TEMPORAL COURSE OF EXECUTIVE CONTROL FUNCTIONS
AN ERP STUDY OF THE STROOP COLOR-WORD INTERFERENCE EFFECT

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Introduction

Executive control system regulates information processing and response selection in situations, where routine mechanisms are unavailable or inadequate (Norman and Shallice 1986, Posner and Dehaene 1994). According to Norman and Shallice these situations include planning, error correction, novel or difficult situations and response inhibition. The neural basis of this executive system is thought to be a network involving the anterior cingulate gyrus and prefrontal cortex (Posner and DiGirolamo 1998, Smith and Jonides 1999).

The event-related potential (ERP) studies of Stroop color-word interference effect provide controversial results (Posner & Rothbart 1998, Liotti et al. 2000). The aim of this study was to investigate the neurophysiological correlate of the Stroop interference effect in high density event-related potentials (ERPs). The Stroop Color-Word Test (SCWT) requires executive control functions and particularly inhibition of a learned routine (in this case word reading).

Methods

Subjects: 16 (12 f) healthy right-handed subjects were tested using high-density ERPs.

Task: In the SCWT 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. In the present experiment computer and manual responses were employed. The experiment consisted of three test conditions which were neutral (non word letter strings), congruent and incongruent and two runs (see figure 1). One run consists of one third of each stimulus class, which are randomly presented. Each run consisted of 188 stimuli.

ERPs: EEG was recorded continuously using a 64-channel Easy Cap.

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

On the ERP data we calculated mean amplitudes for the early time window (350-450 ms) over frontocentral scalp region and for the late time window (600-1000 ms) over parietal scalp region. An ANOVA was performed for both time windows with task condition, run and hemisphere as within subject factors. Newman-Keuls tests were used for post-hoc comparisons.

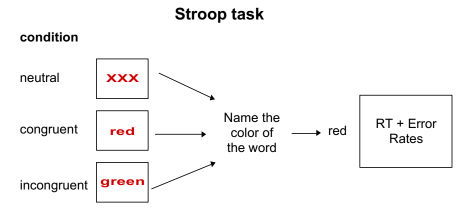

Figure 1: Experimental design

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 effect size = 109 ms). There was also significant condition x run interaction (F(2,30) = 5.6, P < 0.01) (see figure 2). Post hoc tests revealed significantly longer reactions times in the incongruent condition in the first run as compared to the second run (P < 0.01).

ERP data: ERP revealed the neurophysiological substrate of Stroop color-word interference effect: A first effect consisted of a negativity more pronounced to incongruent than to congruent and neutral words in a 350-450 ms time window over left frontocentral scalp region (see figure 3) (main effect of condition F(2,30) = 6.0, P < 0.01). Later on in time, a prolonged positivity greater to incongruent than to congruent and neutral words was observed in a 600-1000ms time window over parietal scalp region (see figure 4) (main effect of condition F(2,30) = 6.8, P < 0.005).

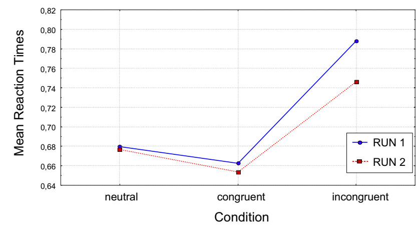

Figure 2: Mean reaction times for different conditions and both runs. Interaction condition x run F (2,30) = 5.6, P < 0.01

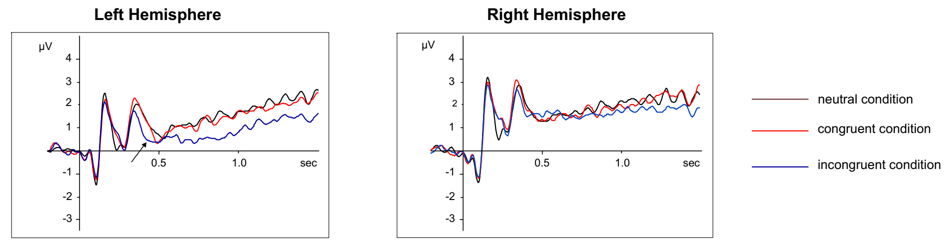

Figure 3: Grand Averages for pooled frontocentral electrodes over both hemispheres for neutral, congruent and incongruent conditions. Interference effect is visible as a negative wave over left hemisphere in a 350-500 ms time window.

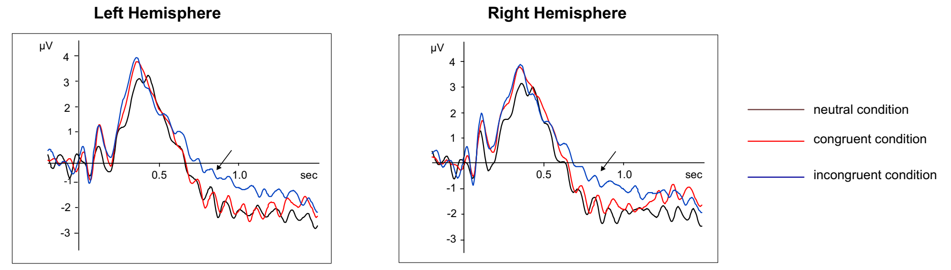

Figure 4: Grand Averages for pooled parietal electrodes over both hemispheres for neutral, congruent and incongruent conditions. Late positivity is visible as a positive wave in a 600-1000 ms time window.

Conclusion

In the present study, a robust behavioral Stroop color-word interference effect was obtained in the mixed-trial manual version of Stroop task. The neural correlates of this interference effect were explored: ERP data show a biphasic activation which was observed first over left frontocentral scalp region in a 350-450 ms time window and then over parietal scalp region in a 600-1000 ms time window.

These data clarify the earlier ERP findings of the Stroop interference effect. Posner & Rothbart (1998) found no differences in temporal and spatial patterns of ERP data for the congruent and incongruent conditions. On the contrary, Rebai et al. (1997) reported an interference effect peaking at 400 ms (which was interpreted as an traditional N400) and West and Alain (1999) found a positivity of the slow potential beginning 500ms after stimulus onset elicited by the incongruent condition as compared to congruent condition. However Rebai et al. and West & Alain employed only a few midline electrodes. Using high density ERPs but only eight subjects Liotti et al. (2000) recently found two Stroop interference effects: a left-sided early negativity (350-500 ms) and late positivity (500-800 ms). Our study replicated the ERP findings of the temporal pattern of Stroop interference effect using high-density ERPs. However, we observed a slightly different spatial pattern of the ERP data than other studies.

We interpret the early negativity effect as relating to the inhibition processes and the later positivity effect to the postevaluation of the performance after the response has been delivered. Taking into account previous neuroimaging studies of Stroop task (Pardo et al. 1990, Peterson et al. 1999), the possible neural generator of the negative wave may be the anterior cingulate cortex.

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