



Topographical differences of frontal-midline theta activity reflect functional differences in cognitive control abilities

Kathrin C. J. Eschmann*, Regine Bader, Axel Mecklinger

Experimental Neuropsychology Unit, Department of Psychology, Saarland University, Saarbrücken, Germany

ARTICLE INFO

Keywords:

Frontal-midline Theta
Cognitive Control
Working Memory
Interference

ABSTRACT

Electrophysiological oscillations are assumed to be the core mechanism for large-scale network communication. The specific role of frontal-midline theta oscillations as cognitive control mechanism is under debate. According to the dual mechanisms of control framework, cognitive control processes can be divided into proactive and reactive control. The present study aimed at investigating the role of frontal-midline theta activity by assessing oscillations in two tasks varying in the type of cognitive control needed. More specifically, a delayed match to sample (DMTS) task requiring proactive control and a color Stroop task recruiting reactive control processes were conducted within the same group of participants. Moreover, both tasks contained conditions with low and high need for cognitive control. As expected larger frontal-midline theta activity was found in conditions with high need for cognitive control. However, theta activity was focally activated at frontal sites in the DMTS task whereas it had a broader topographical distribution in the Stroop task, indicating that both proactive and reactive control are reflected in frontal-midline theta activity but reactive control is additionally characterized by a broader theta activation. These findings support the conclusion that frontal-midline theta acts functionally different depending on task requirements.

1. Introduction

Cognitive control processes are needed to function in everyday life and are assumed to be reflected in theta activity (ca. 4–7 Hz) that mainly occurs at mid-frontal electrode sites (see Cavanagh & Frank, 2014; Sauseng, Griesmayr, Freunberger, & Klimesch, 2010, for review). Although frontal midline (FM) theta has been found in numerous studies investigating cognitive control abilities, its precise functional role is still under debate. In a recent comprehensive review, Cavanagh and Frank (2014) proposed that FM theta represents a general control mechanism that reflects the need for and the implementation of cognitive control. This assumption is based on observations of goal-directed or habituating behavior, in which cognitive control processes are needed in order to resolve a situation with the best possible outcome and to adaptively optimize performance for future encounters of similar situations. The assumption of a general control mechanism (Cavanagh & Frank, 2014) receives support by several electrophysiological studies investigating cognitive effort in a large variety of context situations, such as during working memory (WM) encoding and maintenance or episodic memory encoding and retrieval. For instance, both stimulus- and response-locked event-related potential (ERP) components that are elicited by novelty, conflict, errors or negative feedback are

accompanied by increased FM theta activity (Cavanagh, Zambrano-Vazquez, & Allen, 2012). Moreover, in WM studies, FM theta power was shown to increase in conditions with high WM load and task difficulty (Gevins, Smith, McEvoy, & Yu, 1997; Griesmayr, Gruber, Klimesch, & Sauseng, 2010; Jensen & Tesche, 2002; Onton, Delorme, & Makeig, 2005; Roberts, Hsieh, & Ranganath, 2014; Wilson, Swain, & Ullsperger, 1999; see Sauseng et al., 2010, for review). In some of these studies, the increase in theta activity during WM was also predictive of later long-term memory retrieval (Gruber, Tsivilis, Giabbiconi, & Müller, 2008; Khader, Jost, Ranganath, & Rösler, 2010; Osipova et al., 2006; Sederberg, Kahana, Howard, Donner, & Madsen, 2003; see Nyhus & Curran, 2010, for review), suggesting that FM theta reflects cognitive control processes that serve both WM and episodic memory functions. In contrast to WM memory studies, difficulty of episodic memory retrieval can lead to both increases and decreases of FM theta, indicating that FM theta reflects different aspects of episodic memory, such as memory representation strength or memory evaluation processes (Klimesch et al., 2006). FM theta power was also shown to reflect the amount of cognitive control recruitment in interference situations in which two contrary responses are in conflict to each other, e.g. in incongruent trials of a Stroop, Simon and flanker task or No-Go trials in a Go/No-Go task (Hanslmayr et al., 2008; Nigbur, Ivanova, & Stürmer,

* Corresponding author at: Experimental Neuropsychology Unit, Department of Psychology, Saarland University, Campus Building A2 4, Room 2.15, 66123 Saarbrücken, Germany.
E-mail address: kathrin.eschmann@uni-saarland.de (K.C.J. Eschmann).

2011). Additionally, FM theta activity declines with increasing interference resolution in competitive memory retrieval (Ferreira, Marful, Staudigl, Bajo, & Hanslmayr, 2014; Spitzer, Hanslmayr, Opitz, Mecklinger, & Bäuml, 2009; Waldhauser, Bäuml, & Hanslmayr, 2014). In these situations, memory representations, which either belong to the same category or are associated with each other, compete for retrieval. While interference induces FM theta activity, the successful suppression of competing associations leads to a decrease in FM theta activity.

FM theta oscillations are assumed to communicate and implement the need for cognitive control in different neural systems comprising both neighboring as well as distant brain regions (Cavanagh & Frank, 2014; Cavanagh et al., 2012; Helfrich & Knight, 2016). Thereby, the synchronization of neurons that belong to assumed FM theta source regions, such as the anterior cingulate cortex (ACC) or the midcingulate cortex (MCC), leads to FM theta amplitudes that provide temporal windows for segregating information intake via corresponding activity of other cortical populations (Cavanagh & Frank, 2014). The coincident activation between FM theta source regions and other task-relevant brain regions is reflected in theta phase synchronization and can be interpreted as information intake and transfer between these regions (Asada, Fukuda, Tsunoda, Yamaguchi, & Tonoike, 1999; Cohen, 2011; Gevins et al., 1997; Onton et al., 2005). For instance, situations, in which an unexpected feedback or conflict occurs, are characterized by theta phase synchronization between areas that play an important role in conflict detection and the lateral prefrontal cortex (LPFC), an area critical for active task-goal maintenance (Cavanagh, Frank, Klein, & Allen, 2010). Accordingly, information about the detected conflict is communicated and leads to the adaptive modification of task-goals. In contrast, after an erroneous response in a No-Go trial, mid-frontal brain areas synchronize with occipital sensory regions in order to prevent response errors in the future (Cohen, van Gaal, Ridderinkhof, & Lamme, 2009). This theta phase synchronization between mid-frontal and occipital areas after an error even persists into following trials. It is assumed that mid-frontal brain regions thereby exert top-down control over stimulus processing that happens in sensory areas. Consistent with this view, theta phase synchronization between mid-frontal brain regions and motor areas that was found in humans and in rats is interpreted to reflect the control over conflicting motor responses (Narayanan, Cavanagh, Frank, & Laubach, 2013). All in all, although different brain regions synchronize in different tasks serving different control mechanisms due to different task demands, the neural activity reliably results in FM theta activity measured at mid-frontal sites (see Cavanagh & Frank, 2014, for review).

The aforementioned studies mainly focused on cognitive control processes that are recruited after events with enhanced need for control in order to adaptively modify behavior. The dual mechanisms of control (DMC) framework by Braver (2012) distinguishes these forms of reactive control from proactive control. Proactive control reflects an early selection process that supports the facilitated processing of task-relevant information in a top-down manner. This is achieved by the active maintenance of task-goal information in order to bias sensory processing before the occurrence of a cognitively demanding event. The maintenance of task-goals and task-contexts is assumed to be reflected in sustained LPFC activation. In line with this assumption, several brain imaging studies could show sustained LPFC activation during WM maintenance (Braver & Bongiolatti, 2002; Braver & Cohen, 2001; Paxton, Barch, & Racine, 2007; Veltman, Rombouts, & Dolan, 2003). In contrast, reactive control is defined as a late correction process that is initiated when interference is detected and a prepotent response has to be inhibited in favor of a less prepotent one. According to the DMC framework, this reactive control is anchored in the LPFC and the ACC but also recruits a wider brain network compared to proactive control (Braver, 2012). Brain imaging studies investigating the reactive control mechanisms in color Stroop tasks could show simultaneous activation of prefrontal brain areas, such as the LPFC, and parietal regions (Grandjean et al., 2012; Milham et al., 2002; Zysset, Mu, Lohmann, &

von Cramon, 2001; see Niendam et al., 2012, for review). It is assumed that in the case of reactive control the processing of sensory or episodic memory information first leads to activation of posterior brain regions followed by conflict detection by the ACC before top-down control is exerted by PFC regions. In addition to imaging studies, studies investigating theta phase coherence between frontal and parietal sites could show the activation of different fronto-parietal theta networks in proactive and reactive control tasks (Cooper, Wong, McKewen, Michie, & Karayanidis, 2017; Cooper et al., 2015). However, for the analysis of proactive control, these studies focused on transient changes in proactive control for trial-type preparation that might involve a different control network than sustained maintenance of task-goals or stimuli (Cooper et al., 2015). In sum, previous research showed that proactive and reactive control processes are reflected in the activation of different networks, suggesting a smaller proactive control network including the LPFC and a wider reactive control network including frontal and parietal regions. Consequently, the question arises whether proactive and reactive control processes are also accompanied by scalp topographical differences of theta oscillations that become visible by directly comparing two tasks differing in the recruited cognitive control processes.

The present study aimed at investigating whether different forms of FM theta activity are recruited in two cognitive control tasks that are characterized by either proactive or reactive control demands. For this purpose, a delayed match to sample (DMTS) task and a color Stroop task, that were part of a larger study including also an episodic retrieval task, were analyzed. Although the study was not initially designed to compare proactive and reactive control processes, the DMTS and Stroop task were assumed to differentially recruit either proactive or reactive control mechanisms. In the DMTS task, participants have to maintain or manipulate a stimulus over a delay period in order to compare it to an expected probe afterwards. This task is assumed to mainly involve proactive control that supports the sustained and anticipatory maintenance of goal-relevant information. In contrast, in the color Stroop task, participants have to inhibit the prepotent response of reading the written color word that interferes with the task goal of naming the ink color. This is expected to primarily recruit reactive control that supports the suppression of the strongly activated task-irrelevant reading response and the strengthening of the weakly activated but task relevant color-naming response. In order to show that the degree of cognitive control recruitment has a behavioral and electrophysiological effect irrespective of the elicited cognitive control mode, both tasks contained a number of conditions differing in task difficulty and thus in the amount of cognitive control needed for performance of the respective condition. Based on previous findings, we expected slower reaction times (RTs) and lower accuracy in the conditions with high cognitive control compared to those with low cognitive control demands in both tasks. Additionally, stronger recruitment of cognitive control should be reflected in larger FM theta activation in the more difficult conditions of both tasks. Due to the fact that the cognitive control tasks differed in their proactive and reactive control demands, it was expected that the recruitment of differential cognitive control mechanisms would lead to scalp topographical differences of theta activity between both tasks.

2. Methods

2.1. Participants

Overall, 34 right-handed German volunteers who were recruited from Saarland University's student community participated in the study. For analyses of the Stroop task, data of all 34 participants (11 male, $M_{\text{age}} = 23.15$ years, age range = 19–27 years) was used. For analyses of the DMTS task, seven participants had to be excluded due to chance performance (determined by individual χ^2 tests for each participant), resulting in a sample of 27 participants (9 male, $M_{\text{age}} = 22.81$ years, age range = 19–27 years). Consequently, as the comparison of theta activity between tasks was within-participants, we

Download English Version:

<https://daneshyari.com/en/article/7282618>

Download Persian Version:

<https://daneshyari.com/article/7282618>

[Daneshyari.com](https://daneshyari.com)