



## Sensitivity of EEG upper alpha activity to cognitive and affective creativity interventions

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### ABSTRACT

We investigated whether creative cognition can be improved by means of cognitive and affective stimulation and whether these interventions are associated with changes of EEG alpha activity. Participants were required to generate original uses of conventional objects (Alternative Uses task, AU) while the EEG was recorded. In the cognitive stimulation condition, participants worked on the AU task subsequent to the exposure to other people's ideas. In the affective stimulation condition, they had to think creatively in positive affective states, induced via emotionally contagious sound clips. Creative cognition generally elicited alpha synchronization, most prominent in the prefrontal cortex and in the right hemisphere. The interventions were associated with stronger prefrontal alpha activity in the upper alpha band (10–12 Hz) than the control condition (no intervention), possibly indicating a state of heightened internal awareness, which might have a beneficial impact on creativity.

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### 1. Introduction

Neuroscientific approaches to the study of creativity, which is commonly defined as the ability to produce work that is both novel and useful within a certain social context (see, e.g., [Flaherty, 2005](#); [Stein, 1953](#); [Sternberg and Lubart, 1996](#)), have produced valuable insights into potential brain correlates underlying this prominent mental ability domain. As nicely delineated in recent reviews of relevant neuroimaging studies in the burgeoning field of creativity ([Arden et al., 2010](#); [Dietrich and Kanso, 2010](#)), brain activity has been investigated in response to divergent (as opposed to convergent) thinking (e.g., [Mölle et al., 1999](#); [Razumnikova, 2000](#)), during insightful problem solving or the subjective experience of “AHA!” (e.g., [Jung-Beeman et al., 2004](#); [Sandkühler and Bhattacharya, 2008](#)), likewise during the performance of classic creativity tasks such as the unusual uses test (e.g., [Chávez-Eakle et al., 2007](#); [Folley and Park, 2005](#)), or in relation to musical creativity or visual art (e.g., [Bhattacharya and Petsche, 2005](#)).

Brain correlates underlying different facets of creative cognition have mostly been investigated in employing EEG techniques. Research in this field has been stimulated by the pioneering work of Colin Martindale

who showed that highly creative individuals were more likely to exhibit higher EEG alpha wave activity (i.e., EEG activity approximately in the frequency range between 8 and 12 Hz) than less creative individuals while performing the classic Alternate Uses (AU) test, which requires individuals to generate original uses of conventional, everyday objects ([Martindale and Hines, 1975](#)). In [Martindale and Hasenfus \(1978\)](#), a higher level of alpha activity has been observed while participants were instructed to think of a story (i.e., inspirational phase) than during an analog of creative elaboration (i.e., writing down the story). Interestingly, this effect was more pronounced when individuals were explicitly instructed to be original in doing their responses (cf. [Martindale and Hasenfus, 1978](#)).

Meanwhile the particular role of EEG alpha activity in the context of creative cognition has been corroborated in a series of studies employing a broad range of different creativity-related task demands (e.g., [Bazanava and Aftanas, 2008](#); [Fink et al., 2007](#); [Jaušovec, 2000](#); [Jaušovec and Jaušovec, 2000](#); [Jung-Beeman et al., 2004](#); [Razumnikova, 2000](#); [Martindale, 1999](#); [Sandkühler and Bhattacharya, 2008](#)). Specifically, on the basis of existing evidence in this field it can be concluded that EEG alpha activity varies as a function of the creativity-related task demands (the more creative a task the higher the level of alpha activity; [Fink et al., 2007](#); [Martindale and Hasenfus, 1978](#)) and subjective experience of insight (more alpha in insight vs. non-insight solutions; [Jung-Beeman et al., 2004](#); see also [Bowden et al., 2005](#)). Also, EEG alpha activity has been observed to be related to an individuals' creativity level (more alpha in higher creative individuals; e.g. [Fink et al., 2009a,b](#); [Jaušovec, 2000](#); [Martindale and Hines, 1975](#)) and to the originality of responses ([Fink and Neubauer, 2006, 2008](#); [Grabner](#)

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et al., 2007; Martindale and Hasenfus, 1978). In addition, research in this field also suggests that alpha activity increases as a result of a verbal creativity training (Fink et al., 2006). The training was composed of exercises requiring participants to originally complete or compose words, to build three-word sentences, to generate slogans or nicknames, or to think of original descriptions to a given verbal stimulus (see also Benedek et al., 2006). Results indicate that the training was effective in improving creativity, and training effects were also apparent at the level of the brain, as it was reflected in stronger frontal alpha activity in the training than in the control group after completing the training.

Alpha synchronization has traditionally been considered as a functional correlate of cortical idling, presumably reflecting a reduced state of active information processing in the underlying neuronal networks (Pfurtscheller et al., 1996). However, in the meanwhile more and more studies suggest that synchronization of alpha activity does not merely reflect cortical deactivation or cortical idling (a highly readable review on this topic is given in Klimesch et al., 2007). In fact, alpha synchronization appears to be especially relevant during internal processing demands, for instance when participants are required to hold information temporarily in mind. For instance, Klimesch et al. (1999) reported a study (entitled “Paradoxical’ alpha synchronization in a memory task”) in which event-related synchronization of alpha activity has been observed during the retention interval of a memory task. In another study, Sauseng et al. (2005) interpreted their findings of prefrontal alpha synchronization during working memory processing in a manner that “... frontal areas must not become involved in (distracting) new activities as long as an ongoing working memory task is carried out” (p. 154). Quite similarly, Jensen et al. (2002) interpreted their finding of an increase in occipital–parietal alpha synchronization with increasing memory load as being indicative of some kind of suppression of the input from the visual system, which would disturb working memory processing in frontal brain areas. Nicely in support of this view, von Stein and Sarnthein (2000) argue that alpha activity could reflect the absence of stimulus-driven, external bottom up stimulation and, thus, a form of top-down activity which “is maximal in situations where cortical processes ... are driven by free floating associations, mental imagery, planning etc.” (p. 311).

Along these lines, the observed alpha synchronization during creative cognition (see e.g., Fink et al., 2007, 2009a,b), could reflect the absence of stimulus-driven, external bottom-up stimulation and, thus, a form of top-down activity (cf. von Stein and Sarnthein, 2000), or a state of heightened internal attention facilitating the (re-)combination of semantic information that is normally distantly related. In a similar vein, alpha synchronization during creative idea generation could also reflect a state of enhanced concentration or alertness of involved brain circuits (cf. Knyazev et al., 2006; see also Knyazev, 2007).

This study was designed to investigate the sensitivity of EEG alpha activity to two short-term creativity interventions (i.e., cognitive and affective stimulation) which have been observed to yield beneficial effects on creative cognition in relevant behavioral and neuroscientific research, in order to examine whether changes in EEG alpha activity may in part explain these effects. Cognitive stimulation in the context of creative idea generation, which 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), is realized via the exposure and active attendance to other people’s ideas. As it is the case in classic group-based brainstorming techniques (Osborn, 1957), each single idea or solution a person generates to a specific problem may stimulate new ideas or solutions in others. Relevant literature from the behavioral or cognitive creativity research tradition suggests that creative performance increases as a result of such idea sharing or idea exchange processes (Dugosh et al., 2000; Dugosh and Paulus, 2005; Paulus and Brown, 2007; Paulus and Nijstad, 2003).

Furthermore, neuroscientific studies in this research field also emphasized the particular role of positive affect in the context of creative cognition. Relevant literature in this field of research suggests that positive affect has a beneficial influence on cognition and creative problem solving (Ashby et al., 1999; Baas et al., 2008). Induced positive mood and higher levels of current positive mood have been shown to be related to several functions closely associated with creativity, such as greater spread of activation in associative networks (Bolte et al., 2003; Isen et al., 1985; Rowe et al., 2007), a more flexible and broader attentional focus (Compton et al., 2004; Wadlinger and Isaacowitz, 2006), greater ability to disengage from no longer relevant stimulus categories (Dreisbach and Goschke, 2004), improved ability to inhibit prepotent motor responses (Van der Stigchel et al., 2011), and a greater number of responses in the Alternative Uses task (Phillips et al., 2002). Increased emotional arousal has been related to brain activation in the right hemisphere in right parieto-temporal and prefrontal regions; effects on prefrontal activation may additionally be lateralized depending on valence, with relatively greater activation in the left prefrontal cortex being associated with positive or approach-related affect and relatively greater activation in the right prefrontal cortex associated with negative or withdrawal-related affect (Davidson, 2003; Hagemann et al., 2005; Harmon-Jones et al., 2010; Heller, 1993; Heller et al., 2003; Papousek et al., 2009). Specific studies have shown that creativity may be enhanced by emotional arousal as such. Both positive and negative high-arousal moods (such as cheerfulness and anger) led to better performance in creative tasks than did positive and negative low-arousal moods (such as serenity or sadness). However, the findings also indicated that the processes underlying the performance enhancement differed according to valence: Positive high-arousal affect seems to influence creativity because of enhanced cognitive flexibility, whereas enhanced persistence seems to underlie the beneficial effect of high-arousal negative affect (De Dreu, et al., 2008). Consequently, a high-arousal positive affect (cheerfulness) was chosen for the affective intervention in the present study.

In this study, participants’ task was to generate original or creative uses of conventional everyday objects (AU task) while the EEG was recorded. Three different experimental conditions were realized. In the cognitive stimulation condition, participants worked on the AU task subsequent to a short intervention in which they were – as it is the case in classic group-based creativity techniques such as brainstorming – confronted with creative ideas of other people (cf. Dugosh et al., 2000; Dugosh and Paulus, 2005). In the affective stimulation condition, participants had to generate creative ideas after the presentation of sound clips of merrily laughing people. Relevant experimental studies demonstrated that positive affect is contagious from short auditory stimuli comprised of human vocal affect expressions such as laughter (Hietanen et al., 1998; Meyer et al., 2005; Warren et al., 2006). In the control condition no intervention was applied. In each experimental condition, participants were instructed to respond as creatively and as originally as possible to the presented stimulus words. We expect that participants generate ideas of higher originality when they are cognitively and affectively stimulated, as compared with the control condition in which no intervention is applied. At the neurophysiological level, the creativity interventions should be reflected in changes of EEG alpha activity patterns. Given that this is the first study in this field which investigates potential brain mechanisms related to affective and cognitive creativity interventions, this study must be considered as rather exploratory, and the formulation of specific hypotheses may be rather difficult. However, based on recent findings in this field (e.g. Fink et al., 2009a,b), we might generally assume alpha activity in bilateral frontal and right parietal brain regions as being particularly sensitive to creative cognition. Given the particular role of the prefrontal cortex in positive affective states, along with its prominent role in creative cognition, both creativity interventions may be assumed to be closely associated with activity in this brain region.

## 2. Method

### 2.1. Participants

Forty-eight adult students (22 females, 26 males) participated in this EEG study. Due to technical problems the data of three persons had to be excluded from further analyses. The final sample comprised 45 participants (23 males, 22 females) in the age range between 18 and 32 years ( $M = 23.09$ ,  $SD = 3.48$ ). All participants were healthy volunteers with no history of substance abuse or other medical, psychiatric, or neurological disorders which could affect the measures. In addition, participants were screened for gelotophobia (i.e., the fear of being laughed at) using the GELOPH <15> (Ruch and Proyer, 2008). Only low gelotophobic individuals (scores  $\leq 1.5$ ) were invited to participate. All participants were right-handed as assessed by a standardized handedness test (performance test; Papousek and Schultze, 1999; Steingrüber and Lienert, 1971), and gave written informed consent prior to the EEG recording session.

### 2.2. Experimental tasks

Participants worked on three experimental conditions while the EEG was recorded. In each condition, conventional everyday objects were shown on the computer screen and participants were instructed to generate as creative and as original uses of these objects as possible (Alternative Uses task, AU). (1) In the cognitive stimulation condition (COG) we sought to stimulate our participants cognitively via the exposure to other people's ideas (see, e.g., Dugosh and Paulus, 2005). For this purpose, the stimulus word appeared on the computer screen conjointly with two highly original example answers (see Fig. 1), as they were obtained in a pre-experimental pilot test. (2) In the affective stimulation condition (AFF) we aimed at inducing positive affective states by means of emotionally contagious sound clips that have proven to successfully induce cheerful mood in previous studies of our lab (Weber et al., 2011; Papousek et al., 2011). In these clips, a small, mixed-gender group of people were laughing heartily. Five different 4 s-parts of the originally 90 s long sound clip were presented over headphones during each of the AFF trials.<sup>1</sup> Finally (3), in the control condition the stimulus word was displayed without any intervention. In each condition (COG, AFF, control), 15 stimulus words were presented, resulting in a total number of 45 trials.

As exemplarily shown in Fig. 1, each trial started with the presentation of a fixation cross for a time period of 10 s. This time period served as reference interval for the quantification of task-related power changes in the EEG (description see below) and participants had to look at the presented cross during this time. Then, the stimulus word appeared for 4 s on the computer screen, conjointly with two highly original example answers (COG) or with laughter (AFF). In the control condition, only the stimulus word was presented. In each experimental condition participants were instructed to respond as creatively and as originally as possible. After the presentation of the stimulus word, a white-colored interrogation mark was displayed and remained on the screen for a time period of 10 s. During this time participants had to think of possible uses for the object denoted by the stimulus word (with eyes open) and they were asked not to speak aloud. Then the interrogation mark changed its color from white into green and participants were asked to articulate their

most original idea. For this they had four seconds (see Fig. 1). The generated oral responses were recorded and later transcribed for further analyses. At the end of each trial, participants were requested to evaluate the originality of their ideas by selecting either the "creative" or "uncreative" check box on the screen by mouse click.

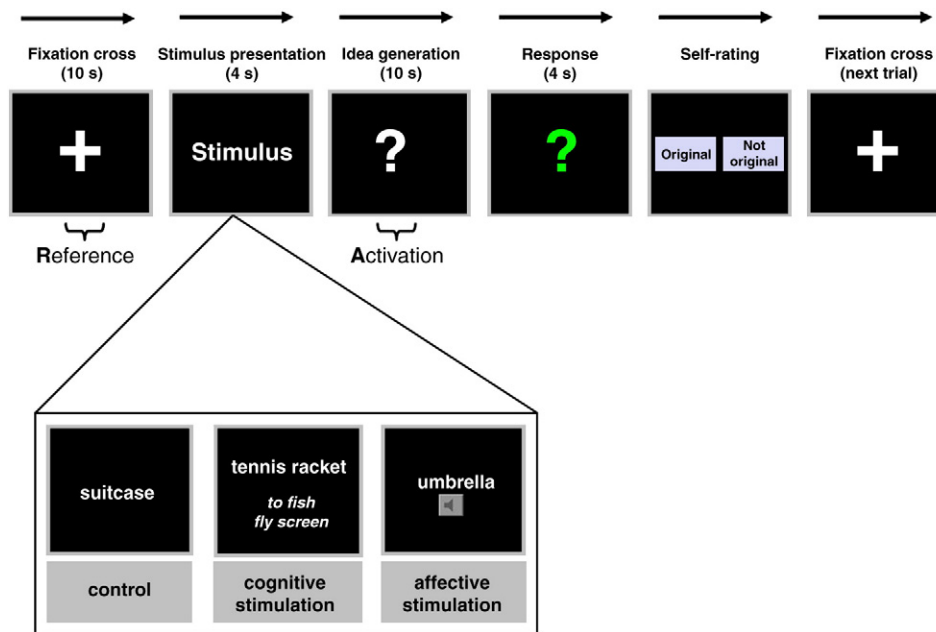
### 2.3. Apparatus/EEG recording

The EEG was measured with a Brainvision BrainAmp Research Amplifier (Brain Products) by means of Ag/AgCl electrodes located in an electrode cap in 19 positions (FP<sub>1</sub>, FP<sub>2</sub>, F<sub>3</sub>, F<sub>7</sub>, F<sub>z</sub>, F<sub>4</sub>, F<sub>8</sub>, T<sub>7</sub>, C<sub>3</sub>, C<sub>z</sub>, C<sub>4</sub>, T<sub>8</sub>, P<sub>7</sub>, P<sub>3</sub>, P<sub>z</sub>, P<sub>4</sub>, P<sub>8</sub>, O<sub>1</sub>, O<sub>2</sub>); the ground electrode was located at FP<sub>z</sub>, the reference electrode was placed on the nose. To register eye movements, an electrooculogram (EOG) was recorded bipolarly between two electrodes diagonally placed above and below the inner respectively the outer canthus of the right eye. The EEG signals were filtered between 0.1 Hz and 100 Hz; an additional 50 Hz notch filter was applied. Electrode impedances were kept below 5 kΩ for the EEG and below 10 kΩ for the EOG. All signals were sampled at a frequency of 500 Hz.

As in our previous studies (e.g., Fink et al., 2009a,b), we quantified task-related power (TRP) changes in different EEG alpha frequency band, viz. in the lower alpha (8–10 Hz) and in the upper alpha band (10–12 Hz). Both alpha bands showed similar effects, but the upper alpha band was somewhat more sensitive to the employed creativity interventions. For reasons of clarity we therefore decided to focus on this frequency band here. Task related power at an electrode  $i$  was obtained by subtracting (log-transformed) power during a pre-stimulus reference interval ( $Pow_i$  reference) from (log-transformed) power during the activation interval ( $Pow_i$  activation) according to the formula:  $TRP(\log Pow_i) = \log [Pow_i \text{ activation}] - \log [Pow_i \text{ reference}]$  (Pfurtscheller, 1999). Therefore, decreases in power from the reference to the activation interval are expressed as negative values (i.e., desynchronization), while task-related increases in power (synchronization) are expressed as positive values.  $Pow_i$  activation and  $Pow_i$  reference were determined as follows: EEG alpha activity was measured during the entire experimental session, but for the analyses of task-related changes of alpha activity (i.e., rest vs. creative idea generation) only the following time intervals were used: First, an 8 s interval out of the 10 s long reference interval, during which a fixation cross was presented (1 s after onset of the fixation cross and 1 s prior to the offset of the fixation cross or prior to stimulus presentation, respectively, were omitted in the TRP analyses). And second, an 8 s time interval during the 10 s long creative idea generation period served as activation interval (1 s after stimulus onset and 1 s prior to the offset of the stimulus were again omitted in the analyses of TRP). With respect to the activation interval it is important to note that we used the time interval subsequent to (and not during) the stimulation; also, we included only trials in which actually an idea was generated. For both the reference and the activation periods EEG data were carefully checked for artifacts and artifactual epochs caused by muscle tension, eye blinks or eye movements were excluded from further analyses. In a next step, EEG signals were filtered by applying an FFT filter for the analyzed alpha frequency bands (lower alpha: 8–10 Hz; upper alpha: 10–12 Hz). Subsequently, power estimates were obtained by squaring filtered EEG signals and then band power values ( $\mu V^2$ ) were (horizontally) averaged for both the pre-stimulus reference and the activation intervals, so that for each single trial alpha power estimates for the activation and the reference period were available. Subsequently, the alpha power measures were averaged over the trials of a condition.

The TRP values were analyzed by means of repeated measurement ANOVAs in considering the factors CONDITION (COG, AFF, control), HEMISPHERE (left vs. right) and POSITION (eight positions in each hemisphere) as within-subjects variables. The midline electrodes (F<sub>z</sub>, C<sub>z</sub>, P<sub>z</sub>) were not included in the analyses (as we were also interested in potential hemispheric differences). In case of violations of sphericity assumptions, the multivariate approach to the repeated measurements variables was used (Vasey and Thayer, 1987).

<sup>1</sup> For thirty-one participants of this study, who took also part in another study, subjective ratings on the originally 90 s long audio clips were available. These participants rated the stimulus material as being significantly more pleasurable than displeasing (83.6 vs. 8.9, on a graphical 100-point scale,  $F(1,30) = 171.87$ ,  $p < .01$ ,  $\eta_p^2 = .85$ ; as assessed by means of an ANOVA for repeated measures). Also, participants indicated that the presented sound clips of laughing people affected them more strongly with cheerfulness/happiness ( $M = 92.2$ ;  $SD = 13.5$ ) than with fear ( $M = 3.7$ ,  $SD = 13$ ), sadness ( $M = 3.5$ ,  $SD = 14.3$ ), anger ( $M = 8.3$ ,  $SD = 19.2$ ) and shame ( $M = 8.5$ ,  $SD = 19.8$ ),  $F(4, 27) = 116.27$ ,  $p < .01$ ,  $\eta_p^2 = .88$ .



**Fig. 1.** Overview of experimental design and measurement intervals. Each trial started with the presentation of a fixation cross for a time period of 10 s. Then, the stimulus word was shown for 4 s, conjointly with two highly original example answers (cognitive stimulation condition) or with laughter (affective stimulation condition). In the control condition, only the stimulus word was presented. In each experimental condition participants were instructed to respond as creatively and as originally as possible. After the presentation of the stimulus word, a white-colored interrogation mark was displayed and remained on the screen for a time period of 10 s. During this time participants had to think of possible uses for the object denoted by the stimulus word and they were asked not to speak aloud. Then the interrogation mark changed its color from white to green and participants were asked to articulate their most original idea. At the end of each trial, participants were requested to evaluate the originality of their ideas by selecting either the “creative” or “uncreative” check box on the screen by mouse click. For the analyses of task-related changes in EEG alpha activity during creative idea generation we used an 8 s time interval out of the 10 s long presentation of the fixation cross (prior to stimulation) and an 8 s time interval during the 10 s long creative idea generation period (i.e. subsequent to and *not* during stimulation).

#### 2.4. Behavioral data analysis

Originality of creative idea generation during the EEG experiment was assessed by means of self-ratings (obtained during the EEG experiment, see Fig. 1) and external ratings (outside the EEG laboratory by nine independent judges). With respect to the external ratings (cf. Amabile, 1982), seven females and two males were instructed to evaluate each single idea of a participant on a five-point rating scale ranging from 1 (“highly original”) to 5 (“not original at all”). Subsequently, the ratings were averaged over all items of a condition, so that one originality measure was available for each condition and participant. Inter-rater agreement was satisfactory (intra-class correlation coefficients for the three conditions: COG: .73; AFF: .71; control: .76). The self-ratings and the external ratings, averaged for each participant and condition, were analyzed by means of ANOVAs for repeated measures with the within-subjects factor condition (COG, AFF, control).

#### 2.5. Procedure

Recordings were made in an acoustically and electrically shielded examination chamber. At the beginning of the EEG recording session, two 2-min EEG sequences under resting conditions were recorded, the first with eyes closed, the second with eyes open (data not reported). Then, after a thorough task instruction (demonstration of tasks, type of responding etc.) the participants started to work on the experimental tasks. The presentation of the stimulus words and the assignment of conditions (cognitive stimulation, affective stimulation, no stimulation) to the stimulus words were fully randomized. During the recordings, the experimenter was outside the chamber, and the participants were observed by use of a monitoring camera. The total time of the EEG testing session including other measurements was about 60 min.

### 3. Results

#### 3.1. EEG results

Creative idea generation was generally accompanied by comparatively strong increases in alpha activity relative to the pre-stimulus reference period. Specifically, the ANOVA for repeated measures revealed a significant main effect of POSITION ( $F(7, 38) = 3.15, p < .05, \eta_p^2 = .13$ ), indicating comparatively strong increases in alpha activity in frontal ( $F_3, F_4, F_7, F_8$ ) and particularly in frontopolar ( $FP_1, FP_2$ ) regions, while in temporal cortices ( $T_7, T_8$ ) even a small alpha desynchronization was observed. Specific post hoc tests by means of the Tukey HSD test revealed significant differences ( $p < .05$ ) only between frontopolar and the remaining cortical positions. In addition, creative idea generation was generally associated with stronger increases in alpha activity in the right hemisphere (i.e. main effect of HEMISPHERE:  $F(1, 44) = 27.89, p < .01, \eta_p^2 = .39$ ). As shown in Fig. 2, this effect was moderated by topographical area, as it was reflected in a significant interaction between POSITION and HEMISPHERE ( $F(7, 38) = 3.28, p < .01, \eta_p^2 = .13$ ). Accordingly, left-hemispheric cortices in central ( $C_3$ ), parietal ( $P_3, P_7$ ), occipital ( $O_1$ ) and particularly in temporal ( $T_7$ ) areas showed task-related desynchronization of alpha activity (i.e., decreases in alpha activity relative to rest), while right-hemispheric cortices exhibited a diffuse and widespread pattern of alpha synchronization. The Tukey HSD test revealed significant hemispheric differences ( $p < .01$ ) at all electrode sites, except for  $FP_1$  vs.  $FP_2$  and for  $F_3$  vs.  $F_4$ .

Regarding the effects related to the experimental condition, the ANOVA for repeated measures revealed a significant main effect of STIMULATION ( $F(2, 88) = 4.43, p < .05, \eta_p^2 = .09$ ), indicating that cognitive stimulation via the exposure to other people's ideas elicited the strongest increases in alpha activity, followed by affective stimulation and the control condition which exhibited lower levels of alpha synchronization. Post tests revealed significant differences only between

the cognitive stimulation and the control condition ( $p < .05$ ). This stimulation effect on brain activity was further moderated by topographical area (STIMULATION  $\times$  POSITION:  $F(14, 31) = 4.35, p < .01, \eta_p^2 = .043$ ).

As illustrated in Fig. 3, both the cognitive and the affective stimulation were accompanied by comparatively strong alpha increases in the dorsolateral prefrontal cortex ( $F_7, F_8$ ) as compared with the control condition. The cognitive stimulation intervention additionally exhibited strong alpha activity in frontopolar ( $FP_1, FP_2$ ) regions. Alpha synchronization was lowest in temporal areas ( $T_7, T_8$ ), particularly in the affective and in the control condition where even alpha desynchronization emerged. The subsequent post hoc test (Tukey HSD) showed that the cognitive stimulation condition was associated with significantly stronger alpha synchronization than the affective and the control condition at frontopolar leads ( $p < .01$ ). Moreover, the cognitive stimulation condition also elicited more alpha at dorso-lateral leads ( $F_7, F_8$ ) than the control condition ( $p < .05$ ); the comparison between the affective and the control condition at these positions just failed to reach statistical significance in the Tukey HSD test ( $p = .09$ ).

3.2. Behavioral results

An ANOVA for repeated measures revealed no significant differences in originality between the three experimental conditions (COG, AFF, control), neither with respect to the self-rated measures which were obtained at the end of each trial during the EEG recording session ( $F(2, 88) = 1.17, p > .05, \eta_p^2 = .03$ ), nor with respect to the ratings of the judges ( $F(2, 88) = 0.86, p > .05, \eta_p^2 = .02$ ). The judges evaluated the ideas as being of a similar originality level across the three experimental conditions (COG:  $M = 3.16, SD = 0.21$ ; AFF:  $M = 3.16, SD = 0.20$ , Control:  $M = 3.12, SD = 0.20$ ).

Experimental conditions differed significantly with respect to the number of generated ideas,  $F(2, 43) = 3.85, p < .05, \eta_p^2 = .10$ . In each condition 15 trials were given and the participants were required to verbalize only one single idea per trial, resulting in a maximum possible number of ideas of 15 per condition. Stimulating participants via the exposure to other people's ideas yielded a significantly ( $p < .05$ ) lower number of generated ideas ( $M = 12.78, SD = 2.38$ ) than affective stimulation ( $M = 13.44, SD = 1.47$ ) and the control condition ( $M = 13.60, SD = 1.54$ ), as it was revealed by the Tukey HSD test.

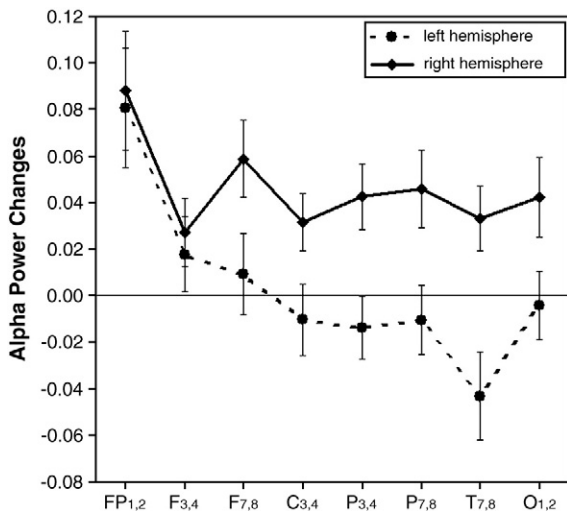


Fig. 2. Task-related changes in EEG alpha power in the upper alpha band (10–12 Hz) during creative idea generation: interaction between hemisphere and cortical position.

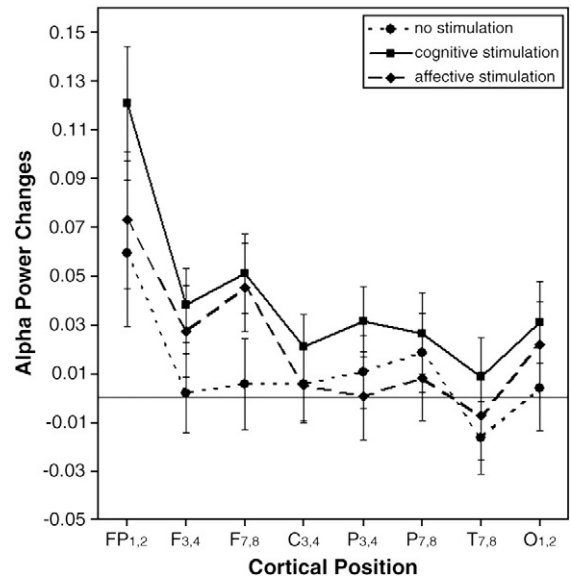


Fig. 3. Task-related changes in EEG alpha power in the upper alpha band (10–12 Hz) during creative idea generation: interaction between stimulation condition and cortical position.

4. Discussion

Similar to previous EEG studies in this field, this study revealed evidence that creative idea generation was associated with comparatively strong increases in alpha activity relative to a pre-stimulus reference period. Particularly the finding that creative cognition elicits a diffuse and widespread pattern of alpha synchronization in the right-hemisphere, along with weak alpha desynchronization in left parietal and temporal brain regions (see Fig. 2) nicely replicates previous studies of our laboratory (e.g., Fink et al., 2009a). In addition, this is to our very best knowledge the first study which shows that stimulating creativity via the exposure to other people's ideas and via positive affect was associated with alpha increases in prefrontal regions of the brain (see Fig. 3). This effect was somewhat stronger for the cognitive stimulation condition, and specific post hoc comparisons between the affective and the control condition just failed to reach statistical significance in the Tukey HSD test.

In this vein, the findings of this study contribute to the existing literature in the burgeoning field of creativity which has produced reliable evidence of EEG alpha activity as being fairly sensitive to a broad variety of different creativity-related task demands (e.g., Bazanova and Aftanas, 2008; Fink et al., 2009a,b; Jaušovec, 2000; Jaušovec and Jaušovec, 2000; Razumnikova, 2000). According to the relevant literature in this field, alpha synchronization appears to be especially relevant during internal processing demands, for instance when participants are required to hold information temporarily in mind (see, e.g., Jensen et al., 2002; Sauseng et al., 2005; Klimesch et al., 2007). Along these lines, the observed alpha synchronization during creative cognition could reflect the absence of stimulus-driven, external bottom-up stimulation and, thus, a form of top-down activity (cf. von Stein and Sarnthein, 2000), or a state of heightened internal attention (cf. Knyazev et al., 2006) facilitating the (re-)combination of semantic information that is normally distantly related.

As evident in Fig. 3, intervention-related increases in alpha synchronization were highest at frontal electrode sites. With respect to the cognitive stimulation condition, we may interpret the observed findings in a manner that the presented stimuli induced a state of heightened internal attention facilitating the efficient (re-)combination of memory contents, which appears to remain immune to bottom-up-stimulation or potentially interfering cognitive activities (cf. Klimesch et al., 2007; Sauseng et al., 2005). At the first glance,

increased alpha synchronization after the affective stimulation may seem to contradict the expected activating effect of emotional arousal on the frontal cortex (e.g., Hagemann et al., 2005; Harmon-Jones et al., 2010; Papousek et al., 2009). However, it is important to note that we did not analyze the effect of the emotional stimulation as such (i.e., during the stimulation or in a rest condition following it, where alpha desynchronization may have been expected), but did analyze which effect the emotional stimulation had on the transient task-related change of alpha activity during performance of the creativity task (showing that the transient relative increase of alpha activity during creative cognition was further enhanced by the stimulation). The exact mechanisms by which this effect may be caused are a challenging issue for future research. Further, as only a positive affect condition was used, it cannot be decided if the effect was mainly due to the positive valence of the stimulation or to the emotional arousal as such. Previous empirical evidence suggested that both factors may play a role (De Dreu, et al., 2008).

Contrary to our expectations we observed no increases in originality as a result of the creativity interventions. One might therefore conclude that the employed interventions were not effective in improving creative cognition. Though this interpretation might be the most obvious one at first sight, we may alternatively also assume that the processes which were initialized by both creativity interventions were not restricted to one single EEG test trial, but may rather have spread across all trials of the experiment (also including those of the control condition). In this particular context, the fully randomized presentation of trials belonging to different conditions, rather than the blockwise presentation of the trials of an experimental condition, may be also responsible for possible diluting of the effects. For instance, the emotional arousal induced by the affective stimulation condition may have equally affected trials of the cognitive stimulation and the control condition, thereby yielding comparable behavioral effects. With particular respect to the cognitive stimulation intervention we might presume that the employed example answers were simply too complex or “too original” in order to improve originality in a significant manner. Performance data which reveal the lowest number of generated ideas in the COG condition appear to support this to some extent. This assumption is also backed up by a recent study of our lab revealing evidence that participants tend to be more creative when they are cognitively stimulated via the exposure to common or moderately original ideas, rather than to highly creative ideas (Fink et al., *in press*). Similarly, Dugosh and Paulus (2005) argued that shared or common information may have greater associative strength. According to the authors, common ideas are often accompanied by positive affective reactions and are (as opposed to unique information) more likely to be discussed and remembered, thereby increasing their associative strength (cf. Dugosh and Paulus, 2005, p. 319). In a similar vein, Paulus and Brown (2007) refer to behavioral findings whereupon the exposure to other people’s ideas may also have distracting or inhibiting effects on the generation of ideas (cf. also Nijstad and Stroebe, 2006), particularly in case that a person is exposed to an idea to which she or he knows little about, or to an idea that has no relation to the semantic network of this person.

In order to provide a possible explanation for the finding that the creativity interventions did not improve originality, we might also refer to the fact that the three experimental conditions did not elicit different activation patterns in posterior regions of the right hemisphere. As repeatedly shown in previous studies of our laboratory, alpha activity in right parietal brain regions appear to have an important role in creative cognition, which particularly applies for the originality facet of creativity. For instance, participants who generated highly original ideas during the Alternative Uses task showed stronger alpha activity in parietal brain regions of the right hemisphere than individuals who performed worse on this task (Fink et al., 2009a). In another study, professional dancers were observed to

exhibit alpha in these brain regions during imagining a creative improvisation dance (Fink et al., 2009b). Thus, though speculatively, another possible reason for failing to find significant stimulation effects on the behavioral level might be the lack of a condition-related effect in right parietal regions.

There are also some important limitations of this study which should be briefly mentioned. First, we used a comparatively low number of trials within each condition, which may weaken the statistical significance of the observed results; indeed, the observed effect size indices related to the creativity interventions appear to be of rather small magnitude; in addition, a larger number of trials would also facilitate the investigation of brain activity patterns in response to ideas of varying originality (e.g., alpha activity associated with lower vs. higher original ideas). Second, future studies in this field are also challenged by the research question whether or to which extent the observed findings are influenced by individual differences in personality (such as extraversion, openness or neuroticism). And finally, the affective stimulus material was presented aurally, whereas the cognitive stimulus material was presented via the visual channel. This study does not allow assessing how these two different modalities of stimulus presentation may have affected the observed patterns of alpha activity.

Notwithstanding the restrictions mentioned above, the present findings suggest that both cognitive stimulation by means of original examples and affective stimulation via positive mood induction may further augment the effect that the creative task as such has on the prefrontal cortex. This could be interpreted as being related to an enhancement of internally oriented attention, which may have a beneficial effect on creative cognition. However, future studies specifically designed for that purpose are required to reliably examine whether the observed changes in brain activity may in fact be associated with improved originality in creative cognition. Related to this, future studies in this field should also specifically address the central research question whether cognitive and affective creativity interventions unfold comparable or distinct contributions to the process of creative cognition, both behaviorally and at the level of the brain.

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