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# Neural correlates of serial order effect in verbal divergent thinking

Meijuan Wang[a], Ning Hao[a,*], Yixuan Ku[a,*], Roland H. Grabner[b], Andreas Fink[b]

[a] School of Psychology and Cognitive Science, East China Normal University, No. 3663, North Zhong Shan Road, Shanghai 200062, China
[b] Institute of Psychology, University of Graz, Graz, Austria

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ABSTRACT

During the course of divergent thinking (DT), the number of generated ideas decreases while the originality of ideas increases. This phenomenon is labeled as serial order effect in DT. The present study investigated whether different executive processes (i.e., updating, shifting, and inhibition) specifically contribute to the serial order effect in DT. Participants' executive functions were measured by corresponding experimental tasks outside of the EEG lab. They were required to generate original uses of conventional objects (alternative uses task) during EEG recording. The behavioral results revealed that the originality of ideas was higher in later stage of DT (i.e., Epoch 2) than in its earlier stage (i.e., Epoch 1) for higher-shifting individuals, but showed no difference between two epochs for lower-shifting individuals. The EEG results revealed that lower-inhibition individuals showed stronger upper alpha (10–13 Hz) synchronization in left frontal areas during Epoch 1 compared to during Epoch 2. For higher-inhibition individuals, no changes in upper alpha activity from Epoch 1 to Epoch 2 were found. These findings indicated that shifting and inhibition contributed to create a serial order effect in DT, perhaps because individuals suppress interference from obvious ideas and switch to new idea categories during DT, thus more original ideas appear as time passes by.

## 1. Introduction

Divergent thinking (DT) is a facet of cognition that leads in various directions (Runco, 1999). It is usually referred to as a thought process used to generate original ideas by exploring diverse possible solutions, which is involved in many creative efforts (Kaufman et al., 2008). It was demonstrated that during the course of DT, the number of ideas decreases while the originality of ideas increases (Johns et al., 2001; Milgram and Rabkin, 1980; Phillips and Torrance, 1977; Runco, 1986; Ward, 1968). This phenomenon has been labeled as *serial order effect* and was first introduced by Christensen and his colleagues (Christensen et al., 1957). The present study aimed to investigate whether different executive processes specifically contribute to the serial order effect in DT, and explore electroencephaographical (EEG) correlates underlying the effects of executive processes on the serial order effect in DT.

### 1.1. Executive processes and divergent thinking

Divergent thinking is, according to the *controlled-attention theory of creative cognition* (Beaty et al., 2014b), a top-down process that involves executive processes (see also Runco, 1994). Previous studies revealed that some control processes affected DT performance, such as fluid intelligence (Beaty et al., 2014b; Jauk et al., 2013, 2014) and working memory capacity (De Dreu et al., 2012; Hao et al., 2015; Lee and Therriault, 2013). Recent psychometric studies demonstrated that inhibitory function had positive correlation with DT performance (Benedek et al., 2012), and DT performance was positively predicted by both inhibitory and updating functions (Benedek et al., 2014a). Furthermore, more creative individuals exhibited higher levels of inhibition than less creative individuals (Edl et al., 2014).

Plenty of EEG studies revealed that EEG activity in the alpha band was highly sensitive to certain creativity-related factors (see Fink and Benedek, 2014). First, the performance of creativity-demanding tasks induces stronger event-related synchronization of alpha (ERS; i.e., task-related band power increases relative to baseline) than the performance of “convergent” or intelligence-related tasks (Bazanova and Aftanas, 2008; Fink et al., 2007, 2009a; Martindale and Hasenfus, 1978). Likewise, alpha ERS was found to be related to divergent rather than convergent modes of thinking within the same task (Jauk et al., 2012). Second, more original ideas were accompanied by a stronger alpha activity at the central-parietal (and to some minor extent also at the anterior-frontal) sites (Fink and Neubauer, 2006; Grabner et al., 2007). Third, alpha ERS correlated with an individual's creative level (i.e., more creative individuals showing stronger alpha power than less creative ones when performing creativity tasks) (Fink et al., 2009a,

* Corresponding authors.
*E-mail addresses:* nhao@psy.ecnu.edu.cn (N. Hao), yxku@psy.ecnu.edu.cn (Y. Ku).

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2009b; Jausovec and Jausovec, 2000; Martindale et al., 1984). Fourth, alpha ERS was sensitive to a verbal creativity training (Fink et al., 2006) and to short-lasting creativity interventions (i.e., exposure to other people's ideas and induction of positive affection) (Fink et al., 2011). Fifth, enhancing alpha power of the frontal cortex using 10 Hz transcranial alternating current stimulation (10 Hz-tACS) increased facets of creativity, but 40 Hz-tACS unfolded no effects, which suggests that alpha activity in frontal brain areas is selectively involved in creativity (Lustenberger et al., 2015). Notably, Alpha ERS has traditionally been considered to reflect cortical deactivation (Pfurtscheller and da Silva, 1999), whereas alpha event-related de-synchronization (ERD; i.e., band power decreases) reflects cortical activation (Klimesch, 1999). However, alpha ERS has recently been found to reflect a form of top-down activity (Payne and Sekuler, 2014; von Stein and Sarnthein, 2000), such as the inhibition of interfering memories (Hanslmayr et al., 2011; Jensen and Mazaheri, 2010; Klimesch et al., 2007), or a state of heightened internal attention (Benedek et al., 2011, 2014b; Fink and Woschnjak, 2011; Handel et al., 2011; Jaarsveld et al., 2015; Klimesch et al., 2007). Hence, the aforementioned EEG researches support the important roles of executive processes in DT.

Recent fMRI studies also indicated that executive processes were involved in DT. Beaty et al. (2015) assessed dynamic interactions between brain regions (e.g., the default-mode, control, and salience networks) during DT. The results revealed that the posterior cingulate cortex (PCC) showed increased coupling with regions of the control network (i.e., dorsolateral prefrontal cortex, DLPFC) and salience network (i.e., bilateral insula). Moreover, the dynamic interaction between these networks depended on the stage of DT; that is, the PCC showed early coupling with the right anterior insula and later coupling with the right DLPFC. Similarly, Beaty et al. (2017) investigated dynamic interactions between the default-mode, control and salience networks in solving a verb generation task (a DT task). They found that the default-mode and control networks exhibited strong functional connectivity when participants solving task in the high-constraint (i.e., high semantic interference) condition. These findings suggest that interactions between the default and control networks may underlie response inhibition during constrained idea production. Another fMRI study demonstrated that the originality of DT responses (accessed by trained raters) predicted increased functional coupling of the ventral ACC and the left angular gyrus (Mayseless et al., 2015), which are regions involved in cognitive control and self-generated thoughts, respectively. The important roles of the control network in DT are also supported by the resting-state fMRI studies. Beaty et al. (2014a) examined resting-state network patterns in people with better DT ability. The results revealed that highly creative participants showed increased coupling of default network regions with the left inferior frontal gyrus, a region associated with cognitive control that is widely implicated in studies of DT. Zhu et al. (2017) used functional connectivity analysis of resting-state fMRI data to investigate visual and verbal creativity-related regions and networks. They found the strength of connectivity between the default network and the control network was positively related to both creative domains. In a recent review, Beaty and his colleagues (Beaty et al., 2016) proposed that the default network contribute to the generation of candidate ideas (potentially useful information derived from long-term memory) in light of its role in self-generated cognition, while the control network would often be required to evaluate the efficacy of candidate ideas and modify them to meet the constraints of task-specific goals. Such a proposal was highlighted in another review (Zabelina and Andrews-Hanna, 2016), in which it suggests DT, especially its later stages, may benefit from the dynamic cooperation of the default network and control network.

### *1.2. Possible effects of executive processes on the serial order effect in DT*

Why does the number of ideas decrease but the originality of ideas increase during the course of DT? According to the associative model of creativity (Mednick, 1962), DT is considered as a process of spreading activation through related semantic networks. The neighboring ideas in the semantic network are usually thought as being common and less creative, while the more remote ideas are regarded to be more unusual and creative. Understandably, it takes some time for distant associations or concepts to be activated and connected; creative ideas may hence emerge later than more common ideas, and ideas become increasingly sparse as time passes by. In this vein, the serial order effect in DT reflects the gradual spreading of activation towards increasingly remote associations (Beaty and Silvia, 2012; Wallach and Kogan, 1965).

However, some executive processes may also account for the serial order effect in DT. First, executive switching helps individuals stop generating ideas in one category and switch to another category, which could create a serial effect. More specifically, people typically start with a salient and obvious category in solving the DT problems. Once the category is exhausted, they need to stop the search process, switch to a new category, and then construct responses within it. Previous studies revealed that some people (those with lower intelligence and working memory span) had difficulties in such deliberate control of cognition; they switch less often and hence have fewer ideas in verbal fluency tasks (Unsworth et al., 2011) and less creative ideas in DT tasks (Nusbaum and Silvia, 2011a). Understandably, if people first exhaust an obvious category and then stop and switch to new idea categories, their later responses will be better than their earlier responses. Second, executive inhibition helps suppress task-irrelevant information (Carson et al., 2003; Klimesch, 2012), which could also create a serial order effect. That is, obvious, common ideas come to mind first; as time passes, more original ideas appear when people overcome interference from obvious ideas and early responses. This proposal was supported by a recent study (Beaty and Silvia, 2012), in which participants were asked to solve a verbal DT problem in 10 min. The results showed that compared to participants with lower fluid intelligence (i.e., Gf), participants with higher Gf started with more original ideas, and the originality of their ideas remained at a high level of quality across time. The authors suggested that this effect might be driven by executive mechanisms; that is, participants with higher Gf can inhibit the salient but unoriginal ideas that typically come to mind at the beginning of DT (Beaty and Silvia, 2012). Third, updating supports the active maintenance of task-relevant information and the controlled search from memory (Unsworth and Engle, 2007), which could create a serial order effect as well. It is known that creative ideas originate from the successful association of previously unrelated concepts taken from memory (Mednick, 1962). Fertile strategies for idea generation involve the controlled search and selective retrieval from memory. Updating is involved in the identification and maintenance of relevant cues that help delimiting the actual search set (Unsworth and Engle, 2007). From the point of view, updating may help people continue to retrieve semantically remote but useful concepts from memory, and then produce more creative ideas as time passes by.

### *1.3. The present study*

Up to now, it is still an open question how executive processes play roles in the serial order effect in DT. The present study aimed to investigate whether different executive processes (i.e., updating, shifting, and inhibition) specifically contribute to the serial order effect in DT, and explore the EEG correlates underlying the effects of executive processes on the serial order effect in DT. We particularly addressed two questions. First, are brain activity patterns different between the earlier and later stages of DT, which may reflect different roles of executive processes involved in DT as time passes? Second, do individuals' executive functions (EFs) levels influence brain activity patterns in the earlier and later stages of DT? Since temporal change is a critical factor in this study, we preferred to use electroencephalography (EEG) to record brain activity during the course of DT, given its high temporal resolution.

In the present study, participants were required to solve the Alternative Uses Task (Guilford, 1967) problems. The AUT is a typical verbal DT task. The participants were instructed to report their answers one by one as soon as they got it. The EEG activity during solving the AUT problems was recorded. After the EEG recording session, participants' executive functions were measured by means of corresponding experimental tasks outside of the EEG lab (i.e., updating: the letter-memory task; shifting: the number-letter task; inhibition: the Stroop task). The fluency and originality of the generated ideas were compared between the earlier and later stages during the course of DT, as well as between individuals with higher and lower EFs. Given that the signals in several frequency bands, such as the theta (4–8 Hz), alpha (8–13 Hz), and beta (13–30 Hz) bands, are associated with creative thinking (see Dietrich and Kanso, 2010), EEG activity in theta, alpha, and beta bands were compared between the earlier and later stages during DT, and between individuals with higher and lower EFs. We predicted that, (1) the number of ideas would decrease but the originality of ideas would increase when solving the AUT problems, (2) EEG alpha activity in the earlier and later stages when solving the AUT problems would be distinctive (probably most prominent in the frontal cortex), and (3) such EEG alpha activity would be influenced by individuals' executive function levels. Because only several studies have explored EEG beta or theta activity in creative thinking and the findings were contradictory (see Dietrich and Kanso, 2010), we could not propose precise predictions for EEG beta or theta activity before our experiment.

## 2. Method

### 2.1. Participants

Thirty-five right-handed undergraduates (10 males, 25 females; in the range between 19 and 26 years, $M$=22.6, $SD$ =2.02) participated in this study. They were all native Chinese speakers. They reported no history of neurological or psychiatric diseases, had normal or corrected to normal vision. Participants received 15 dollars as compensation for their participation. They signed informed consent at the beginning of the experiment. The procedure was approved by the Ethics Committee of East China Normal University. Due to technical problems, the data of 11 participants were excluded from the EEG analyses. This left a final EEG sample of 24 participants (7 male) with an average age of 22.01 years old ($SD$ =2.09; range from 19 to 26 years old).

### 2.2. Experimental tasks

The Alternative Uses Task (AUT) (Guilford, 1967) was used as the experimental task. It required respondents to generate as many unusual or original uses as possible for common objects, such as a paperclip ("making a ring", "cleaning fingernails"). The AUT is a typical DT task and a well-established test of creative potential (Guilford, 1967; Runco, 1999; Runco and Mraz, 1992). Performance on this task has been found to be a reliable predictor of actual, real-world creative performance (Runco and Acar, 2012).

The letter-memory task (Miyake et al., 2000; Morris and Jones, 1990) was used to assess "updating" function. In this task, several letters were presented serially for 1500 ms per letter. The task was simply to recall the last 4 letters presented in the list. To ensure that the task required continuous updating, the instructions required the participants to rehearse out loud the last 4 letters by mentally adding the most recent letter and dropping the 5th letter back and then speaking the new string of 4 letters out loud. For example, if the letters presented were "T, H, G, B, S, K, R," the participants should have said, "T … TH … THG … THGB … HGBS … GBSK … BSKR" and then recalled "BSKR" at the end of the trial. The participants performed 12 trials for a total of 48 letters recalled. The dependent measure was the proportion of letters recalled correctly.

The number-letter task (Rogers and Monsell, 1995; Spector and Biederman, 1976) was selected to assess "shifting" function. In this task, number-letter pairs (e.g., 8G) were presented in one of the four quadrants of the computer screen in a clockwise order. Participants were required to switch between two subtasks. They were asked to indicate whether the number was odd or even when the stimulus was presented in one of the upper two quadrants, and to indicate whether the letter was a consonant or vowel when it was in one of the bottom two quadrants. Participants thus had to switch tasks in half of the trials (i.e., trials from the upper left and lower right quadrants). The shift cost for this task was the difference between the average RTs of the trials in the third block that required a mental shift (trials from the upper left and lower right quadrants) and the average RTs of the trials from the first two blocks in which no shift was necessary. A smaller shift cost was taken to indicate more effective executive shifting function.

The Stroop color-word-interference task (Stroop, 1935) is a prototypical task used to measure the "inhibition of prepotent responses" (Miyake et al., 2000). Prepotent response inhibition is thought to facilitate creative thought by suppressing interference caused by dominant response tendencies (Benedek et al., 2012; Gilhooly et al., 2007). Performance on the Stroop task was demonstrated to have positive correlations with creative performance (Benedek et al., 2014a; Edl et al., 2014; Golden, 1975; Groborz and Necka, 2003). The Stroop task presents single words denoting either a color name ("red", "green", "blue", or "yellow") on a black computer screen. Participants were asked to name the color of the stimuli as fast as possible (time-out =4 s) by entering one out of four keys associated with the color. The Stroop effect was scored for each block as the difference of the mean reaction time in incongruent and congruent trials, which was considered a reverse indicator of inhibitory ability.

### 2.3. Experiment procedure

The participants were required to solve eight AUT problems (i.e., pencil, key, clock, shoes, table, button, lipstick, mobile phone). The presented sequences of the eight AUT problems were randomly arranged by a computer for every participant. In solving an AUT problem, participants were encouraged to try their best to produce ideas that would be thought of by no one else, as suggested by Harrington (1975), Runco and Pritzker (1999).

The procedure of solving an AUT problem (i.e., a trial) is illustrated in Fig. 1. Participants were required to work on a problem for 3 min. Before each AUT problem, there was a plus ("+") lasting for 15 s for fixation. Then the AUT problem appeared on the computer screen. Once participants had an idea, they pressed the button SPACE, and then orally reported the idea. After reporting, participants pressed the button SPACE again, and continued to think about potential ideas. The oral responses for the AUT problems were recorded by a voice recorder and transcribed afterwards for further analysis. This session lasted for approximately 30 min.

Afterwards, participants had a rest for 20 min, and then continued to perform the executive function tasks without EEG recording. The executive function tasks were also presented on the computer, which need approximately 45 min for participants to complete.

### 2.4. Electrophysiological recording and analysis

Participants sat in a comfortable chair in a quiet, dim-lighted room that was sound-proof and electromagnetic-proof. They were faced with a CRT screen at eye level. Thirty channels of EEG signals and two

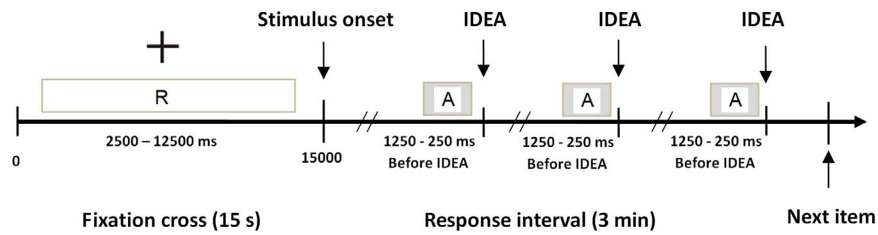


**Fig. 1.** The procedure of solving an AUT problem. A 10 s time interval during the presentation of the fixation cross (pre-stimulus reference interval R) as well as a 1 s time interval 250 ms before pressing the IDEA-button (activation interval A) were used for EEG analyses. "+" = the fixation.

channels of electrooculography (EOG) signals (horizontal and vertical eye movements) were recorded by a 32-channel BrainAmp amplifier (Brian Products GmbH, Munich, Germany), with the reference electrodes placed on the left and right mastoids. All electrode impedances were maintained below 10 kΩ. The EEG and EOG signals were amplified, filtered (.5–100 Hz band-pass), digitized (1000 Hz sampling rate), and stored for off-line analysis. The EEG and EOG signals were recorded through each trial.

EOG-contaminated elements among the EEG signals were removed by an infomax independent component analysis (ICA) method implemented in EEGLAB toolbox (Swartz Center for Computational Neurosciences, US) (Delorme and Makeig, 2004). Signals in all 32 channels were down-sampled to 250 Hz and used for ICA. Independent components (ICs) representing eye movement artifacts were selected by both topography and temporal activities, and were removed from the EEG signals (Jung et al., 2000). Afterwards, the EEG data were re-referenced using the common average reference, and then divided into epochs as Baseline and Activations (see Fig. 1).

The EEG signals were first filtered by using an infinite impulse response (IIR) band-pass filter. Forward-and-reverse filtering was used to avoid phase distortions. Ripple amplitudes in the pass band and stop band were set as .0025 dB and 40 dB respectively. The filtered data were then squared to obtain the band power values. In the theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz), upper beta (20–30 Hz) frequency bands, ERD/ERS values of the activation periods were calculated as following equation (Pfurtscheller and da Silva, 1999). ERD/ERS $=(MP_{activation} - MP_{baseline})/MP_{baseline}$. As in a previous study (Fink et al., 2007), the time periods for the spectrum calculation of Baseline were 10,000 ms (i.e., 2500–12,500 ms after the onset of Fixation). The time periods for the spectrum calculation of Activation were 1000 ms (i.e., −1250 to −250 ms before pressing the IDEA-button) (see Fig. 1).

### 2.5. Assessment of performance on AUT problems

Participants' performance on the AUT problem was measured by the scores of fluency and originality (Guilford, 1967; Runco, 1991). Fluency scores were based on the number of ideas given in the AUT problem. Originality scores were given by the subjective scoring method, following the procedures outlined in previous studies (De Dreu et al., 2012; Gilhooly et al., 2012; Hocevar, 1979; Silvia, 2011). First, five raters independently evaluated the originality for each idea reported by the participants on a 5-point Likert scale (1- not original at all, 5- highly original). The inter-rater agreement (ICCs =.69) was acceptable. Then, the ratings for each single idea from the five raters were averaged into one originality score for each idea.

### 2.6. Defining the "order" for the fluency and originality scores

Previous studies usually defined the "order" of ideas according to the "time" when the ideas were produced (Beaty and Silvia, 2012) or the "positions" in which the ideas were located (Christensen et al., 1957). For example, the ideas participants produced can be divided into the first and the second halves according to the "positions" (e.g., 8 ideas, the early 4 ideas into the first half, the later 4 ideas into the second half), or based on the "time" (e.g., 3-min idea generation, the ideas produced in the first 1.5 min as the first half, those produced in the second 1.5 min as the second half). Creative performance (e.g., fluency and originality) was then compared between two halves of ideas.

Given that fluency refers to the quantity of ideas, the fluency scores in two halves of ideas would be exactly equal if the method of "position" was adopted. Therefore, we used the method of "time" to divide ideas, and then compared the differences of the fluency scores in the first half and the last half of 3 min. By contrast, we used the method of "position" rather than the method of "time" to define the "order" for the originality scores. On the one hand, participants occasionally produced no idea in the second 1.5 min in this study; thus, the originality of idea generation in the second 1.5 min could not been scored if the method of "time" was adopted. On the other hand, given that originality refers to the quality of ideas, it seems open-and-shut to explore the changes of ideas' originality from the beginning to the ending "positions". It must be pointed out that participants produced a few of ideas (*M*=6.26; *SD* =2.97) and the number of ideas varied considerably for every participant in the present study. In order to ensure numerical equivalence and temporal variation of the selected ideas, the first two ideas and last two ideas were grouped together respectively and represented the earlier epoch (i.e., Epoch 1) and the later epoch (i.e., Epoch 2). Notably, in some trials, participants produced less than four ideas (i.e., 3 or 2 ideas). In this case, the first one and last one idea was selected to represent the Epoch 1 and 2 respectively. Moreover, eleven trials with only one idea were not included because one idea could not be split into the two halves.

Therefore, participants got the fluency scores in the first and second 1.5 min and the originality scores in Epoch 1 and Epoch 2 for every AUT problem. Afterwards, the fluency scores in the first and second 1.5 min and the originality scores in Epoch 1 and Epoch 2 were averaged across 8 AUT problems for every participant. These scores were used to explore the effects of "order" on creative performance. In the same vein, the ERS/ERD values while participants generated the first and the last two ideas for each frequency band were averaged into Epoch 1 and Epoch 2, respectively.

## 3. Result

### 3.1. Serial order effect of the fluency and originality scores

The mean fluency score (i.e., the number of ideas) of solving 8 AUT problems was 6.26 (*SD*=2.97), in the range from 1.88 to 15.88. Overall, participants produced more ideas (*M*=3.6, *SD* =1.64) in the first 1.5 min than in the second 1.5 min (*M* =2.68, *SD* =1.43), $t$ (34) =6.83, $p < .001$, Cohen's $d$=.6 (see Fig. 2A). Furthermore, the originality scores were lower in Epoch 1 (*M* =1.94, *SD* =.24) than in Epoch 2 (*M* =2.13, *SD* =.23), $t$ (34) =5.2, $p < .001$, Cohen's $d$ =.81 (see Fig. 2B). These results indicated that the fluency of ideas decreased but the originality of ideas increased during the course of DT. The serial order effect was confirmed in this study.

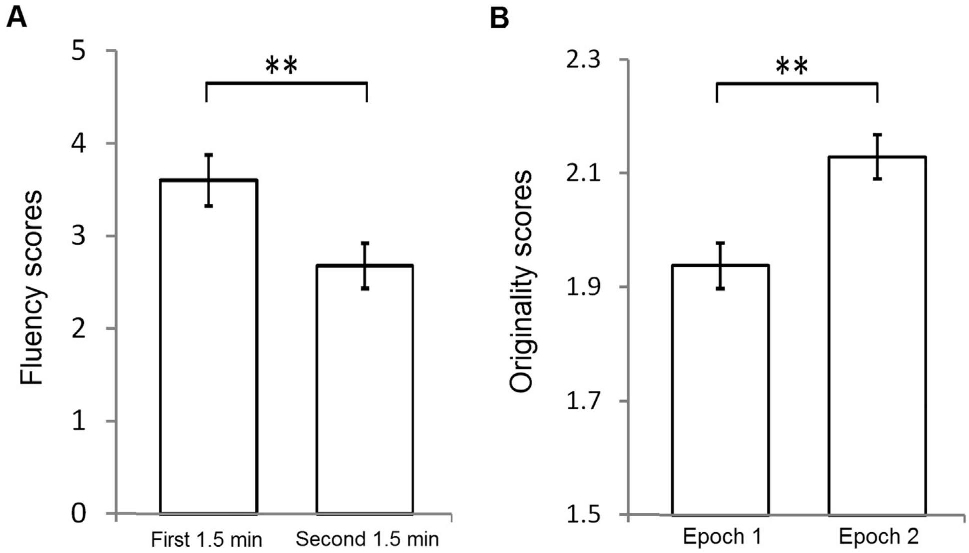


**Fig. 2.** Alternative Uses task (AUT) fluency scores in the first 1.5 min and the second 1.5 min (panel A), and AUT originality scores in Epoch1 and Epoch 2 (panel B). Error bars indicate standard errors of the mean. ** $p < .01$.

### 3.2. Effects of "order" and executive functions on the fluency and originality scores

According to performance on three EF tasks, participants were divided into two groups (i.e., higher and lower levels separated by median) in the updating, shifting and inhibitory functions, respectively. These three between-subject factors were used in further ANOVA analyses.

Three separate repeated measures ANOVAs with EPOCH as within-subject factor and inhibitory, shifting and updating functions (higher vs. lower) as between-subject factors were conducted on the originality scores, respectively. In three ANOVAs, the main effects of EPOCH were all significant. That is, participants, no matter higher or lower executive functions, produced ideas with higher originality in Epoch 2 than in Epoch 1. Interestingly, there was a significant interaction effect of EPOCH × SHIFTING, $F$ (1, 33) =4.48, $p < .05$, $\eta_p^2$ =.12. Specifically, for the higher-shifting individuals, they produced ideas with higher originality in Epoch 2 ($M$=2.19, $SD$ =.19) than in Epoch 1 ($M$=1.92, $SD$ =.28), $t$ (16)=6.9, $p < .001$, Cohen's $d$ =1.13. For the lower-shifting individuals, there was no difference of ideas' originality between Epoch 1 ($M$ =1.95, $SD$ =.19) and Epoch 2 ($M$ =2.07, $SD$ =.25), $t$ (17) =2.08, $p$=.053.

Similarly, three separate repeated measures ANOVAs were conducted on the fluency scores. The results revealed the main effects of TIME (i.e., the first 1.5 min vs. the second 1.5 min) in all three ANOVAs. That is, participants, no matter with higher or lower executive functions, produced more ideas in the first 1.5 min than in the second 1.5 min. No significant interaction between TIME and any of three executive functions was found.

### 3.3. EEG activity during Epoch 1 and Epoch 2

Repeated measures ANOVAs were performed on the ERD/ERS values in the theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz) and upper beta (20–30 Hz) frequency bands separately, with EPOCH, POSI ($FP_{3,4}$, $F_{3,4}$, $F_{7,8}$, $FC_{1,2}$, $FC_{5,6}$, $C_{3,4}$, $P_{3,4}$, $P_{7,8}$, $T_{7,8}$, $O_{1,2}$) and HEMI (left vs. right) as within-subject variables. The results were summarized in Table 1.

For the lower alpha, upper alpha and lower beta bands, there were significant main effects of POSI. For the lower beta band, the results revealed a significant interaction of HEMI×EPOCH on the ERD/ERS values, $F$ (1, 23) =9.09, $p < .01$, $\eta_p^2$ =.28. Specifically, right hemisphere showed stronger lower beta activity than left hemisphere during Epoch 2, while there was no difference of lower beta activity between hemispheres during Epoch 1 (see Fig. 3).

### 3.4. Effects of Epoch and executive functions on ERS/ERD values

Mixed-design repeated measures ANOVAs with EPOCH, POSI, and HEMI as within-subject factors, and three executive functions (i.e., inhibition, shifting and updating) as the grouping value for a between-subject factor, were conducted on the ERS/ERD values of theta, lower alpha, upper alpha, lower beta, and upper beta frequency bands, respectively.

For the upper alpha band, there was a significant interaction effect of POSI× HEMI × EPOCH × INHIBITION on the ERD/ERS values, $F$ (9, 198) =2.30, $p < .05$, $\eta_p^2$ =.10. For the higher-inhibition individuals, there was no effect of EPOCH on ERD/ERS values in both left and right hemisphere. But for the lower-inhibition individuals, there was a significant interaction effect of POSI × EPOCH, $F$ (9, 99) =2.17, $p < .05$, $\eta_p^2$ =.17. Specifically, upper alpha activity in left hemisphere showed stronger in frontal areas ($PF_1$, $F_3$, $F_7$) during Epoch 1 than Epoch 2 (post hoc Tukey HSD test, $ps < .05$), but such a different was not observed in right hemisphere (see Fig. 4).

For the theta, lower alpha, lower beta and upper beta bands, there were no effects of three executive functions on the ERS/ERD values.

## 4. Discussion

In the present study, we aimed to test whether executive processes (i.e., updating, shifting and inhibition) specifically contribute to the serial order effect in DT. We asked participants to generate and orally report ideas for the AUT problems, while the EEG activity was recorded. The behavioral results found that participants produced fewer ideas in the second 1.5 min than in the first 1.5 min, and the originality of ideas was higher in the ending positions (i.e., Epoch 2) than in the beginning positions (i.e., Epoch 1)(see Fig. 1). These findings indicated that the fluency of ideas decreased but the originality of ideas increased with time passing, which confirmed the serial order effect in DT.

The behavioral results showed that the originality of ideas in Epoch 2 was higher than in Epoch 1 for the higher-shifting individuals, but showed no difference between the two epochs for the lower-shifting individuals. That is, individuals with higher shifting levels exhibited the serial order effect in DT, while those with lower shifting levels did not. These findings provided evidences to support the role of executive

**Table 1**
The ANOVA results of ERD/ERS values of theta (4–8 Hz), lower alpha (8–10 Hz), upper alpha (10–13 Hz), lower beta (13–20 Hz), and upper beta (20–30 Hz) bands.

| | Theta | Lower alpha | Upper alpha | Lower beta | Upper beta |
|---|---|---|---|---|---|
| POSI | *F* (9207)=1.92[a] | *F* (9207)=3.79[**] | *F* (9207)=2.17[*] | *F* (9207)=4.77[**] | *F* (9207)=1.78 |
| HEMI | *F* (1,23)=1.83 | *F* (1,23)= .07 | *F* (1,23)=1.29 | *F* (1,23)=3.77 | *F* (1,23)=1.32 |
| EPOCH | *F* (1,23)= .07 | *F* (1,23)= .49 | *F* (1,23)= .88 | *F* (1,23)= .31 | *F* (1,23)= 1.06 |
| POSI * HEMI | *F* (9207)=1.24 | *F* (9207)=1.27 | *F* (9207)=1.28 | *F* (9207)= .84 | *F* (9207)=1.38 |
| POSI * EPOCH | *F* (9207)=1.24 | *F* (9207)=1.01 | *F* (9207)=1.64 | *F* (9207)= .68 | *F* (9207)= .87 |
| HEMI * EPOCH | *F* (1,23)=1.25 | *F* (1,23)= .01 | *F* (1,23)=1.24 | *F* (1,23)=9.09[**] | *F* (1,23)=2.42 |
| POSI*HEMI* EPOCH | *F* (9207)= .93 | *F* (9207)=1.15 | *F* (9207)=1.10 | *F* (9207)=1.08 | *F* (9207)= .84 |

[*] $p < .05$.
[**] $p < .01$.
[a] $p$=.05.

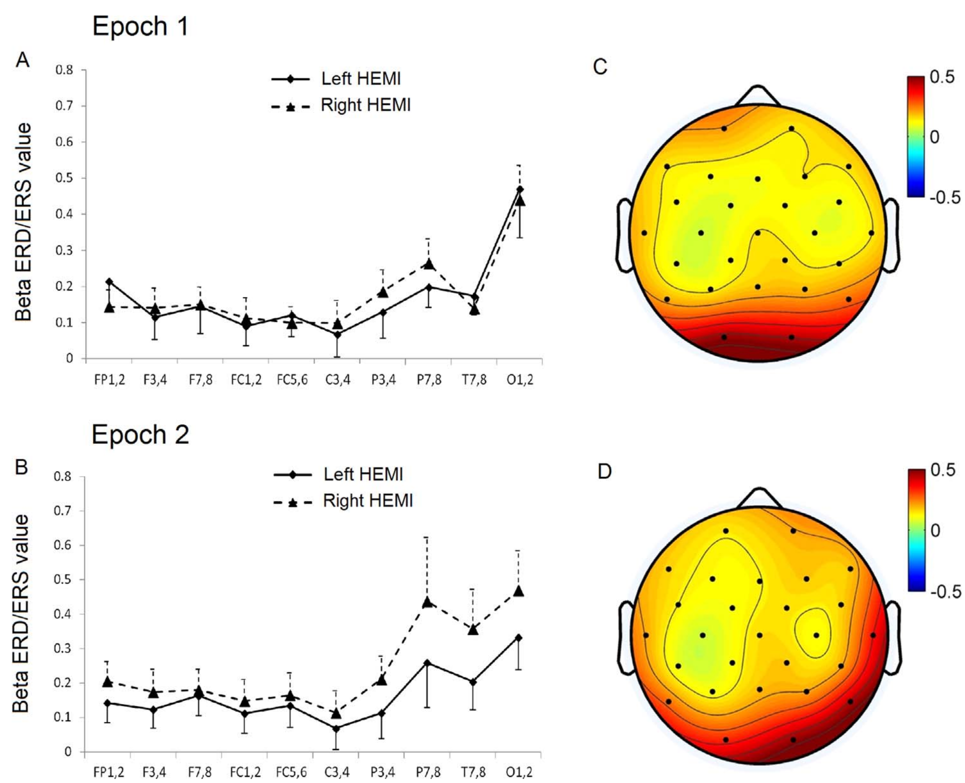


**Fig. 3.** (A) and (B) show the ERS/ERD values in the lower beta band (13–20 Hz) during Epoch 1 and Epoch 2. (C) and (D) illustrate the topographies of ERS/ERD values in the lower beta band during Epoch 1 and Epoch 2. Error bars indicate standard errors of the mean.

shifting in the serial order effect during DT. Shifting function represents individuals' cognitive flexibility (Diamond, 2013). Creativity requires flexibility of thought (Chi, 1997). The *dual pathway to creativity model* (De Dreu et al., 2008; Nijstad et al., 2010) proposes flexibility be an important pathway to creative performance, in which individuals break mental sets, reorganize cognitive structures, and generate various cognitive categories. In this sense, the higher-shifting individuals might be good at switching to new idea categories when necessary during the course of DT, thus their later responses were better than their earlier responses. Notably, our results revealed that higher- vs. lower-inhibition individuals, or higher- vs. lower-updating individuals, showed no difference in the serial order effect during DT. Such results did not refute the possibility that inhibition or updating contributed to the serial order effect. Perhaps, the lower-inhibition or lower-updating individuals could invest a larger amount of cognitive resources to inhibit obvious ideas or maintain the controlled search from memory during DT, thus they exhibited the serial order effects similar as those of the higher-inhibition or higher-updating individuals. Or, a relatively small sample of participants in this study was not enough to reveal the differences between higher and lower-inhibition or between higher and lower-updating individuals. In brief, it should be cautious when interpreting the null results, further research is necessary.

The EEG results revealed that upper alpha activity of the higher- and lower-inhibition individuals exhibited different change patterns from Epoch 1 to Epoch 2. For the higher-inhibition individuals, upper alpha activity showed no change from Epoch 1 to Epoch 2. For the lower-inhibition individuals, upper alpha activity was strong in left frontal areas in Epoch 1, but it decreased in Epoch 2 (see Fig. 4). It has been shown that alpha synchronization appears to reflect a form of top-down activity (Payne and Sekuler, 2014; von Stein and Sarnthein, 2000), such as the inhibition for the interfering memories (Hanslmayr et al., 2011; Jensen and Mazaheri, 2010; Klimesch et al., 2007). Therefore, the observed strong alpha synchronization in Epoch 1 for the lower-inhibition individuals could plausibly reflect that they invested a large amount of cognitive resources to suppress interference from obvious or common ideas during the beginning epoch of DT. As time passed by, they got used to such a top-down activity and fewer common ideas were available to be suppressed, thus less cognitive resources were invested in inhibition, which was reflected in the decrease of upper alpha activity in Epoch 2. In a similar vein, we suggested that the higher-inhibition individuals might have higher

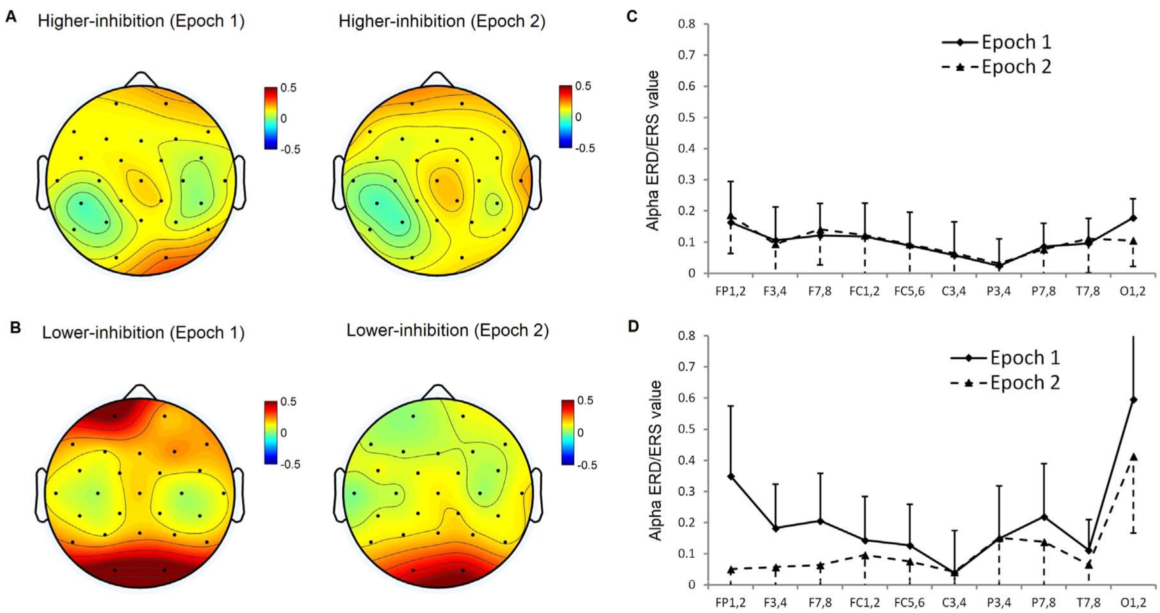


**Fig. 4.** (A) and (B) illustrate the topographies of ERS/ERD values in the upper alpha band (10–13 Hz) during Epoch 1 and Epoch 2 for higher-inhibition and lower-inhibition individuals respectively. (C) and (D) show the ERS/ERD values in the upper alpha band during Epoch 1 and Epoch 2 for higher-inhibition and lower-inhibition individuals. Error bars indicate standard errors of the mean.

efficiency to suppress the interfering information, thus they invested small quantity of cognitive resource to inhibit obvious ideas during the beginning epoch of DT. This was also the case during the ending epoch of DT. Thus, the higher-inhibition individuals exhibited similar upper alpha activity in both epochs. Overall, the EEG findings indicated that executive inhibition could contribute to the serial order effect in DT, as suggested in the previous study (Beaty and Silvia, 2012). Briefly, the higher-inhibition individuals invest less cognitive resources in inhibition, whereas lower-inhibition ones invest more. And, when they overcome interference from obvious or common ideas, more original ideas appear as time passes by.

Recent fMRI studies demonstrated that coupling of the default network and control network benefited creative performance especially in the later stage of DT, probably because the control network would be often required to evaluate and modify candidate ideas in this stage (see Beaty et al., 2016; Zabelina and Andrews-Hanna, 2016). In the present study, we found strong EEG upper alpha activity in early stage of DT for the lower-inhibition individuals (see Fig. 4). This finding indicated that top-down suppression of predominant responses via functional interactions of the control network (inhibition) with the default network (memory retrieval) could occur at the early stage of DT. Recall here that we instructed participants to "try their best to produce ideas that would be thought of by no one else", which emphasized the originality of ideas. Participants had to inhibit common but predominant ideas, evaluate candidate ideas, and report high original ideas from the beginning of DT. In this sense, the patterns of inhibition being engaged in DT might be influenced by task demand.

Another interesting finding was that lower beta activity showed different patterns during Epoch 1 and Epoch 2 (see Fig. 3). Lower beta activity was stronger in the right hemisphere than the left hemisphere in Epoch 2, while there was no such difference in Epoch 1. Previous studies revealed that the right hemisphere (RH) contributes to language comprehension and semantic coding (Beeman et al., 1994). Engagement of RH in verbal DT could facilitate originality by activating large semantic fields (including concepts distantly related to the input word) (Beeman, 1993), and promoting access to alternate or weak associations (Grabner et al., 2007; Jung-Beeman et al., 2004; O'Rourke et al., 2015). As for EEG beta activity, it was usually found to be associated with motor control (Pfurtscheller et al., 1996). Recently, van Elk and his colleague (van Elk et al., 2008) proposed that the function role of motor activation (e.g. beta band activity) could be to support lexical-semantic retrieval. So, the observed stronger beta activity in the right hemisphere during Epoch 2 may reflect that the brain was conducting coarse semantic processes that benefited the generation of original ideas. In this sense, this finding indicated that associative processes contributed to the serial order effect in DT as well. However, given that few empirical studies demonstrated the association between EEG beta activity and semantic processes, the explanation above was an inference, and further research is necessary.

There are three limitations of this study. First, to ensure numerical equivalence and temporal variation of the selected ideas, the first two ideas and last two ideas were grouped together respectively and represented the earlier and later epochs. Consequently, it is impossible to draw a whole picture to describe the change of ideas' originality and EEG frequency oscillation during the course of DT. Further study could ask participants to solve a DT problem in several sessions (e.g., 4 sessions, 16 s for mental thought and 10 s for oral response in each session). Such a design can create "orders" with the distinctive positions and the fixed time periods. Second, the behavioral results revealed higher- and lower-shifting individuals exhibited different serial order effect in DT; however such differences were not reflected in EEG activity. Perhaps task-related EEG synchronization is not sensitive to executive shifting. Further study should develop methods or techniques that can sensitively detect executive shifting in DT. Third, the present study focused on three core EFs (i.e., updating, shifting and inhibition) instead of the higher-order EF (i.e., fluid intelligence). In fact, fluid intelligence influences the serial order effect in DT (Beaty and Silvia, 2012). EEG alpha activity is sensitive to the roles of fluid intelligence in the problem solving process evolving in open problem space (Jaarsveld et al., 2015). Therefore, future study about EEG correlates underlying the effects of fluid intelligence on the serial order effect in DT will be interesting.

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## References


Bazanova, O.M., Aftanas, L.I., 2008. The individual alpha activity indices as predictors of fluency, flexibility and originality of nonverbal creativity. Int. J. Psychophysiol. 69. http://dx.doi.org/10.1016/j.ijpsycho.2008.05.469.

Beaty, R.E., Benedek, M., Kaufman, S.B., Silvia, P.J., 2015. Default and executive network coupling supports creative idea production. Sci. Rep. 5, 10964. http://dx.doi.org/10.1038/srep10964.

Beaty, R.E., Benedek, M., Silvia, P.J., Schacter, D.L., 2016. Creative cognition and brain network dynamics. Trends Cognive Sci. 20, 87–95. http://dx.doi.org/10.1016/j.tics.2015.10.004.

Beaty, R.E., Benedek, M., Wilkins, R.W., Jauk, E., Fink, A., Silvia, P.J., Neubauer, A.C., 2014a. Creativity and the default network: a functional connectivity analysis of the creative brain at rest. Neuropsychologia 20, 92–98. http://dx.doi.org/10.1016/j.neuropsychologia.2014.09.019.

Beaty, R.E., Christensen, A.P., Benedek, M., Silvia, P.J., Schacter, D.L., 2017. Creative constraints: brain activity and network dynamics underlying semantic interference during idea production. Neuroimage 148, 189–196. http://dx.doi.org/10.1016/j.neuroimage.2017.01.012.

Beaty, R.E., Silvia, P.J., 2012. Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. Psychol. Aesthet., Creat., Arts 6, 309–319. http://dx.doi.org/10.1037/a0029171.

Beaty, R.E., Silvia, P.J., Nusbaum, E.C., Jauk, E., Benedek, M., 2014b. The roles of associative and executive processes in creative cognition. Mem. Cogn. 42, 1186–1197. http://dx.doi.org/10.3758/s13421-014-0428-8.

Beeman, M., 1993. Semantic processing in the right hemisphere may contribute to drawing inferences from discourse. Brain Lang. 44, 80–120. http://dx.doi.org/10.1006/brln.1993.1006.

Beeman, M., Friedman, R.B., Grafman, J., Perez, E., 1994. Summation priming and coarse semantic coding in the right hemisphere. J. Cogn. Neurosci. 6, 26–45. http://dx.doi.org/10.1162/jocn.1994.6.1.26.

Benedek, M., Bergner, S., Koenen, 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. http://dx.doi.org/10.1016/j.neuropsychologia.2011.09.004.

Benedek, M., Franz, F., Heene, M., Neubauer, A.C., 2012. Differential effects of cognitive inhibition and intelligence on creativity. Personal. Individ. Differ. 53, 480–485. http://dx.doi.org/10.1016/j.paid.2012.04.014.

Benedek, M., Jauk, E., Sommer, M., Arendasy, M., Neubauer, A.C., 2014a. Intelligence, creativity, and cognitive control: the common and differential involvement of executive functions in intelligence and creativity. Intelligence 46, 73–83. http://dx.doi.org/10.1016/j.intell.2014.05.007.

Benedek, M., Schickel, R.J., Jauk, E., Fink, A., Neubauer, A.C., 2014b. Alpha power increases in right parietal cortex reflects focused internal attention. Neuropsychologia 56, 393–400. http://dx.doi.org/10.1016/j.neuropsychologia.2014.02.010.

Carson, S.H., Peterson, J.B., Higgins, D.M., 2003. Decreased latent inhibition is associated with increased creative achievement in high-functioning individuals. J. Personal. Soc. Psychol. 85, 499–506. http://dx.doi.org/10.1037/0022-3514.85.3.499.

Chi, M.T.H., 1997. Creativity: shifting across ontological categories flexibly. In: Ward, T.B., Smith, S.M., Vaid, J. (Eds.), Creative Thought: An Investigation of Conceptual Structures and Processes. American Psychological Association, Washington, DC, 209–234.

Christensen, P.R., Guilford, J.P., Wilson, R.C., 1957. Relations of creative responses to working time and instructions. J. Exp. Psychol. 53, 82–88. http://dx.doi.org/10.1037/h0045461.

De Dreu, C.K.W., Baas, M., Nijstad, B.A., 2008. Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. J. Personal. Soc. Psychol. 94, 739–756. http://dx.doi.org/10.1037/0022-3514.94.5.739.

De Dreu, C.K.W., Nijstad, B.A., Baas, M., Wolsink, I., Roskes, M., 2012. Working memory benefits creative insight, musical improvisation, and original ideation through maintained task-focused attention. Personal. Soc. Psychol. Bull. 38, 656–669. http://dx.doi.org/10.1177/0146167211435795.

Delorme, Arnaud, Makeig, Scott, 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J. Neurosci. Methods 134, 9–21. http://dx.doi.org/10.1016/j.jneumeth.2003.10.009.

Diamond, A., 2013. Executive functions. Annu. Rev. Psychol. 64, 135–168. http://dx.doi.org/10.1146/annurev-psych-113011-143750.

Dietrich, A., Kanso, R., 2010. A review of EEG, ERP, and neuroimaging studies of creativity and insight. Psychol. Bull. 136, 822–848. http://dx.doi.org/10.1037/a0019749.

Edl, S., Benedek, M., Papousek, I., Weiss, E.M., Fink, A., 2014. Creativity and the stroop interference effect. Personal. Individ. Differ. 69, 38–42. http://dx.doi.org/10.1016/j.paid.2014.05.009.

Elk, M. van, Schie, H.T. van, Bekkering, H., 2008. Semantics in action: an electrophysiological study on the use of semantic knowledge for action. J. Physiol.-Paris 102, 95–100. http://dx.doi.org/10.1016/j.jphysparis.2008.03.011.

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. http://dx.doi.org/10.1016/j.ymeth.2006.12.001.

Fink, A., Grabner, R.H., Benedek, M., Neubauer, A.C., 2006. Divergent thinking training is related to frontal electroencephalogram alpha synchronization. Eur. J. Neurosci. 23, 2241–2246. http://dx.doi.org/10.1111/j.1460-9568.2006.04751.x.

Fink, A., Grabner, R.H., Benedek, M., Reishofer, G., Hauswirth, V., Fally, M., Neubauer, A.C., 2009a. The creative brain: investigation of brain activity during creative problem solving by means of EEG and FMRI. Hum. Brain Mapp. 30, 734–748. http://dx.doi.org/10.1002/hbm.20538.

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. http://dx.doi.org/10.1016/j.neuroimage.2009.02.036.

Fink, A., Neubauer, A.C., 2006. EEG alpha oscillations during the performance of verbal creativity tasks: differential effects of sex and verbal intelligence. Int. J. Psychophysiol. 62, 46–53. http://dx.doi.org/10.1016/j.ijpsycho.2006.01.001.

Fink, A., Schwab, D., Papousek, I., 2011. Sensitivity of EEG upper alpha activity to cognitive and affective creativity interventions. Int. J. Psychophysiol. 82, 233–239. http://dx.doi.org/10.1016/j.ijpsycho.2011.09.003.

Fink, A., Woschnjak, S., 2011. Creativity and personality in professional dancers. Personal. Individ. Differ. 51, 754–758. http://dx.doi.org/10.1016/j.paid.2011.06.024.

Fink, Andreas, Benedek, Mathias, 2014. EEG alpha power and creative ideation. Neurosci. Biobehav. Rev. 44, 111–123. http://dx.doi.org/10.1016/j.neubiorev.2012.12.002.

Gilhooly, K.J., Fioratou, E., Anthony, S.H., Wynn, V., 2007. Divergent thinking: strategies and executive involvement in generating novel uses for familiar objects. Br. J. Psychol. 98, 611–625. http://dx.doi.org/10.1348/096317907x173421.

Gilhooly, K.J., Georgiou, G.J., Garrison, J., Reston, J.D., Sirota, M., 2012. Don't wait to incubate: immediate versus delayed incubation in divergent thinking. Mem. Cogn. 40, 966–975. http://dx.doi.org/10.3758/s13421-012-0199-z.

Golden, C.J., 1975. The measurement of creativity by the Stroop Color and Word Test. J. Personal. Assess. 39, 502–506. http://dx.doi.org/10.1207/s15327752jpa3905_9.

Grabner, R.H., Fink, A., Neubauer, A.C., 2007. Brain correlates of selfrated originality of ideas: evidence from event-related power and phase-locking changes in the EEG. Behav. Neurosci. 121, 224–230. http://dx.doi.org/10.1037/0735-7044.121.1.224.

Groborz, M., Necka, E., 2003. Creativity and cognitive control: explorations of generation and evaluation skills. Creat. Res. J. 15, 183–197. http://dx.doi.org/10.1080/10400419.2003.9651411.

Guilford, J.P., 1967. The Nature of Human Intelligence. McGraw-Hill, NY.

Handel, B.F., Haarmeier, T., Jensen, O., 2011. Alpha oscillations correlate with the successful inhibition of unattended stimuli. J. Cogn. Neurosci. 23, 2494–2502. http://dx.doi.org/10.1162/jocn.2010.21557.

Hanslmayr, S., Gross, J., Klimesch, W., Shapiro, K.L., 2011. The role of alpha oscillations in temporal attention. Brain Res. Rev. 67, 331–343. http://dx.doi.org/10.1016/j.brainresrev.2011.04.002.

Hao, N., Yuan, H., Cheng, R., Wang, Q., Runco, M.A., 2015. Interaction effect of response medium and working memory capacity on creative idea generation. Front. Psychol. 6, 1582. http://dx.doi.org/10.3389/fpsyg.2015.01582.

Harrington, D.M., 1975. Effects of explicit instructions to "be creative" on the psychological meaning of divergent thinking test scores. J. Personal. 43, 434–454. http://dx.doi.org/10.1111/j.1467-6494.1975.tb00715.x.

Hocevar, D., 1979. A comparison of statistical infrequency and subjective judgment as criteria in the measurement of originality. J. Personal. Assess. 43, 297–299. http://dx.doi.org/10.1207/s15327752jpa4303_13.

Jaarsveld, S., Fink, A., Rinner, M., Schwab, D., Benedek, M., Lachmann, T., 2015. Intelligence in creative processes: an EEG study. Intelligence 49, 171–178. http://dx.doi.org/10.1016/j.intell.2015.01.012.

Jauk, E., Benedek, M., Neubauer, A.C., 2012. Tackling creativity at its roots: evidence for different patterns of EEG alpha activity related to convergent and divergent modes of task processing. Int. J. Psychophysiol. 84, 219–225. http://dx.doi.org/10.1016/j.ijpsycho.2012.02.012.

Jauk, E., Benedek, M., Dunst, B., Neubauer, A.C., 2013. The relationship between intelligence and creativity: new support for the threshold hypothesis by means of empirical breakpoint detection. Intelligence 41, 212–221. http://dx.doi.org/10.1016/j.intell.2013.03.003.

Jauk, E., Benedek, M., Neubauer, A.C., 2014. The road to creative achievement: a latent variable model of ability and personality predictors. Eur. J. Personal. 28, 95–105. http://dx.doi.org/10.1002/per.1941.

Jausovec, N., Jausovec, K., 2000. EEG activity during the performance of complex mental problems. Int. J. Psychophysiol. 36, 73–88. http://dx.doi.org/10.1016/S0167-8760(99)00113-0.

Jensen, O., Mazaheri, A., 2010. Shaping functional architecture by oscillatory alpha activity: gating by inhibition. Front. Hum. Neurosci. 4, 186. http://dx.doi.org/10.3389/fnhum.2010.00186.

Johns, G.A., Morse, L.W., Morse, D.T., 2001. An analysis of early vs. later responses on a divergent production task across three time press conditions. J. Creat. Behav. 35, 65–72. http://dx.doi.org/10.1002/j.2162-6057.2001.tb01222.x.

Jung-Beeman, M., Bowden, E.M., Haberman, J., Frymiare, J.L., Arambel-Liu, S., Greenblatt, R., Kounios, J., 2004. Neural activity when people solve verbal problems with insight. PLOS Biol. 2, 500–510. http://dx.doi.org/10.1371/journal.pbio.0020097.

Jung, T.P., Makeig, S., Humphries, C., Lee, T.W., McKeown, M.J., Iragui, V., Sejnowski, T.J., 2000. Removing electroencephalographic artifacts by blind source separation. Psychophysiology 37, 163–178. http://dx.doi.org/10.1017/S0048577200980259.

Kaufman, J.C., Plucker, J.A., Baer, J., 2008. Essentials of Creativity Assessment. John Wiley & Sons Inc, Hoboken, NJ US.

Klimesch, W., 1999. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res. Rev. 29, 169–195. http://dx.doi.org/10.1016/S0165-0173(98)00056-3.

Klimesch, W., 2012. Alpha-band oscillations, attention, and controlled access to stored information. Trends Cogn. Sci. 16, 606–617. http://dx.doi.org/10.1016/j.tics.2012.10.007.

Klimesch, W., Sauseng, P., Hanslmayr, S., 2007. EEG alpha oscillations: the inhibition-timing hypothesis. Brain Res. Rev. 53, 63–88. http://dx.doi.org/10.1016/j.brainresrev.2006.06.003.

Lee, C.S., Therriault, D.J., 2013. The cognitive underpinnings of creative thought: a latent variable analysis exploring the roles of intelligence and working memory in three creative thinking processes. Intelligence 41, 306–320. http://dx.doi.org/10.1016/j.intell.2013.04.008.

Lustenberger, C., Boyle, M.R., Foulser, A.A., Mellin, J.M., Frohlich, F., 2015. Functional role of frontal alpha oscillations in creativity. Cortex 67, 74–82. http://dx.doi.org/10.1016/j.cortex.2015.03.012.

Martindale, C., Hasenfus, N., 1978. EEG differences as a function of creativity, stage of the creative process, and effort to be original. Biol. Psychol. 6, 157–167. http://dx.doi.org/10.1016/0301-0511(78)90018-2.

Martindale, C., Hines, D., Mitchell, L., Covello, E., 1984. EEG alpha asymmetry and creativity. Personal. Individ. Differ. 5, 77–86. http://dx.doi.org/10.1016/0191-8869(84)90140-5.

Mayseless, N., Eran, A., Shamay-Tsoory, S.G., 2015. Generating original ideas: the neural underpinning of originality. Neuroimage 116, 232–239. http://dx.doi.org/10.1016/j.neuroimage.2015.05.030.

Mednick, S.A., 1962. The associative basis of the creative process. Psychological Review 69, 220–232. http://dx.doi.org/10.1037/h0048850.

Milgram, R.M., Rabkin, L., 1980. Developmental test of Mednick's associative hierarchies of original thinking. Dev. Psychol. 16, 157–158. http://dx.doi.org/10.1037/0012-1649.16.2.157.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., Wager, T.D., 2000. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. Cogn. Psychol. 41, 49–100. http://dx.doi.org/10.1006/cogp.1999.0734.

Morris, N., Jones, D.M., 1990. Memory updating in working memory: the role of the central executive. Br. J. Psychol. 81, 111–121. http://dx.doi.org/10.1111/j.2044-8295.1990.tb02349.x.

Nijstad, B.A., De Dreu, C.K., Rietzschel, E.F., Baas, M., 2010. The dual pathway to creativity model: creative ideation as a function of flexibility and persistence. Eur. Rev. Soc. Psychol. 21, 34–77. http://dx.doi.org/10.1080/10463281003765323.

Nusbaum, E.C., Silvia, P.J., 2011a. Are intelligence and creativity really so different? Fluid intelligence, executive processes, and strategy use in divergent thinking. Intelligence 39, 36–45. http://dx.doi.org/10.1016/j.intell.2010.11.002.

O'Rourke, P., Haarmann, H.J., George, T., Smaliy, A., Grunewald, K., Dien, J., 2015. Hemispheric alpha asymmetry and self-rated originality of ideas. Laterality, 20. http://dx.doi.org/10.1080/1357650X.2015.1037309.

Payne, L., Sekuler, R., 2014. The importance of ignoring: alpha oscillations protect selectivity. Curr. Dir. Psychol. Sci. 23, 171–177. http://dx.doi.org/10.1177/0963721414529145.

Pfurtscheller, G., da Silva, F.H.L., 1999. Event-related EEG/MEG synchronization and desynchronization: basic principles. Clin. Neurophysiol. 110, 1842–1857. http://dx.doi.org/10.1016/S1388-2457(99)00141-8.

Pfurtscheller, G., Stancák, A., Neuper, C., 1996. Post-movement beta synchronization. A correlate of an idling motor area? Electroencephalogr. Clin. Neurophysiol. 98, 281–293. http://dx.doi.org/10.1016/0013-4694(95)00258-8.

Phillips, V.K., Torrance, E.P., 1977. Levels of originality at earlier and later stages of creativity test tasks. J. Creat. Behav. 11. http://dx.doi.org/10.1002/j.2162-6057.1977.tb00602.x.

Rogers, R.D., Monsell, S.D., 1995. Costs of a predictable switch between simple cognitive tasks. J. Exp. Psychol. Gen. 124, 207–231. http://dx.doi.org/10.1037/0096-3445.124.2.207.

Runco, M.A., 1991. Divergent Thinking. Ablex, Norwood, NJ.

Runco, M.A., 1994. Cognitive and psychometric issues in creativity research. In: Isaksen, S.G., Murdock, M.C., Firestien, R.L., Treffinger, D.J. (Eds.), Understanding and Recognizing Creativity. Ablex, Norwood, NJ, 331–368.

Runco, M.A., 1999. Creative thought: an investigation of conceptual structures and processes. Contemp. Psychol.-Apa Rev. Books 44, 554–555. http://dx.doi.org/10.1037/10227-006.

Runco, M.A., 1986. Flexibility and originality in children's divergent thinking. J. Psychol. Interdiscip. Appl. 120, 345–352. http://dx.doi.org/10.1080/00223980.1986.9712632.

Runco, M.A., Acar, S., 2012. Divergent thinking as an indicator of creative potential. Creat. Res. J. 24, 66–75. http://dx.doi.org/10.1080/10400419.2012.652929.

Runco, M.A., Mraz, W., 1992. Scoring divergent thinking tests using total ideational output and a creativity index. Educ. Psychol. Meas. 52, 213–221. http://dx.doi.org/10.1177/001316449205200126.

Runco, M.A., Pritzker, S.R., 1999. Encyclopedia of Creativity. Academic Press, San Diego, CA.

Silvia, P.J., 2011. Subjective scoring of divergent thinking: examining the reliability of unusual uses, instances, and consequences tasks. Think. Skills Creat. 6, 24–30. http://dx.doi.org/10.1016/j.tsc.2010.06.001.

Spector, A., Biederman, I., 1976. Mental set and mental shift revisited. Am. J. Psychol. 89, 669–679. http://dx.doi.org/10.2307/1421465.

Stroop, J.R., 1935. The basis of Ligon's theory. Am. J. Psychol. 47, 499–504. http://dx.doi.org/10.2307/1416349.

Unsworth, N., Engle, R.W., 2007. The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. Psychol. Rev. 114, 104–132. http://dx.doi.org/10.1037/0033-295X.114.1.104.

Unsworth, N., Spillers, G.J., Brewer, G.A., 2011. Variation in verbal fluency: a latent variable analysis of clustering, switching, and overall performance. Q. J. Exp. Psychol. 64, 447–466. http://dx.doi.org/10.1080/17470218.2010.505292.

von Stein, A., Sarnthein, J., 2000. Different frequencies for different scales of cortical integration: from local gamma to long range alpha/theta synchronization. Int. J. Psychophysiol. 38, 301–313. http://dx.doi.org/10.1016/s0167-8760(00)00172-0.

Wallach, M.A., Kogan, N., 1965. Modes of Thinking in Young Children: A Study of the Creativity–Intelligence Distinction. Rinehart, & Winston, New York: Holt.

Ward, W.C., 1968. Rate and uniqueness in children's creative responding. ETS Res. Bull. Ser. 1968, 1–17. http://dx.doi.org/10.1002/j.2333-8504.1968.tb00560.x.

Zhu, W., Chen, Q., Xia, L., Beaty, R.E., Yang, W., Tian, F., Qiu, J., 2017. Common and distinct brain networks underlying verbal and visual creativity. Hum. Brain Mapp.. http://dx.doi.org/10.1002/hbm.23507.

Zabelina, D.L., Andrews-Hanna, J.R., 2016. Dynamic network interactions supporting internally-oriented cognition. Curr. Opin. Neurobiol. 40, 86–93. http://dx.doi.org/10.1016/j.conb.2016.06.014.