Neuropsychologia 56 (2014) 393–400

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Alpha power increases in right parietal cortex reflects focused internal attention

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ARTICLE INFO

Article history:
Received 19 September 2013
Received in revised form
6 February 2014
Accepted 11 February 2014
Available online 18 February 2014

Keywords:
Attention
Memory
Inhibition
EEG
Alpha
Divergent thinking

ABSTRACT

This study investigated the functional significance of EEG alpha power increases, a finding that is consistently observed in various memory tasks and specifically during divergent thinking. It was previously shown that alpha power is increased when tasks are performed in mind—e.g., when bottom-up processing is prevented. This study aimed to examine the effect of task-immanent differences in bottom-up processing demands by comparing two divergent thinking tasks, one intrinsically relying on bottom-up processing (sensory-intake task) and one that is not (sensory-independence task). In both tasks, stimuli were masked in half of the trials to establish conditions of higher and lower internal processing demands. In line with the hypotheses, internal processing affected performance and led to increases in alpha power only in the sensory-intake task, whereas the sensory-independence task showed high levels of task-related alpha power in both conditions. Interestingly, conditions involving focused internal attention showed a clear lateralization with higher alpha power in parietal regions of the right hemisphere. Considering evidence from fMRI studies, right-parietal alpha power increases may correspond to a deactivation of the right temporoparietal junction, reflecting an inhibition of the ventral attention network. Inhibition of this region is thought to prevent reorienting to irrelevant stimulation during goal-driven, top-down behavior, which may serve the executive function of task shielding during demanding cognitive tasks such as idea generation and mental imagery.

1. Introduction

EEG alpha activity is the dominant oscillatory activity of the human brain (Niedermeyer & Lopes da Silva, 1999). It has been associated with basic cognitive functions such as attention or memory (Klimesch, 2012), and also with more complex cognitive processes such as divergent thinking (i.e., creative idea generation; Fink and Benedek, 2013, in press). A recent experimental study found that a prevention of bottom-up information processing causes alpha power increases in convergent and divergent thinking tasks (Benedek, Bergner, Könen, Fink, & Neubauer, 2011). The present study aims to follow up these findings to disentangle alpha effects as a cause of experimentally enforced internal attention, and due to task-dependent attention demands.

EEG research has a long tradition in studying oscillatory brain activity related to various cognitive tasks and emotional states. This led to the identification of different frequency bands within the EEG power spectrum, such as alpha, beta, gamma or theta, which proved to be sensitive to discriminable psychological functions (e.g., Klimesch, 1999; Fries, 2005; von Stein & Sarntheim, 2002). The investigation of alpha activity (8–12 Hz) led to some controversy about its functional significance. The frequent observation that alpha activity shows task-related decreases in various cognitive tasks (i.e., alpha desynchronization) but increases (i.e., alpha synchronization) during rest and with eyes closed, led to the notion that alpha activity reflects a cognitive default state such as 'cortical idling' (Pfurtscheller, Stancak, & Neuper, 1996). Other studies observing task-related increases of alpha activity e.g., during memory retention (Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999), or with increasing task load (Jensen, Gelfand, Kounios, & Lisman, 2002), however, suggest a more active role of alpha activity.

Examining the functional significance of EEG alpha and beta activity, Ray and Cole (1985) found that alpha power is lower in *sensory-intake* tasks (i.e., tasks that rely on processing of external stimuli, such as counting verbs in a passage or the paper folding task) as compared to *intake-rejection* tasks (i.e., tasks that do not require processing of external sensory stimuli, such as mental arithmetic or imagination of an imaginary walk). They suggested that alpha activity reflects attentional demands and is higher for tasks with internal attention focus than for tasks with external attention focus. Other research using short-term memory tasks found alpha activity to increase as a function of memory load

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http://dx.doi.org/10.1016/j.neuropsychologia.2014.02.010

(Jensen et al., 2002; Klimesch et al., 1999). It was proposed that alpha increases may reflect active top-down inhibition of task irrelevant brain regions, such as inhibition of access to semantic long-term memory (Klimesch et al., 1999), or inhibition or disengagement of visual areas to suppress the processing of irrelevant visual information (Jensen et al., 2002). The latter interpretation is supported by findings showing alpha increases over occipital cortex contralateral to the position of distractor stimuli in spatial cuing paradigms (Händel, Haarmeier, & Jensen, 2011; Rihs, Michel, & Thut, 2007; Worden, Foxe, Wang, & Simpson, 2000).

Another function that has been attributed to alpha activity is that phase coherence in the alpha range between different brain regions may be an important mechanism underlying intracortical interaction such as top-down control (Engel, Fries, & Singer, 2001; Von Stein & Sarnthein, 2000; Zanto, Rubens, Thangavel, & Gazzaley, 2011). Moreover, it was suggested that the phase characteristics of alpha activity reflect a mechanism of functional inhibition at neuronal level that supports rhythmic updating (Chakravarthi & VanRullen, 2012), gating of information (Jensen & Mazaheri, 2010), and phase coding of information (Jensen, Bonnefond, & VanRullen, 2012). Klimesch (2012) proposed that alpha activity has both roles: inhibition of task-irrelevant networks and timing within task-relevant networks. Alpha activity thus plays an important role for attention by supporting processes within the attentional focus and blocking processes outside its focus.

Over the last years, task-related increases in alpha activity have also been consistently observed during performance of divergent thinking tasks (i.e., creative idea generation tasks; Fink and Benedek, 2013, in press). For example, in the alternate uses task (a task also commonly used in psychometric research on creative potential; Benedek, Mühlmann, Jauk, and Neubauer, 2013; Kaufman, Plucker, and Baer, 2008) participants are asked to generate creative new uses for common objects such as a "shoe". Performance of this and other divergent thinking tasks consistently results in task-related power (TRP) increases in the alpha band as compared to a pre-task reference period. Alpha synchronization was found to be strongest in frontal brain regions but also high in posterior parts of the right hemisphere (Fink & Benedek, in press). A number of EEG studies further revealed that EEG alpha activity is sensitive to creativity-related demands of tasks (more alpha in task showing higher as compared to lower free-associative, divergent thinking; e.g., Jauk, Benedek, and Neubauer (2012), Jaušovec (1997) to creativity of ideas (more alpha for more as compared to less creative ideas; Fink and Neubauer, 2006; Grabner, Fink, and Neubauer, 2007), to individual differences in creativity (more alpha in more creative people; Fink and Neubauer, 2008; Fink et al., 2009a,b); Jaušovec, 2000; Martindale and Hines, 1975; Martindale and Hasenfus, 1978), and to increase after successful creativity-enhancing interventions (Fink, Grabner, Benedek, & Neubauer, 2006; Fink, Schwab, & Papousek, 2011). These findings suggest that creative cognition is reliably associated with increased alpha power levels in the brain (for a review, see Fink and Benedek, 2013, in press).

Considering the evidence on the functional significance of alpha activity, it yields the question to what extent alpha activity during divergent thinking is either due to processes specific for creative cognition, or due to more general (e.g., attentional) demands of these tasks. This question has recently been addressed in an EEG study varying creative cognition-related task demands (convergent vs. divergent thinking) and attentional task demands (low vs. high internal attention demands) as experimental factors in a within-subject design (Benedek et al., 2011). In the convergent thinking task participants had to solve four-letter anagram problems which have just one correct solution; in the divergent thinking task participants were presented the same four-letter words but had to generate original four-word sentences with the letters as initials. Additionally, stimuli either remained visible throughout the task, or were masked after 500 ms to avoid any further bottom-up information processing. The latter condition was intended to implement higher internal attention demands. A comparison of task-related alpha power between tasks and conditions showed that alpha power increases were particularly related to high internal attention demands, rather than differences between tasks. During high internal attention demands alpha synchronization was observed in both tasks especially at frontal sites, and for the divergent thinking task also at posterior parietal sites of the right hemisphere. During low internal attention demands, however, both tasks showed task-related decreases of alpha power. This finding supports the notion of alpha activity reflecting internal attention.

What is still unclear, however, is the question why in this study in the divergent thinking task alpha synchronization was only observed when high internal attention demands were experimentally induced, although it had been observed in many previous studies for divergent thinking without any stimulus masking (Fink & Benedek, in press). It was proposed that this may be due to the nature of the employed divergent thinking task that was specifically adapted for this study (Benedek et al., 2011): Generating four-word sentences from four letters may rely on the processing of external information as four abstract stimuli have to be considered and manipulated. Most other divergent thinking tasks, however, encode and process verbal stimuli as single concepts and thus may not require further bottom-up processing during the task. We assume that the amount of task-related alpha activity during divergent thinking does not only depend on the availability of relevant external information but particularly on whether the task requires that attention is continuously directed to the processing of external information or not.

To test this hypothesis, we performed another experiment similar to the previous one, but this time contrasting two types of divergent thinking (DT) tasks—one DT task involving the processing of external information, whereas the other one is not. These tasks could be categorized as *sensory-intake* and *sensory-independence* (or intake-rejection; Ray and Cole, 1985) tasks. For the sensory-intake task, we again employed the four-word sentence generation task. This task was shown to involve processing of external information since performance decreases after stimulus masking (Benedek et al., 2011). For the sensory-independence task, we employed the alternate uses task, a widely used divergent thinking task which requires generating creative uses of common objects. In both tasks we presented four-letter words denoting objects. In the four-word sentence task this stimulus is processed as four abstract elements of information, whereas in the alternate uses task it is processed as one conceptual stimulus. Additionally, as in the previous study, both tasks were performed with the stimulus either remaining visible (low internal attention condition) or being masked directly after encoding (high internal attention condition). We hypothesized that the stimulus masking would predominantly affect the sensory-intake task which typically relies on processing of external information, leading to higher alpha power in the high as compared to the low internal attention condition. In contrast, stimulus masking should not affect the sensory-independent task as it does not rely on processing of external information. Finally, since the sensory-independence task naturally shows focused internal attention, it should show higher alpha power than the sensory-intake task especially in the low internal attention condition.

2. Methods

2.1. Participants

40 students (20 female) participated in this study. On average, participants were 25.4 years old (SD=2.87; range=20–32 years). All participants were right-handed, had normal or corrected-to-normal vision and reported no medical or