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EEG alpha oscillations during the performance of verbal creativity tasks: Differential effects of sex and verbal intelligence

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Abstract

Task-related power changes in the EEG alpha band were analyzed in 31 participants (17 males and 14 females) during performance of two verbal creativity tasks. Participants were confronted with verbal problems that are in need of explanation (insight problems) and utopian situations that will actually never happen. In both tasks they were instructed to generate as many but also as unusual, unique or original ideas as possible. To assess brain responses that come along with highly original ideas, individual responses were divided into more and less original ideas (within each participant). Creative problem solving was generally accompanied by lower levels of cortical arousal (i.e., increases in alpha power from a pre-stimulus reference to an activation interval). Additionally, more original (vs. less original) responses were associated with a stronger task-related alpha synchronization in posterior (particularly centroparietal) cortices. Task-related alpha power changes during creative problem solving were also moderated by verbal IQ and sex.

Keywords: EEG; Creativity; Intelligence; Sex differences; Hypofrontality

1. Introduction

Research into the neurophysiology of human mental abilities has primarily aimed at exploring possible neural bases of classical intellectual abilities such as reasoning or working memory. Motivated by the goal to achieve a better understanding of possible neural bases that may underlie these mental ability constructs, a large number of experimental studies using a wide range of different cognitive tasks has been performed in order to examine as to how individuals who show low vs. high intellectual ability differ in the usage of their brains in performing cognitively demanding tasks (an extensive review on the neurobiology of intelligence is given in Gray and Thompson, 2004). In this context, a variety of psychophysiological measurement methods has been employed, ranging from EEG, PET and fMRI, and in the meantime sound evidence points to a more efficient brain activation (i.e., less brain activation) in brighter as compared to less intelligent (or low-performing, respectively) individuals (for recent evidence see e.g., Grabner et al., 2004; Haier et al., 2003; Neubauer et al., 2005; Rypma et al., 2002).

Most of the EEG studies dealing with the relationship between intelligence and cortical activity analyzed task-related or event-related desynchronization (ERD; Pfurtscheller and Lopes da Silva, 2005) of electro-cortical activity, mostly in the alpha frequency band (approx. in the frequency range between 7 and 13 Hz). The ERD is based on the well-established phenomenon that EEG alpha power desynchronizes when individuals are mentally active as compared to a resting condition during which no task is performed. Event-related synchronization (ERS), in contrast, means that (related to a certain event) the underlying neuronal networks display synchronous activity (indicative of cortical deactivation). It is assumed that the ERD of alpha band activity, also called “alpha blocking”, reflects an increased excitability level of neurons in the involved cortical areas, which may be related, for instance, to an enhanced information transfer in thalamo-cortical circuits (Neuper and Pfurtscheller, 2001; Pfurtscheller and Lopes da Silva, 2005).

We employed the ERD method in several studies in order to analyze the relationship between intelligence and cortical activity related to different cognitive demands (for review see

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Neubauer and Fink, 2005). Perhaps the most important finding of these EEG studies was that the inverse intelligence–activation relationship (i.e., neural efficiency) appears to be moderated by task content and individuals' sex (Neubauer et al., 2002). Males and females displayed the expected inverse IQ–activation relationship in just that domain in which they usually perform better: females in the verbal domain, and males in the visuo-spatial ability domain. In Neubauer et al. (2005) we replicated and extended these findings. For this reason, the ERD–intelligence relationship was studied more thoroughly, particularly with respect to topographical patterns and with respect to verbal, numerical and visuo-spatial subcomponents of intelligence. Findings were very similar to the 2002 study: females showed the negative brain–IQ relationship primarily during performance of a verbal task (more prominently over centroparietal and temporal cortices), males only when confronted with visuo-spatial stimulus material (predominantly over frontal cortices). Most interestingly, the IQ–ERD relationship varies considerably with the intelligence factor: in males the highest correlations were found for visuo-spatial IQ, in females for verbal IQ.

Taken together, it has been shown that individual differences in intelligence account for variability in brain responses to a variety of cognitive demands. Nevertheless, it should be kept in mind that intelligence, probably the best researched mental ability construct, constitutes just *one* facet in the complex mental ability domain. Talented or gifted people are not only skilled in logical analytic thinking, reasoning or working memory, they may be versed in other "modes of thinking" as well.

In this context, creativity has been identified as another key variable in the profoundly complex mental ability domain. Creativity is commonly seen as "a kind of novelty that is useful, valuable and generative" (Stokes, 1999). Others (Sternberg and Lubart, 1996) define creativity as the ability to produce work that is both novel (original, unexpected) and appropriate, or work that is practicable and worth implementing (Csikszentmihalyi and Wolfe, 2000). In defining creativity it has often been referred to Guilford's (1950) distinction between *convergent* (discovering the single best answer of a given problem) and *divergent* (a given problem might be tackled in different ways) modes of thinking, with the former capturing the major principle inherent in most intelligence tasks and the latter representing the free-associative thinking style that is commonly linked to creative thinking.

Presumably due to difficulties in defining and measuring creativity, which has mostly been operationalized by means of productivity or ideational fluency (i.e., number of ideas), research aiming at identifying possible brain states related to creative modes of thinking is comparatively rare. Only recently, research on neural bases underlying the unique experience of "AHA!" or "HEUREKA!" has attracted attention in this field of research (Jung-Beeman et al., 2004). There are, however, some empirical reports of possible brain mechanisms related to divergent thinking (as compared to convergent thinking). For instance, in a study by Mölle et al. (1999) participants were asked to name as many unusual uses of a common, everyday object or to think of as many consequences as possible of a given hypothetical situation (i.e., divergent thinking task). In contrast, in the convergent task, requiring logical operations, the correct continuation of a row of letters had to be given. The authors report a higher EEG complexity during the divergent than the convergent task, presumably pointing to a larger number of independently oscillating neural assemblies during divergent thinking. Similar findings were reported by Jausovec (2000) and Razoumnikova (2000) in employing EEG power and coherence analyses, also indicating that divergent vs. convergent modes of thinking are accompanied by different patterns of electrocortical activity.

A reasonable framework hinting at possible biological bases of creativity has been put forward by Martindale (see Martindale, 1999). Martindale integrates elements of former conceptualizations of creativity: Kris' (1952) supposition of primary process cognition in creative individuals, Mendelsohn's (1976) hypothesis of defocused attention, and Mednick's (1962) view of individual differences in associative hierarchies. Accordingly, creative individuals are believed to be more capable of shifting between secondary and primary modes of thinking, or to "regress" to primary process cognition which is necessary for producing novel, original ideas. While secondary processes are abstract and logic-analytical, primary process cognition refers to states such as dreaming or reverie, but also to abnormal states observed in individuals suffering from mental disorders (e.g., psychosis; Vaitl et al., 2005 provide an extensive review of the psychobiology of altered states of consciousness). Creative individuals should also be characterized by "flat" (more and broader associations to a given stimulus) instead of "steep" associational hierarchies (just a few, common associations to a given stimulus), and can attend to more things at the same time (i.e., defocused attention) instead of just narrowly attending to a single task or event.

Martindale also refers to empirical evidence suggesting that primary process cognition, defocused attention, and flat associational hierarchies are linked to lower levels of cortical arousal. In Martindale and Hines (1975) highly creative individuals displayed a comparatively low cortical arousal while performing the Alternate Uses Test (as compared to intelligence test tasks), while medium and low creative subjects were strongly cortically aroused in all experimental tasks. Similarly, in Martindale and Hasenfus (1978) highly creative individuals showed lower levels of cortical arousal than low creative subjects during an inspirational phase (i.e., thinking of a story) but not during an elaboration phase (i.e., writing down the story).

In the present study we analyze cortical activity in the EEG alpha band while individuals are confronted with verbal creativity tasks. Two verbal problems that are in need of explanation (i.e., insight problems) and two hypothetical, utopian situations are presented to the participants, who are instructed to generate as many but also unusual, unique and original ideas as possible. Similar to the search for neural bases underlying unique experience of AHA! of Jung-Beeman et al. (2004), we seek to identify possible brain responses that come along with highly original ideas by contrasting them to brain responses during the production of conventional, customary ideas.