Prefrontal-cingulate activation during executive control: A dipole source analysis of the Stroop interference effect

J. Markela, N. Ille, S. Kaiser, P. Fiedler, C. Mundt, M. Weisbrod

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Introduction

Executive control regulates information processing and response selection in situations, where routine mechanisms are unavailable or inadequate for task performance (Norman & Shallice, 1986). The neural basis of this executive system is thought to be a network involving the anterior cingulate gyrus (ACC) and prefrontal cortex (PFC) (MacDonald et al., 2000; Milham et al., 2001; Pardo et al., 1990; Posner & Rothbart, 1998; Smith & Jonides, 1999). However, the nature of interaction between PFC and ACC remains elusive. Is PFC dependent on the input from ACC or vice versa? Carter et al. (2000) found increased activity in ACC and bilaterally in inferior frontal cortex (IFC) during Stroop task using event-related fMRI. Interestingly, the activity in IFC peaked earlier than was seen in the ACC. Because of the limited temporal resolution of fMRI, it is difficult to examine the exact temporal pattern of activities in different regions with this method. This study investigated the spatiotemporal pattern of brain activation during Stroop task using high-density event-related potentials (ERPs) and dipole source modeling (BESA software).

Methods

Subjects: 16 (12 f) healthy right-handed subjects were included.

Task: In the Stroop task subjects are required to name the color of the word which is itself the name of a color. Subjects are faster to name the color when the color and the word are congruent (the word „red" written in red) than when the color and the word are incongruent (the word „red" written in blue). This increased response time reflects the interference effect of the word reading and is referred to as the Stroop effect. Computer and manual responses were employed. The experiment consisted of three test conditions which were neutral (non word letter strings), congruent and incongruent (see Figure 1) and two runs. One run consists of one third of each stimulus class, which are randomly presented.

ERPs: EEG was recorded continuously using a 64-channel Easy Cap. (Offline, the EEG was segmented into epochs 200 ms prestimulus to 1500 ms poststimulus. Artefact-free trials with correct responses were averaged synchronous to onset of stimulus.)

Statistical Analysis: An ANOVA was performed on the behavioral data using reaction times and error rates as dependent variables and condition as repeated measure variables.

Dipole modeling: Source locations and waveforms were calculated using a brain electrical source analysis (BESA). Dipole analysis was performed on the difference waveform of the incongruent and congruent conditions in order to determine possible neural generators underlying the Stroop effect. The analysis was carried out on grand averaged data in the time window of 350 - 540 ms.

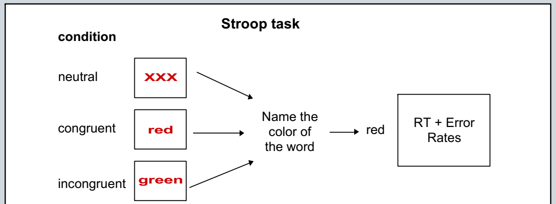

Figure 1: Experimental design

Results

Behavioral data: In the reaction time analysis, a robust Stroop color-word interference effect was observed as indicated by longer mean reaction times for incongruent than congruent words ($F(2,30) = 40.7$, $P < 0.0001$, mean = 109 ms).

ERP data: ERP analysis of the time window 350-540 ms revealed the neurophysiological substrate of the interference effect:

1.) A greater negativity in the incongruent as compared to the congruent and neutral conditions was found between 350-450 ms post-stimulus over left fronto-central and tempo-parietal scalp regions. Source analysis indicated that generators localized in left inferior prefrontal cortex contributed to this effect (peak at 400 ms).

2.) Immediately after the first effect, a greater positivity in the incongruent as compared to the congruent and neutral conditions developed between 450-540 ms post-stimulus over central and fronto-central scalp regions. Generators of this effect were located in right ACC with peak at 500 ms.

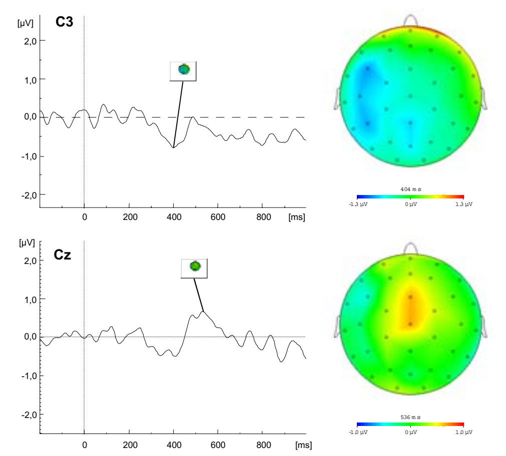

Figure 2: ERP difference waveforms (incongruent vs. congruent) and maps of the electrodes C3 and Cz of grand averaged data.

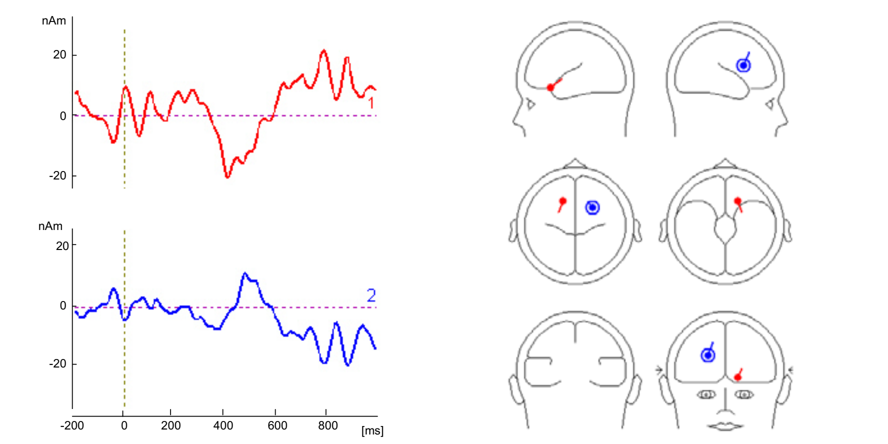

Figure 3: Dipol source analysis of the difference wave.
On the left side the source activity waveforms, on the right side the mean locations of the dipoles.

Conclusion

In the present study, we investigated the spatiotemporal pattern of brain activation during Stroop task. The neural correlates of the interference effect were obtained in the time window 350-540 ms in biphasic activation involving first left frontocentral and tempoparietal scalp and then frontocentral and central scalp. Source analysis indicated two dipoles for this time window: first effect was localized approximately in left inferior PFC and the second in the ACC. It has to be kept in mind, that dipole localizations are necessarily estimates. It is possible, that the frontal dipole is bilateral, the right dipole having less prominent activation. Interestingly, PFC dipole seems to peak about 100 ms before ACC dipole peaks. This finding is compatible with the hypothesis that PFC is engaged during the preparatory period of executive control representing and maintaining the attentional demands and ACC is involved later at the response competition level.

References

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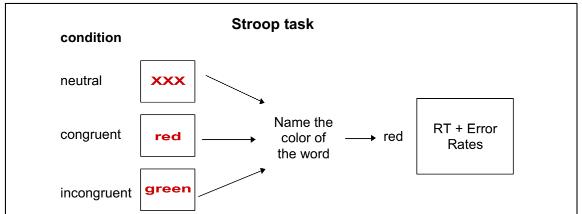

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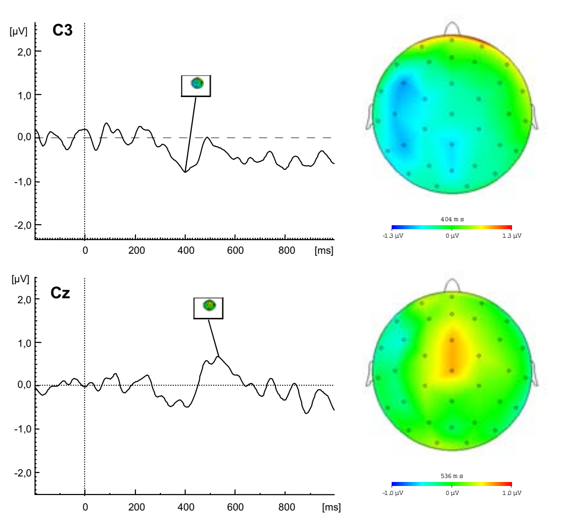

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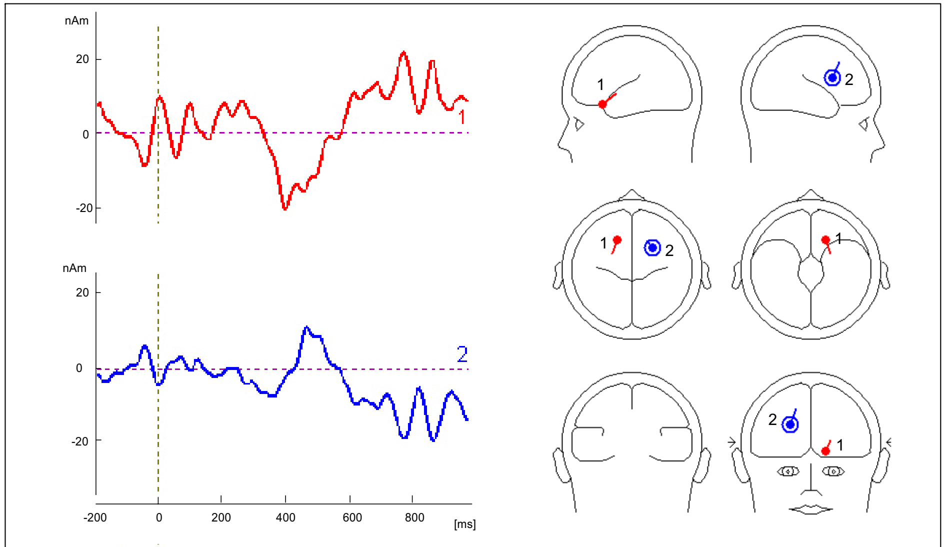

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