# Tackling creativity at its roots: Evidence for different patterns of EEG alpha activity related to convergent and divergent modes of task processing

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ABSTRACT

The distinction between convergent and divergent cognitive processes given by Guilford (1956) had a strong influence on the empirical research on creative thinking. Neuroscientific studies typically find higher event-related synchronization in the EEG alpha rhythm for individuals engaged in creative ideation tasks compared to intelligence-related tasks. This study examined, whether these neurophysiological effects can also be found when both cognitive processing modes (convergent vs. divergent) are assessed by means of the same task employing a simple variation of instruction. A sample of 55 participants performed the alternate uses task as well as a more basic word association task while EEG was recorded. On a trial-by-trial basis, participants were either instructed to find a most common solution (convergent condition) or a most uncommon solution (divergent condition). The answers given in the divergent condition were in both tasks significantly more original than those in the convergent condition. Moreover, divergent processing was found to involve higher task-related EEG alpha power than convergent processing in both the alternate uses task and the word association task. EEG alpha synchronization can hence explicitly be associated with divergent cognitive processing rather than with general task characteristics of creative ideation tasks. Further results point to a differential involvement of frontal and parietal cortical areas by individuals of lower versus higher trait creativity.

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## 1. Introduction

It seems to be a matter of the time we live in that creativity is becoming more and more important, not only in its classic field like the arts but also in scientific, technological and economic contexts as well as in everyday life. As Dietrich and Kanso (2010) put it: "All progress and innovation depend on our ability to change existing thinking patterns, break with the present, and build something new" (p. 822). Therefore, academic psychology has become increasingly interested not only in the study of human intelligence but also creativity as a central variable in human achievement. The psychological line of research since the 1950s has also been able to demystify creativity to a certain degree. While earlier perspectives considered creativity as something dark and mysterious, it can nowadays be regarded as a common cognitive process with relevance to many areas of everyday life (Simonton, 2000).

In his well-known Structure-of-Intellect model, Guilford (1956) distinguished convergent from divergent cognitive processes. While convergent processes are involved in straightforward problem solving,

divergent thinking is the "kind that goes off in different directions" (Guilford, 1959a, p. 381). The unique feature of divergent thinking tests thereby is "that a *variety* of responses is produced" (Guilford, 1959b, p. 473). This view, which could possibly be called a two-process-model, has also been emphasized by other authors such as Kris (1952). Out of a psychoanalytical point of view, he described creativity as the ability to switch between primary and secondary process cognition; i.e. more autonomous and associative versus logical and reality-oriented thinking. Primary processes should be more likely to occur in states of dream or reverie (as well as in the pathological state of psychosis), whereas secondary processes are dominant in waking consciousness. These processes are regarded as two poles of one continuum, on which creative people should be better able to move between them than less creative ones. There is a good line of evidence supporting these hypotheses. It could be shown that creative people report more fantasy activity, remember their dreams better, are more easily hypnotized and show, as predicted by Kris, better ability to shift between primary and secondary processes (for an overview see Martindale, 1999).

Mendelsohn (1976) conceived creativity as a result of individual differences in the focus of attention and attentional capacity. Defocused as opposed to focused attention corresponds to a higher attentional span, and hence allows for more possibilities to combine different concepts and generate novel ideas. Summing up, there exist different models involving two opposing cognitive processes, either called divergent/convergent, primary/secondary or defocused/

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focused. According to Martindale (1999), these classifications are "more or less identical but expressed in very different vocabularies" (p. 139). Generally, creativity is associated with the former rather than the latter process, although there is an agreement that complex creative problem solving often involves both processes (Cropley, 2006).

A number of neurophysiological investigations have addressed the research question whether divergent as opposed to convergent thinking processes are related to dissociable patterns of cortical activation. To this end, many studies contrasted the brain activation during the performance of creative ideation tasks as compared to intelligence-related tasks. In an early study, Martindale and Hasenfus (1978) found higher EEG alpha power during a phase of creative *inspiration* but not during a presumably more convergent phase of creative *elaboration*. The interpretation of alpha power as an *inverse function of cortical arousal* led to a broader theory suggesting that creative cognition is more likely to happen in a state of low cortical arousal (i.e. high alpha power) commonly referred to as the "low-arousal-hypothesis" (Martindale, 1999). More recent neuroscientific studies of creative thinking could not only corroborate but also extend these findings leading to a better understanding of alpha activity in creative cognition: Fink et al. (2007, 2009a) demonstrated higher increases in alpha power (from a prestimulus reference period to an activation period; subsequently referred to as alpha *synchronization*) during the performance of the alternate uses task (i.e., a standard creative ideation task which requires participants to think of original uses for common everyday objects) as compared to more verbal intelligence-related tasks like the completion of word suffixes or the generation of object characteristics. In another study, Fink et al. (2009b) found higher alpha synchronization during the imagination of a dance improvisation than during imagination of performing a standard waltz dance. These findings suggest that the more creativity-related a task is, the higher is the synchronization of alpha activity. Mölle et al. (1999) reported higher dimensional complexity of the EEG alpha and beta spectrum for creative ideation tasks (e.g., alternate uses task) as opposed to intelligence-related tasks (e.g., mental arithmetic task). A further study investigating dimensional complexity showed that the solving of ill-defined problems was accompanied by higher coherence as it was the case in well-defined problems (Jausovec and Jausovec, 2000).

On an interindividual level, Martindale and Hines (1975) found that individuals scoring high on an alternate uses task showed higher alpha power in frontal cortical areas as opposed to less creative persons. In a more recent study, persons who gave more original answers in an alternate uses task were found to show higher alpha power increases in frontal and also posterior brain regions of the right hemisphere (Fink et al., 2009a). This finding stands in line with a hypothesis put forward by Jung-Beeman (2005) suggesting that focused left-hemispheric semantic processing is accompanied by a contralateral, right-hemispheric, process inducing a broader spreading activation in the semantic network. Jausovec (2000) found that functional coupling in frontal and parietal brain regions was higher in creative than in gifted individuals during divergent thinking underpinning the notion of two distinct mental abilities.

Although there is a considerable body of evidence for the phenomenon of alpha synchronization during creative idea generation, other studies using different methodologies provided different results: Razumnikova (2000) found that a divergent thinking task as well as an arithmetic task induced desynchronization in the lower and upper alpha bands compared to a resting condition in a sample of young males. A study involving the remote associates task and a simple associates task demonstrated decreases in lower and upper alpha power especially over posterior cortex sites in both sexes (Razumnikova, 2007).

The cognitive neuroscience of creativity is still struggling with a high grade of heterogeneity concerning its methods of investigation (Arden et al., 2010; Dietrich and Kanso, 2010). According to Dietrich and Kanso's review, it is hard to draw any convincing conclusions

out of the data: "The most forthright conclusion that can be taken away from the present review is that not a single currently circulating notion on the possible neural mechanisms underlying creative thinking survives close scrutiny" (p. 845). Arden et al. state that this might be the case because it is hard to compare studies to one another due to substantially different research paradigms involving different creativity tasks and again different control tasks. In order to study the nature of divergent thinking, it hence appears more accurate to contrast divergent and convergent thinking processes within the same type of task instead of comparing two entirely different tasks (e.g. an alternate uses vs. an arithmetic task). In this study convergent and divergent thinking was operationalized by means of two different response conditions either asking for the generation of original or of common responses to the same task. This procedure allows examining whether alpha synchronization, as commonly observed during divergent thinking tasks, can unambiguously be attributed to the process of divergent thinking and not to other general task characteristics inherent in this specific type of task. In order to study the robustness and generalizability of this phenomenon we employed two different ideation tasks, the alternate uses task as well as a word association task. While the alternate uses task can be conceived as a standard task of creative ideation, the word association task reflects basic ideational processes that were found to underlie creative thinking (Benedek et al., 2012 ; Mednick, 1962; Merten and Fischer, 1999). We hypothesize that divergent task processing in both ideation tasks should be accompanied by stronger synchronization of alpha power as compared to convergent task processing, especially in frontal cortical areas. Furthermore, we expect that the pattern of neurophysiological activity stands in interaction with individual differences in trait creativity.

## 2. Materials and methods

### 2.1. Participants

Participants were sampled from a larger pool of 929 pupils, which had previously been screened for creativity and intelligence (see next section). They were selected to differ with respect to creativity but not with respect to intelligence. The sample consisted of $N = 55$ young males (28 high creative individuals) with an age ranging from 15 to 18 years ($M = 16.79$, $SD = 0.68$). All participants were healthy, right-handed and gave written informed consent prior to the EEG session. They were paid for participation.

### 2.2. Psychometric tests

Creativity screenings were based on the averages of the scales *Anwendungs-Möglichkeiten* [Alternate Uses], *Insight-Test* and *Zeichen-Fortsetzen* [Continue Figures] of the Berliner Intelligenzstrukturtest (BIS; Jäger et al., 1997). These were scored quantitatively reflecting a measure of ideational fluency. Intelligence was assessed by means of the Intelligenzstrukturanalyse (ISA; Institut für Test- und Begabungsfoschung and Gittler, 1998). Personality structure was assessed with the German version of the Eysenck Personality Questionnaire (EPQ-R; Ruch, 1998). The EPQ-R was administered in order to explore possible personality correlates of task performance. State anxiety was assessed as part of a standard procedure in order to rule out the possibility of excessive state anxiety related to the EEG test setting. using a German version of Spielberger's Stait-Trait-Anxiety-Inventory (STAI; Laux et al., 1981).

### 2.3. Experimental tasks and conditions

Two different verbal tasks were employed to assess creative ideation at two different levels of task complexity. The alternate uses (AU) task is a well-established creative ideation task, which requires

participants to think of novel uses for everyday objects (Torrance, 1966). A word association (AS) task which requires participants to name an association to a given concept was employed as a second more basic ideation task. Both tasks had to be performed under two experimental conditions, requiring participants either to find a highly common solution (*common response condition*) or to find a highly uncommon solution (*uncommon response condition*).

For example, in the AU task participants might be shown the stimulus word *brick* and would then respond e.g. *to build a wall* in the common or *to use for karate demonstration* in the uncommon response condition. In the AS task, participants were instructed to produce either a common or an uncommon association to a stimulus. Given for instance the word *mother* as a stimulus, participants could respond *father* in the common or *earth* in the uncommon condition.

Each task featured 10 items per condition. The order of item presentation was randomized within each task; the experimental conditions were counterbalanced for each item in order to ensure equal numbers of responses in either condition. Items for the AU task were adapted from a pool of items used in previous studies (cf. Fink et al., 2009a, 2010), those for the AS task were taken from the word-association lists constructed by Merten and colleagues (Merten, 1990; Merten and Fischer, 1999), and from the German word-association norms by Riedlnger (1994).

Three female and three male students rated originality of responses (similar to the consensual assessment technique proposed by Amabile, 1982) given in both the AU and the AS task on a four-point scale ranging from 1 "very common" to 4 "very uncommon". All ratings displayed high internal consistencies (Cronbach's $\alpha > .85$).

## 2.4. Apparatus/EEG recording

The EEG was measured by means of Ag/AgCl electrodes. 33 electrodes were placed according to the enhanced 10–20-system. A ground electrode was placed on the forehead, a reference electrode on the tip of the nose. To measure eye movements, an electrooculogram (EOG) was recorded bipolarly between two diagonally placed electrodes above and below the inner and the outer canthus of the right eye. EEG impedances were kept below 5 kΩ; EOG below 10 kΩ. All signals were sampled at a frequency of 512 Hz. During recording a bandpass (0.1–100 Hz) as well as a 50 Hz notch-filter in order to avoid power line contaminations were applied (all apparatus distributed by BrainProducts GmbH, Gliching/GER).

The experimental paradigm was the same in the AU and the AS task and comprised four phases within each trial. As depicted in Fig. 1, each trial started with the presentation of a fixation cross during the *reference* phase. Subsequently, a cue indicated the mode of requested cognitive processing in the *preparation* phase: When an *n* was presented, participants were to think of a common (normal) solution for the item to be presented next; a *u* indicated they should find an uncommon solution. (These stimuli were selected because

of their exactly corresponding physical features after spatial rotation by 180 degrees; they nevertheless can clearly indicate a different meaning.) In the *idea generation* phase, participants were shown the actual stimulus word (for instance *brick*). During this time, no response was required and participants were instructed not to speak. As soon as they wanted to name their idea, participants pushed a response button. A speech balloon indicated the onset of the *response phase* in which participants could vocalize their response. Termination of response was indicated by another push of the response button. After an inter-trial-interval of 1000 ms the next trial started. For each trial, the time-out was set to 30 s for AU task, 15 s for AS task.

## 2.5. Quantification of cortical activity

The raw EEG was corrected for ocular artifacts by means of a regression-based algorithm (Gratton et al., 1983) using the software Brain Vision Analyzer (1.05; BrainProducts Gmbh, Gliching/GER). Remaining artifacts were removed by visual inspection. Further analysis steps were performed by means of a set of Matlab scripts (R2011b; The MathWorks, Inc.). The bandpower of the EEG ($\mu V^2$) was computed by means of a time–frequency analysis employing a Fast Fourier-transformation (FFT) with a window size of 1000 ms and an overlap of 900 ms. From this, the power in the lower (7.5–10.5 Hz) and upper (10.5–12.5 Hz) alpha frequency band was extracted. Changes in cortical activation were quantified by means of task-related power (TRP) changes between reference and activation phases for each electrode and trial (Pfurtscheller, 1999; see also Gerloff et al., 1998). The TRP method was used since it yields robust scores and the variance of spectral power measures can further be stabilized by logarithmic (log) transformation (Halliday et al., 1995). Task-related power at an electrode *i* was obtained by subtracting the log-transformed power during prestimulus reference intervals ($Pow_{i, reference}$) from the log-transformed power during the idea generation intervals which served as activation phases ($Pow_{i, activation}$) according to the formula: $TRP_{(i)} = \log(Pow_{i, activation}) - \log(Pow_{i, reference})$. Negative values therefore reflect decreases in power from reference to activation (subsequently referred to as desynchronization), positive values reflect increases (referred to as synchronization; cf. Pfurtscheller and Lopes de Silva, 1999). In both tasks and conditions, the whole time period of idea generation (from 500 ms after stimulus onset to 500 ms before the pushing of the idea button) served as activation interval. Trials with timeouts were excluded from the analyses; at least 500 ms of artifact-free samples were needed in every phase of a trial in order to be counted as valid. Participants were excluded if less than 50% of valid trials were available in either of the experimental conditions.

Electrode positions were aggregated to the following areas: Anteriofrontal (AF) left (FP$_1$, AF$_3$), frontal (F) left (F$_3$, F$_7$), frontocentral (FC) left (FC$_1$, FC$_5$), centrotemporal (CT) left (C$_3$, T$_3$), centroparietal (CP) left (CP$_1$, CP5), parietotemporal (PT) left (P$_3$, T$_5$), parietooccipital (PO) left (PO$_3$, PO$_5$, O$_1$); analogously for the right hemisphere (even numbers).

## 2.6. Procedure

Prior to the EEG session, participants filled in the EPQ-R and the STAI. The EEG session started with the recording of two resting conditions with eyes open and eyes closed for 2 minutes each. Subsequently, participants performed the AS task followed by the AU task. The instructions were presented separately for each task in a standardized manner using an interactive computer presentation featuring two exercise trials. The STAI was administered once more between the two tasks. The whole EEG session took about 1 hour. The procedure was approved by the Ethics Committee of the University of Graz.
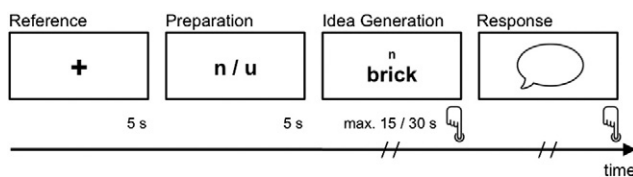


**Fig. 1.** Schematic time course of the experimental tasks. After a reference period of 5 s, participants were instructed either to find a normal (*n*) or an uncommon (*u*) solution to the subsequent task (preparation period of 5 s). Next, a stimulus word was presented (in this example *brick*) until participants pushed a button in order to indicate an idea (idea generation period of max. 15 s in the association task, and 30 s in the alternate uses task). After giving an oral response, a second button press initiated the next trial.

## 3. Results

### 3.1. Behavioral results

Dealing first with the AU task, a two-way ANOVA for repeated measures was conducted using the within-subject factor CONDITION (common vs. uncommon) and the between-subject factor GROUP (low vs. high creative). A significant main effect CONDITION indicated that ideas produced in the uncommon response condition were rated higher on originality ($M = 2.51$ [$SE = 0.39$]) than those given in the common condition ($M = 1.13$ [$SE = 0.33$]; $F$ [1,53] = 938.00, $p < .001$, $\eta^2_{partial} = .95$). A significant main effect GROUP yielded evidence that highly creative individuals produced more original ideas ($M = 1.88$ [$SE = 0.40$]) than their lower creative counterparts ($M = 1.76$ [$SE = 0.40$]; $F$ [1,53] = 4.36, $p < .001$, $\eta^2_{partial} = .08$). The interaction between CONDITION*GROUP remained insignificant ($F$ [1,53] = 1.76, $ns$).

In the AS task, a significant main effect CONDITION indicated that association responses given in the uncommon condition were rated significantly higher on originality ($M = 2.26$ [$SE = 0.47$]) than those given in the common condition ($M = 1.26$ [$SE = 0.14$]; $F$ (1,53) = 242.77, $p < .001$, $\eta^2_{partial} = .82$). The factor group and the interaction between both remained insignificant (GROUP: $F$ [1,53] = 0.38, $ns$, $\eta^2_{partial} = .01$; CONDITION*GROUP: $F$ [1,53] = 0.06, $ns$). The significant CONDITION effects in both tasks hereby provide evidence for the validity of the experimental manipulation.

In both, the AU and the AS task, reaction times were significantly higher in the uncommon than in the common response condition (AU: Common $M = 5.19$ [$SE = 0.37$], Uncommon $M = 10.30$ [$SE = 0.45$]; $F$ (1,53) = 209.28, $p < .001$, $\eta^2_{partial} = .80$; AS: Common $M = 4.15$ [$SE = 0.22$], Uncommon $M = 7.17$ [$SE = 0.31$]; $F$ (1,53) = 145.10, $p < .001$, $\eta^2_{partial} = .74$). There were no further significant effects related to the experimental groups.

Originality of uncommon responses in the AU task was negatively correlated to the lie-scale (L) of the EPQ-R ($r = -.29$, $p < .05$) in the way that persons tending to fake response behavior gave less original answers. In the AS task, originality of uncommon responses was correlated to psychoticism ([P] $r = .34$, $p < .05$) showing that individuals who scored higher on P produced more original associations. Furthermore, higher creative individuals were more extraverted than their lower creative counterparts (Low: $M = 15.22$ [$SE = 7.33$], High: $M = 18.64$ [$SE = 4.00$]; $t_{39.29} = 2.14$, $p < .05$). Concerning state anxiety, no differences between the experimental groups or the time of measurement were found.

### 3.2. EEG results

EEG data were analyzed by means of two separate ANOVAs for each task considering the within-subject factors CONDITION (common vs. uncommon), HEMISPHERE (left vs. right) and AREA (from AF to PO) and the between-subject factor GROUP (low vs. high creative). A multivariate analysis approach was used which is known to be robust in face of violations of sphericity (Vasey and Thayer, 1987). The alpha level was set to 5%.

Since EEG power in the upper and lower alpha bands turned out to be highly correlated in both tasks and experimental conditions ($.50 < r < .70$), the subbands were aggregated to a single alpha band ranging from 7.5 to 12.5 Hz (for correlational evidence see Fink et al., 2005).

In the AU task, a main effect AREA ($F$ [6,43] = 25.02, $p < .001$, $\eta^2_{partial} = .78$) showed a monotonic decrease in TRP from anteriofrontal regions to posterior regions. A main effect HEMISPHERE ($F$ [1,48] = 14.49, $p < .001$, $\eta^2_{partial} = .24$) showed generally stronger decreases in alpha power in the left hemisphere. The interaction between AREA*HEMISPHERE ($F$ [6,43] = 7.14, $p < .001$, $\eta^2_{partial} = .50$) indicated a stronger alpha desynchronization in the left hemisphere as

compared to the right hemisphere at the electrode sites from CT to PO (Tukey's HSD post-hoc tests, $p < .01$).

In line with our hypothesis, a significant main effect was observed for the factor CONDITION ($F$ [1,48] = 36.01, $p < .001$, $\eta^2_{partial} = .43$), reflecting that the production of uncommon uses was generally accompanied by lower decreases of alpha power than the production of common uses. The interaction between CONDITION*AREA ($F$ [6,43] = 5.15, $p < .001$, $\eta^2_{partial} = .42$) indicated that this effect differs over cortical areas: While the condition effect is generally evident at all electrode sites, no power differences between electrodes were observed over anteriofrontal to centroparietal areas during uncommon response generation whereas power significantly declined from anterior to posterior regions in the common condition (Tukey's HSD post-hoc tests, $p < .05$; see Fig. 2). The between-subjects factor GROUP remained insignificant ($F$ [1,48] = 1.25, $ns$).

In the AS task, a significant main effect AREA ($F$ [6,43] = 23.92, $p < .001$, $\eta^2_{partial} = .77$) was observed, reflecting a pattern of decrease in alpha power from anterior to posterior regions as it was found in the AU task. A significant main effect HEMISPHERE showed generally stronger decreases in alpha power in the left hemisphere ($F$ [1,48] = 10.53, $p < .01$, $\eta^2_{partial} = .18$). Again, an interaction between AREA*HEMISPHERE ($F$ [6,43] = 5.81, $p < .001$, $\eta^2_{partial} = .45$) revealed that the left hemisphere exhibited stronger decreases in alpha power as compared to the right hemisphere from centrotemporal to parietooccipital areas (Tukey's HSD post-hoc tests, $p < .05$).

More interestingly, a significant main effect CONDITION ($F$ [1,48] = 25.60, $p < .001$, $\eta^2_{partial} = .35$) revealed again lower desynchronization of alpha power during the production of uncommon as opposed to common ideas. This difference is significant across all cortical areas. Similar to the AU task, no power differences were observed over anteriofrontal to centrotemporal regions in the uncommon response condition whereas significant power declines from anterior to posterior regions were evident in the common condition (CONDITION*AREA: $F$ [6,43] = 3.49, $p < .01$, $\eta^2_{partial} = .33$; Tukey's HSD post-hoc tests, $p < .05$). This effect was further moderated by the factors HEMISPHERE and GROUP (CONDITION*AREA*HEMISPHERE: $F$ [6,43] = 3.15, $p < .05$, $\eta^2_{partial} = .30$; CONDITION*AREA*HEMISPHERE*GROUP: $F$ [6,43] = 2.86, $p < .05$, $\eta^2_{partial} = .28$) suggesting a differential effect of lower and higher creative individuals: In higher creative individuals, the condition effect (lower alpha desynchronization during generation of uncommon responses) is evident throughout all electrode sites in both hemispheres including anteriofrontal and frontal brain regions (Tukey's HSD post-hoc tests, $p < .05$). Lower creative individuals, however, display no significant differences in anteriofrontal and frontal alpha power, but show a condition effect only in frontocentral to parietooccipital regions ($p < .01$). The production of uncommon responses is hereby accompanied by lower desynchronization in centrotemporal to parietooccipital areas in the right as compared to the left hemisphere ($p < .05$; see Fig. 3). The main effect GROUP remained insignificant ($F$ [1,48] = 1.25, $ns$).

Interestingly, a tendential interaction between the factors CONDITION*AREA*HEMISPHERE*GROUP was also found in the AU task ($F$ [6,43] = 2.24, $p = .06$, $\eta^2_{partial} = .24$). Tukey's HSD test revealed significant condition effects ($p < .01$) across all electrode sites in both hemispheres, except for AF in the lower creative group. Higher creative individuals showed the strongest increases in alpha power in frontal areas. Lower creative persons, instead, showed the strongest increases during uncommon idea generation in posterior regions of the right hemisphere ($p < .01$; see Fig. 2).

## 4. Discussion

A central novelty of this study was to examine the brain activation related to convergent and divergent thinking processes using the same task by means of an experimental variation of the instruction. Hence, stimulus material did in no way differ between the experimental
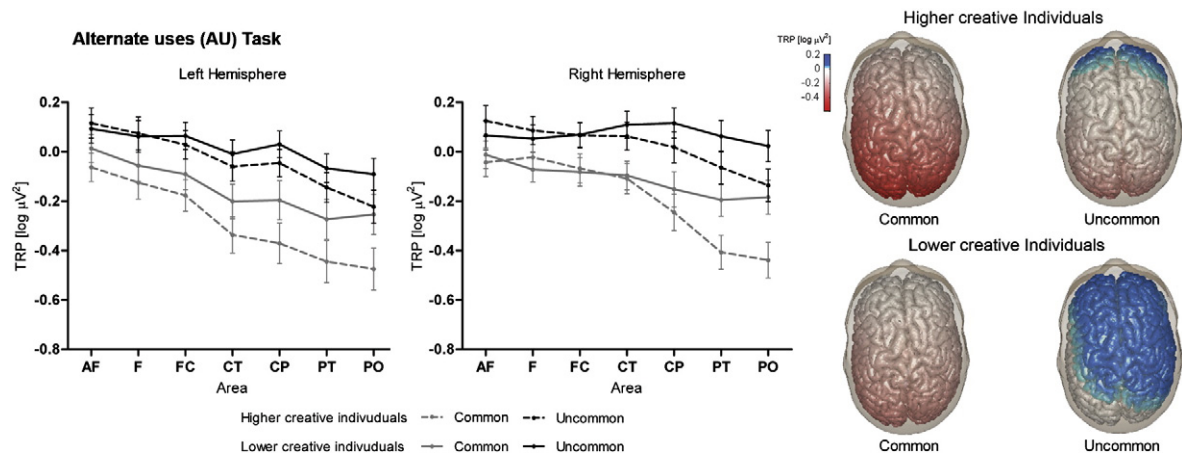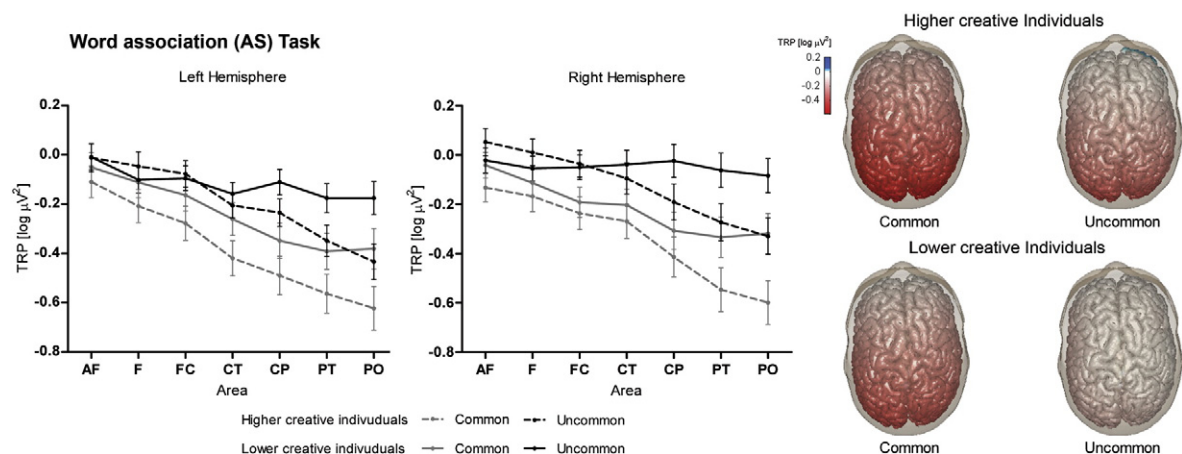
**Fig. 2.** Task-related power (TRP) changes during generation of common vs. uncommon responses in the alternate uses task. Positive TRP indicates task-related alpha synchronization (blue), negative values indicate desynchronization (red). Vertical bars indicate ± 1 standard error (SE) of the mean.

conditions and differences in task performance as well as cortical activity can be fully attributed to the variation of the instruction. This experimental variation was highly effective, as the uncommon response instruction resulted in much more uncommon responses than the common response instruction. This was true for both, the alternate uses task and the word association task. It can, therefore, be assumed that this variation of instruction results in a subtle but effective variation of elicited processing modes, triggering either convergent thinking processes (common response condition) or divergent thinking processes (uncommon response condition). Regarding the originality of responses given, originality of uncommon uses was negatively correlated to the lie-scale (L) of the EPQ-R whereas originality of uncommon associations was related to psychoticism (P). These results provide further support for the validity of the used tasks in terms of Eysenck's notion that: "P combines originality with lack of socialisation, while L combines socialisation with lack of originality" (Eysenck 1995, p. 237).

The experimental variation did not only result in differences of response behavior but also induced different patterns of neurophysiological activation. It was found that the production of uncommon responses was in both tasks generally accompanied by lower decreases of task-related alpha power than the production of common responses. While in the basic association task, generally weaker desynchronization (TRP around zero) of alpha power was observed during uncommon

than common response generation, this result was even more pronounced in the alternate uses task. Here, thinking about uncommon responses yielded synchronization of alpha power in frontal and parietal cortical regions, whereas the generation of common responses induced desynchronization. These results can be seen as supporting our hypothesis and stand in line with a number of studies demonstrating the significance of alpha activity in creative cognition (Fink and Neubauer, 2006; Fink et al., 2007, 2009a). We hence can conclude that increased levels of alpha power (i.e., higher task-related alpha synchronization or reduced task-related desynchronization) are specifically related to the process of divergent thinking rather than other processes elicited by other general task characteristics of creative ideation tasks.

According to current theories on the functional interpretation of EEG alpha synchronization, it is either viewed as a correlate of active top-down inhibition of task-irrelevant processes (Klimesch et al., 2007; Sauseng et al., 2005) or of internally directed attention (Cooper et al., 2003; Jensen et al., 2002). Recent evidence suggests that increased internal processing demands (in convergent and divergent thinking) result in frontal alpha synchronization, whereas parietal synchronization is supposed to facilitate the recombination of semantic information in divergent thinking (Benedek et al., 2011). Divergent thinking as assessed in the present study (i.e., finding uncommon solutions) may thus more strongly draw on internal processing than convergent thinking (i.e., finding common solutions),



**Fig. 3.** Task-related power (TRP) changes during generation of common vs. uncommon responses in the association task. Positive TRP indicates task-related alpha synchronization (blue), negative values indicate desynchronization (red). Vertical bars indicate ± 1 standard error (SE) of the mean.

since common solutions have stronger association strengths and can be retrieved more easily (Mednick, 1962). Moreover, the stronger alpha power increases observed in the alternate uses task (as compared to the association task) point to an increase in internal processing demands along with task complexity. The higher response times in the AU than in the AS task suggest that a higher depth of internal ideational elaboration took place in the former task. At this, it should be noted that other studies which revealed strong alpha synchronization during creative thought used performance intervals of up to 3 minutes (e.g., Fink et al., 2009b). The rather low total response times in the word association task of 4 to 7 s thus may explain why in this task no task-related synchronization of alpha activity was evident, but uncommon responses just resulted in lower task-related desynchronization of alpha activity as compared to uncommon responses.

A recently published fMRI-study using essentially the same research paradigm as we did (although stimuli were presented as visual objects) investigated cortical activity during "creative" as opposed to "common" object use in a between-subject comparison (Chrysikou and Thompson-Schill, 2011). The main result was that creative object use was accompanied by activity in posterior regions of the brain whereas common object use elicited prefrontal activity. The authors interpret the missing prefrontal involvement during creative object use as a state of diffuse attention due to hypofrontality. Considered together with EEG studies that found frontal alpha synchronization in creative ideation tasks, this interpretation rather conforms to the cortical idling-hypotheses (Pfurtscheller et al., 1996). However, the view that EEG alpha during cognitive tasks reflects pure cortical idling has, as discussed above, been mainly superseded and other studies using fMRI point to the active role of prefrontal areas in creative ideation (Fink et al., 2009a, 2010).

The observed four-factorial interactions in the word association task and the alternate uses task suggest a specific pattern of neural activity with respect to interindividual differences: While lower creative persons showed little variance between convergent and divergent processing in the activation of their frontal cortices, highly creative individuals displayed more *variability* in frontal areas. This effect seems more pronounced in the right than in the left hemisphere and is characteristic for both tasks. It could therefore be hypothesized that highly creative individuals are possibly better able to adaptively *switch* between different modes of cognitive processing and accordingly show increased *frontal flexibility*. This interpretation would go along with different theories of creativity, such as Kris' (1952) ability to shift between primary and secondary process cognition, or Martindale's (1999) conception of differential attention. The notion that highly creative individuals display greater variability in frontal cortical activation would also correspond to a neurophysiological framework of creativity proposed by Dietrich (2004), who assumes that frontal cortical areas of the right hemisphere are involved in processes of attentional flexibility. A recent empirical investigation involving a Stroop-paradigm also suggests that highly creative persons show greater flexibility in cognitive control on a behavioral level (Zabelina and Robinson, 2010).

For lower creative individuals, a robust difference between convergent and divergent cognitive processing was observed in posterior rather than in frontal brain regions: It turned out that during the generation of uncommon responses, lower creative persons exhibited alpha synchronization (or weak desynchronization) in centrotemporal to parietooccipital regions, while production of common responses resulted in substantial alpha desynchronization. This interindividual difference in responsivity could lead to the interpretation that lower and higher creative persons may employ *different strategies* in the production of uncommon responses: While highly creative individuals show strong involvement of prefrontal structures which has been related to internally focused attention, lower creative individuals may pursue less a top-down strategy rather involving

parietal regions that have been associated with loose semantic memory processing (Jung-Beeman, 2005).

A possible limitation of the present study could be seen in the difference of reaction times between both response conditions (with uncommon responses taking approximately twice as long as common responses in both tasks). It is, however, quite obvious that the production of uncommon responses usually takes more time than the production of common responses. The employed experimental tasks, which did not enforce constant response times, hence can be considered to allow for a high grade of ecological validity. Nevertheless, the effect of response times was analyzed in additional analyses. These analyses revealed that the strong and highly significant main condition effects persisted when activation periods of equal duration were selected for computation of task-related power changes. A further possible limitation of this study may be the restricted generalizability of results. While in the present study only males were tested in order to avoid an oversized factorial design, future research should address the question to which extent sex might be a moderating variable in neurophysiological creativity research (cf. Fink and Neubauer, 2006).

This study extends the present research insofar as the phenomenon of alpha synchronization was found to be unambiguously associated with the actual mode of cognitive processing (divergent vs. convergent thinking) rather than with other task characteristics possibly varying between different tasks (e.g., alternate uses vs. mental arithmetic). Furthermore, the present study corroborates the notion of alpha power changes as a robust correlate of divergent thinking which generalizes over tasks: It was found that the classic alternate uses task induced similar patterns of cortical activation as did the more basic word association task. Differences between convergent and divergent processing were hereby more pronounced in the alternate uses task. This may lead to the interpretation that alpha power changes reflect ideation processes, which are not task-specific, but that the extent of these effects may still depend upon the depth of ideational elaboration. Furthermore, it is suggested that lower and higher creative individuals make use of different strategies in divergent thinking: While highly creative persons show stronger frontal flexibility, lower creative individuals involve rather parietal regions in the generation of uncommon responses.

Although it is becoming apparent that some consistency can be achieved in neurophysiological creativity research, the complex nature of frontal cortex functioning in divergent and also convergent thinking makes it eligible to gain more knowledge of the involved neuroanatomical structures in different task demands. Studies combining the high temporal resolution of the EEG with the spatial accuracy of the fMRI would be of particular interest in this question and could moreover provide a better understanding of the functional meaning of these signals.

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## References

Amabile, T.M., 1982. Social psychology of creativity: a consensual assessment technique. Journal of Personality and Social Psychology 43, 997–1013.
Arden, R., Chavez, R.S., Grazioplene, R., Jung, R.E., 2010. Neuroimaging creativity: a psychometric view. Behavioural Brain Research 214, 143–156.

Benedek, M., Bergner, S., Könen, T., Fink, A., Neubauer, A.C., 2011. EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. Neuropsychologia 49, 3505–3511.

Benedek, M., Könen, T., Neubauer, A.C., 2012. Associative abilities underlying creativity. Psychology of Aesthetics, Creativity, and the Arts. Electronic publication ahead of print. doi:10.1037/a0027059.

Chrysikou, E.G., Thompson-Schill, S.L., 2011. Dissociable brain states linked to common and creative object use. Human Brain Mapping 32, 665–675.

Cooper, N.R., Croft, R.J., Dominey, S.J., Burgess, A.P., Gruzelier, J.H., 2003. Paradox lost? Exploring the role of alpha oscillations during externally vs. internally diredcted attention and the implication for idling and inhibition hypotheses. International Journal of Psychophysiology 47, 65–74.

Cropley, A., 2006. In praise of convergent thinking. Creativity Research Journal 18, 391–404.

Dietrich, A., 2004. The cognitive neuroscience of creativity. Psychonomic Bulletin & Review 11, 1011–1026.

Dietrich, A., Kanso, R., 2010. A review of EEG, ERP, and neuroimaging studies of creativity and insight. Psychological Bulletin 136, 822–848.

Eysenck, H., 1995. Genius. The Natural History of Creativity. Cambridge University Press, Cambridge. 237 pp.

Fink, A., Neubauer, A.C., 2006. EEG alpha oscillations during the performance of verbal creativity tasks: differential effects of sex and verbal intelligence. International Journal of Psychophysiology 62, 46–53.

Fink, A., Grabner, R.H., Neuper, C., Neubauer, A.C., 2005. EEG alpha band dissociation with increasing task demands. Brain Research. Cognitive Brain Research 24, 252–259.

Fink, A., Benedek, M., Grabner, R.H., Staudt, B., Neubauer, A.C., 2007. Creativity meets neuroscience: experimental tasks for the neuroscientific study of creative thinking. Methods 42, 68–76.

Fink, A., Grabner, R.H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., et al., 2009a. The creative brain: investigation of brain activity during creative problem solving by means of EEG and fMRI. Human Brain Mapping 30, 734–748.

Fink, A., Graif, B., Neubauer, A.C., 2009b. Brain correlates underlying creative thinking: EEG alpha activity in professional vs. novice dancers. NeuroImage 46, 854–862.

Fink, A., Grabner, R.H., Gebauer, D., Reishofer, G., Koschutnig, K., Ebner, F., 2010. Enhancing creativity by means of cognitive stimulation: evidence from an fMRI study. NeuroImage 52, 1687–1695.

Gerloff, C., Richard, J., Hadley, J., Schulmann, A.E., Honda, M., Hallett, M., 1998. Functional coupling and regional activation of human cortical motor areas during simple, internally paced and externally paced finger movements. Brain 121, 1513–1531.

Gratton, G., Coles, M.G., Donchin, E., 1983. A new method for off-line removal of ocular artifact. Electroencephalography and Clinical Neurophysiology 55, 468–484.

Guilford, J.P., 1956. The structure of intellect. Psychological Bulletin 53, 267–293.

Guilford, J.P., 1959a. Personality. McGraw-Hill, New York. 381 pp.

Guilford, J.P., 1959b. Three Faces of Intellect. American Psychologist 14, 469–479.

Halliday, D.M., Rosenberg, J.R., Amjad, A.M., Breeze, P., Conway, B.A., Farmer, S.F., 1995. A framework for the analysis of mixed time series/point process data—theory and application to the study of physiological tremor, single motor unit discharges and electromyograms. Progress in Biophysics and Molecular Biology 64, 237–278.

Institut für Test- und Begabungsfoschung (ITB), Gittler, G., 1998. Intelligenz-Struktur-Analyse (ISA) [Intelligence Structure Analysis]. Ein Test zur Messung der Intelligenz. Swets & Zeitlinger B.V. Swets Test Services, Frankfurt.

Jäger, A.O., Süß, H.M., Beauducel, A., 1997. Berliner Intelligenzstruktur-Test [Intelligence Structure Test]. BIS-Test Form 4. Hogrefe, Göttingen.

Jausovec, N., 2000. Differences in cognitive processes between gifted, intelligent, creative, and average individuals while solving complex problems: an EEG study. Intelligence 28, 213–237.

Jausovec, N., Jausovec, K., 2000. EEG activity during the performance of complex mental problems. International Journal of Psychophysiology 36, 73–88.

Jensen, O., Gelfand, J., Kounios, J., Lisman, J.E., 2002. Oscillations in the alpha band (9–12 Hz) increase with memory load during retention in a short-term memory task. Cerebral Cortex 12, 877–882.

Jung-Beeman, M., 2005. Bilateral brain processes for comprehending natural language. Trends in Cognitive Science 9, 512–518.

Klimesch, W., Sauseng, P., Hanslmayr, S., 2007. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Research. Brain Research Reviews 53, 68–88.

Kris, E., 1952. Psychoanalytic Explorations in Art. International Universities Press, Oxford.

Laux, L, Glanzmann, P., Schaffner, P., Spielberger, C.D., 1981. Das State-Trait-Angstinventar [Stait-Trait-Anxiety Inventory]. Weinheim, Beltz.

Martindale, C., 1999. Biological Bases of Creativity. In: Sternberg, R.J. (Ed.), Handbook of Creativity. Cambridge University Press, Cambridge, pp. 137–152.

Martindale, C., Hasenfus, N., 1978. EEG differences as a function of creativity, stage of the creative process, and effort to be original. Biological Psychology 6, 157–167.

Martindale, C., Hines, D., 1975. Creativity and cortical activation during creative, intellectual and EEG feedback tasks. Biological Psychology 3, 91–100.

Mölle, M., Marshall, L., Wolf, B., Fehm, H.L., Born, J., 1999. EEG complexity and performance measures of creative thinking. Psychophysiology 36, 95–104.

Mednick, S.A., 1962. The associative basis of the creative process. Psychological Review 69, 220–232.

Mendelsohn, G.A., 1976. Associative and attentional processes in creative performance. Journal of Personality 44, 341–369.

Merten, T., 1990. Wortassoziation und Schizophrenie. Freie Universität Berlin, Berlin.

Merten, T., Fischer, I., 1999. Creativity, personality and word association responses: associative behaviour in forty supposedly creative persons. Personality and Individual Differences 27, 933–942.

Pfurtscheller, G., 1999. Quantification of ERD and ERS in the time domain, Event-Related Desynchronization, rev. edition. In: Pfurtscheller, G., Lopes da Silva, F.H. (Eds.), Handbook of Electroencephalography and Clinical Neurophysiology, vol. 6. Elsevier, Amsterdam, pp. 89–105.

Pfurtscheller, G., Lopes de Silva, F.H., 1999. Event-related EEG/MEG synchronization and desynchronization: basic principles. Clinical Neurophysiology 110, 1842–1857.

Pfurtscheller, G., Stancak, A., Neuper, C., 1996. Event-related synchronization (ERS) in the alpha band—an electrophysiological correlate of cortical idling: a review. International Journal of Psychophysiology 24, 39–46.

Razumnikova [Razoumnikova], O.M., 2000. Functional organization of different brain areas during convergent and divergent thinking: an EEG investigation. Brain Research. Cognitive Brain Research 10, 11–18.

Razumnikova, O.M., 2007. Creativity related cortex activity in the remote associates task. Brain Research Bulletin 73, 96–102.

Riedlnger, C.B., 1994. Wortassoziationsnormen für 80 konkrete deutsche Reizwörter. In: Hager, W., Hasselhorn, M. (Eds.), Handbuch deutschsprachiger Wortnormen. Hogrefe, Göttingen, pp. 54–58.

Ruch, W., 1998. Eysenck Personality Questionnaire-revised EPQ-R (deutsche Fassung und deutsche Kurzfassung EPQ-RK). Heinrich-Heine-Universität, Düsseldorf.

Sauseng, P., Klimesch, W., Doppelmayr, M., Pecherstorfer, T., Freunberger, R., Hanslmayr, S., 2005. EEG alpha synchronization and functional coupling during top-down processing in a working memory task. Human Brain Mapping 26, 148–155.

Simonton, D.K., 2000. Creativity. Cognitive, personal, developmental and social aspects. American Psychologist 55, 151–158.

Torrance, E.P., 1966. Torrance Tests of Creative Thinking. Scholastic Testing Service, Bensenville.

Vasey, M.W., Thayer, J.F., 1987. The continuing problem of false positives in repeated measures ANOVA in psychophysiology: a multivariate solution. Psyschophysiology 24, 479–486.

Zabelina, D.L., Robinson, M.D., 2010. Creativity as flexible cognitive control. Psychology of Aesthetics, Creativity, and the Arts 4, 136–143.