stressing more strongly the fluency or the originality facet of creativity), timing (duration of stimulus presentation, etc.), response modalities (e.g. button press, verbal response, etc.), control conditions and so on. This diversity in defining and measuring creativity as well as the diversity of experimental procedures (e.g., stimuli, control conditions, timing, response mode, etc.) may well have contributed to the difficulties in identifying reliable and replicable brain correlates underlying creativity so far. In addition to this, the broad diversity of neurophysiological measures and parameters that were used in this field might be also assumed as being responsible for the fact that no conclusive picture about potential neural mechanisms underlying creativity has been achieved yet. Even if we concentrate on EEG studies on creativity, there are so many different measures or parameters, ranging from event-related potentials and oscillatory brain activity (in a broad range of different EEG frequency bands), over coherence or functional connectivity indicators between different cortical areas (which are also analyzed in a broad range of different frequency bands), to measures of dimensional complexity, etc., with each of them having different functional meanings–that makes it notoriously difficult to compare and integrate findings across different studies.

The undertaking of finding consistent brain mechanisms underlying creativity, therefore, requires above all a clear conceptual definition of what aspect of the multi-facetted construct of creativity is actually looked at (Dietrich and Kanso, 2010). Moreover, it is probably beneficial to focus on specific tasks and specific methods and only extend the scope of research and interpretations as soon as the initial findings are well understood. In this article we aim to specifically focus on brain correlates of the well-established process of creative ideation (or more generally on divergent thinking, respectively). The generation of creative ideas to open problems can be considered as key component of creativity, and the creative ideation approach has already been adopted in a considerable number of neuroscientific studies of creativity (see following section for further definition). As will be shown in this review, recent studies in this field have yielded evidence that brain activity in the EEG alpha frequency band is sensitive to various creativity-related demands involved in creative ideation, thereby revealing a quite consistent and replicable picture about some promising brain mechanisms relevant for creativity.

1.2. Creative ideation

Creative ideation denotes the process of creating a number of different original ideas to given open problems. It is conceptualized as a cognitive process involving "both the retrieval of existing knowledge from memory and the combination of various aspects of existing knowledge into novel ideas" (Paulus and Brown, 2007, p. 252). Creative ideation tasks are commonly called divergent thinking tasks pointing at the notion that thought "goes off in

[1] Throughout the history, many definitions of intelligence have been proposed, and it has been sometimes criticized that there are as many definitions of intelligence as there are researchers attempting to define this construct (Neubauer and Fink, 2009, p. 1005). Meanwhile, some consensus about the core elements of intelligence has been achieved and many scientists (e.g., Jung and Haier, 2007; Neubauer and Fink, 2009) refer to Neisser et al.'s (1996) definition: "Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought" (p. 77).