What does EEG event-related microstate analysis teach us regarding the role of the anterior cingulate cortex in processing conflicting information?

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1 Introduction

Conflict monitoring model predicting a higher anterior cingulate cortex (ACC) neuronal activity on incongruent trials (Botvinick, 2001) has been recently challenged by a model predicting longer neuronal activity in incongruent trials characterized by longer RTs (Grinband, 2011). So far, however, only indirect evidence from fMRI studies has been provided in support to this alternative model. One main issue that remains to clarify is whether higher ACC activation reflects specifically a conflict between brain pathways processing distinct aspects of information or whether a longer duration of ACC activation reflects more generally the brain operations needed to select the correct response.

The present work aimed to provide further evidence to the computational model proposed by Grinband et al. (2011) in combining complementary methods sensitive to the temporality of events. To achieve our goal, brain dynamics were explored through electroencephalography (EEG) recording during performance on a Stroop task.

2 Methods

2.1 *Participants and Procedure*

- 38 young adults (19 females; mean age = 35.5 years, SD = 8.1 years, range 18 to 50 years)
- A modified version of the Stroop paradigm (Fig.1) was used. Participants were asked to indicate which word or color was read by pressing one of three keys on a computer keyboard.
- 324 trials: 50% of congruent and incongruent trials were preceded by a cue indicating to identify the color of the printed word

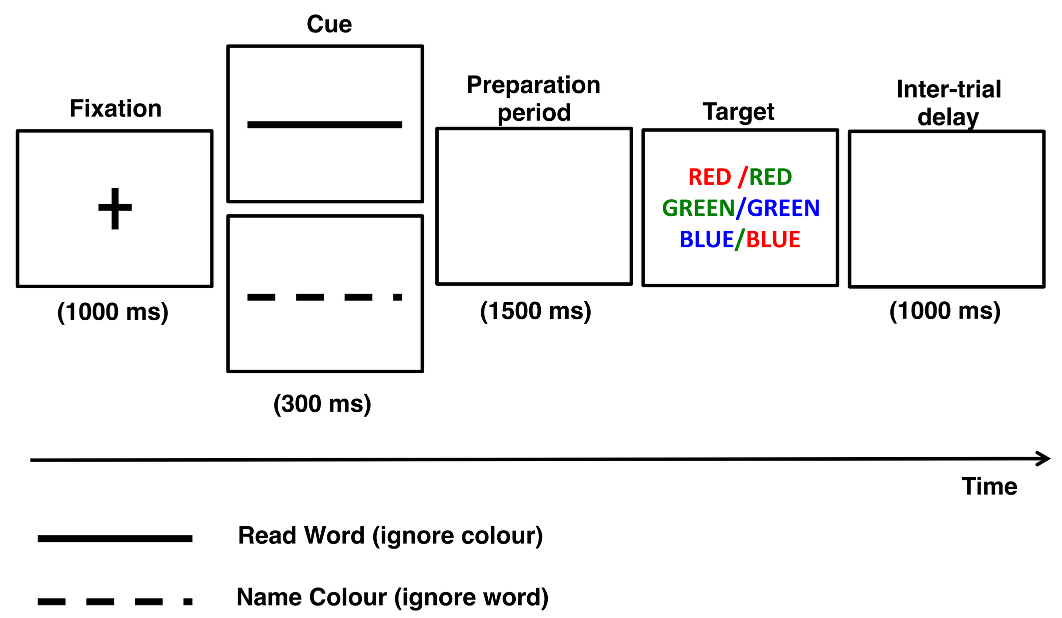


Figure 1: *Trial design: a fixation cross was presented for 1000 ms, followed by a cue of 300 ms duration informing the participants on the type of task to perform (read the word or name the colour). After a delay of 1500 ms, participants were asked to give their response during the presentation of the stimulus that appeared for 300 ms. After the response, a delay of 1000 ms appeared before the next trial.*

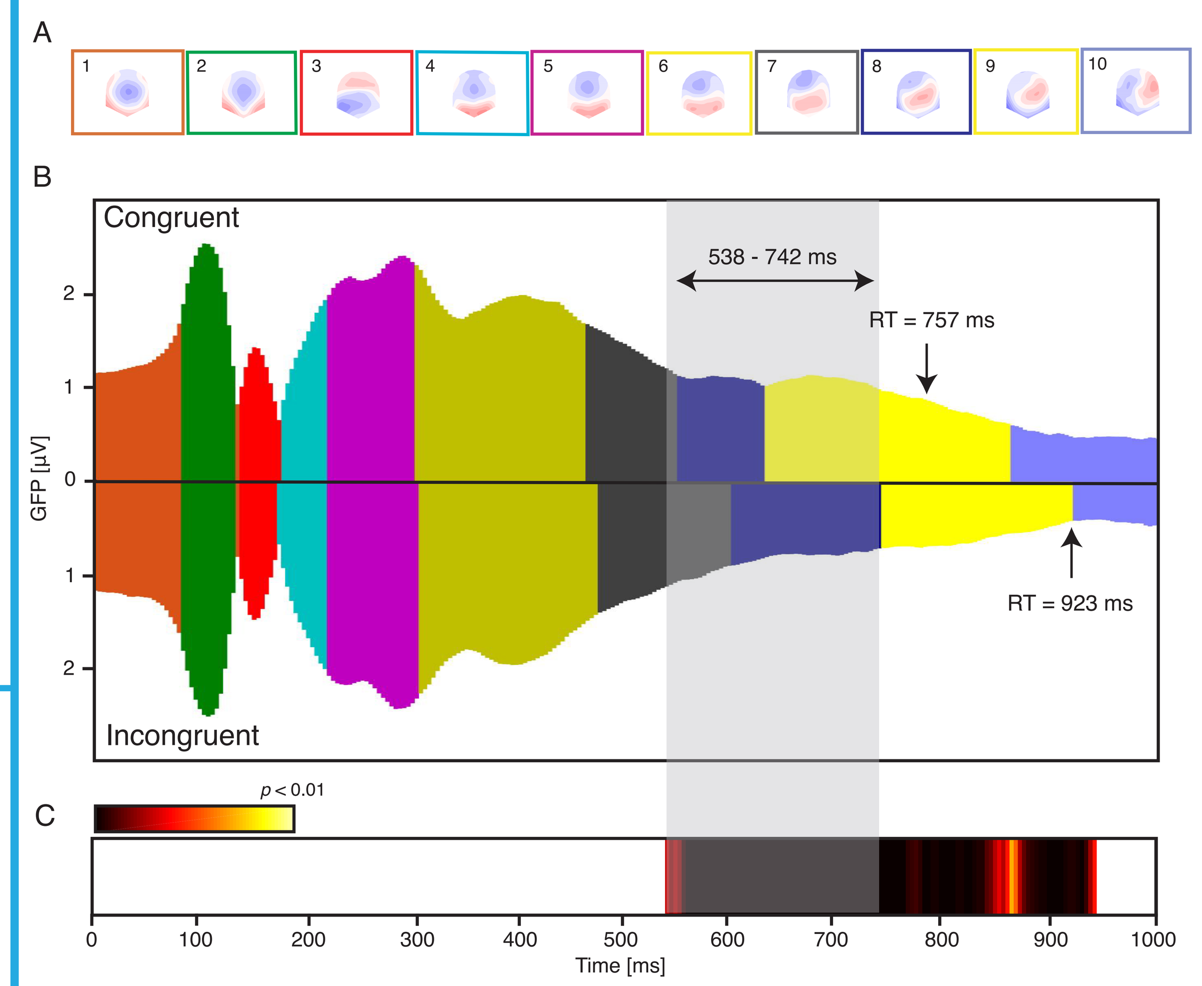
2.2 *EEG Recording and pre-processing*

- EEG was acquired from 64-channel ActiveTwo system (Biosemi)
- Butterworth, second order band-pass filter (0.3 -30 Hz)
- An independent component analysis (ICA) was used to remove vertical and horizontal ocular artifacts
- Segmentation (from stimulus-onset to 1000 ms after) into event-related potential epochs (ERPs)
- Semiautomatic artifact rejection to remove residual artifacts.
- Data were computed against an average reference. No baseline correction was applied

2.3 *EEG analysis and source localization*

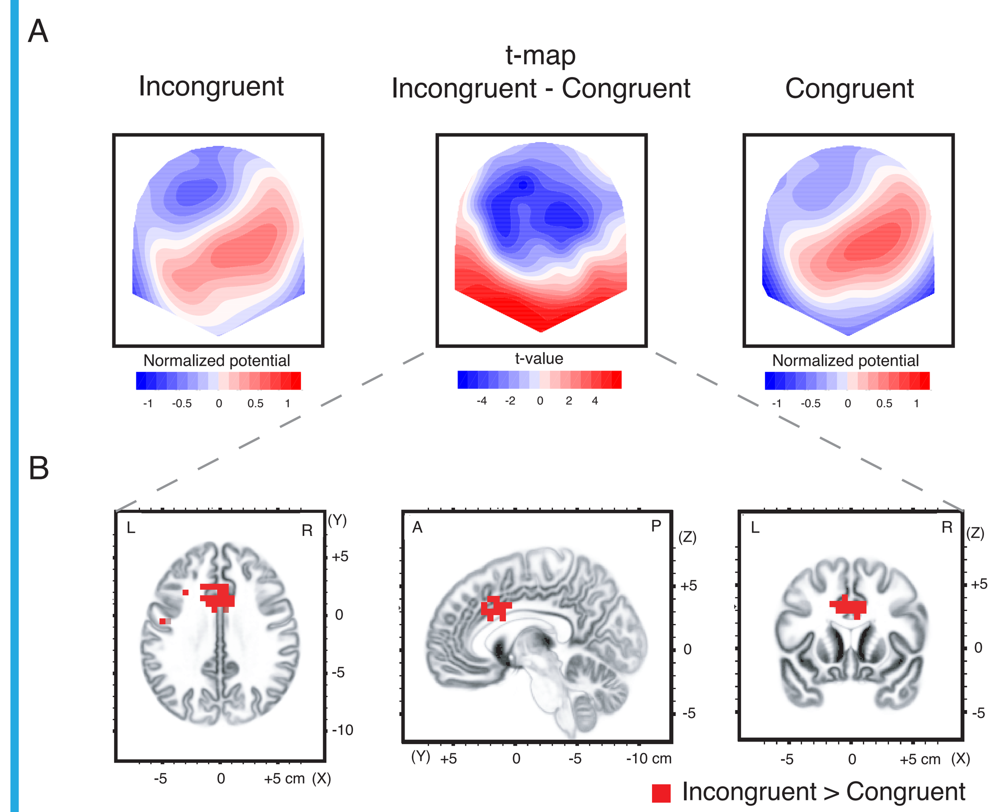
- Task (read-word, name-color) and congruency (congruent, incongruent) were defined as within-subject factors
- Dynamic changes in ERP topographies were classified through microstate analysis. Values of the onset, offset and duration of each microstate map were extracted from the ERP of each condition
- TANOVA analysis was used to assess qualitative topographic differences between conditions
- Source current density estimation was implemented to determine differences in the activation pattern of neural generators that are responsible for the topographic differences observed between conditions

3 EEG results



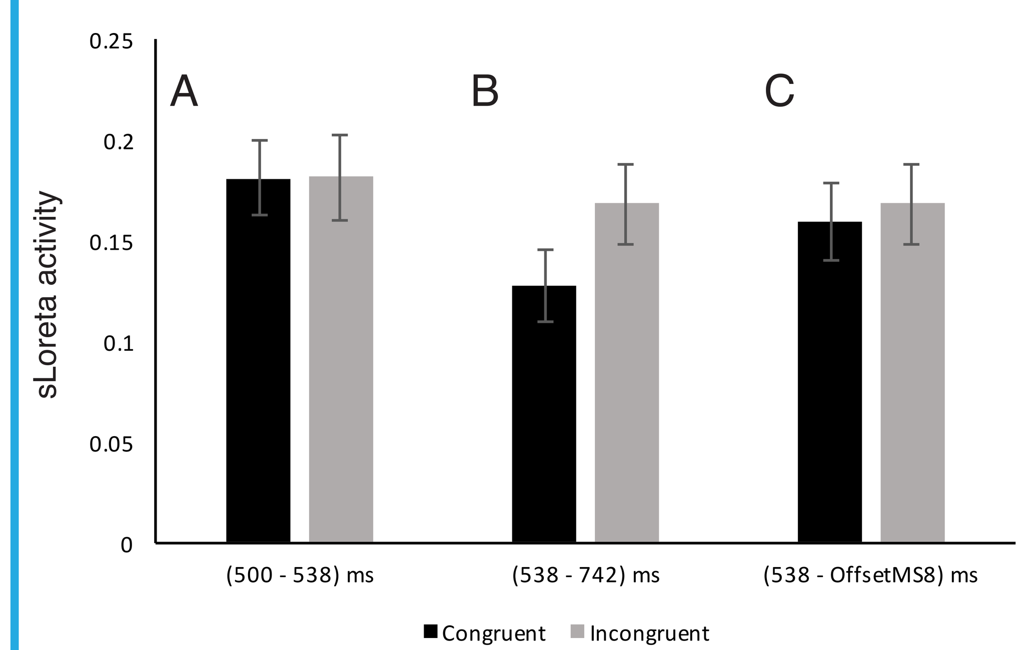
- The fitting of the microstate maps to the grand-mean ERPs between 0 and 1000 ms resulted in ten microstate maps (MS1-10) with the same temporal occurrence in each experimental condition (Fig.2A and B)
- A significant effect of congruency was observed in the duration of MS7 ($p = 0.0003$) and MS8 ($p = 0.002$) (Fig.2B)
- TANOVA revealed significant differences between congruent and incongruent topographies within a time period ranging from 538 and 939 ms (Fig.2C)

Figure 2: *(A) Topographies of the ten microstate maps. (B) The assignment of the ten microstate maps to the grand mean data of the congruent (upper) and incongruent (lower) condition as function of time (horizontal axis) and GFP (vertical axis). (C) The color-coded p-values of the TANOVA plotted for each time point. The white temporal windows reflect non-significant topographic differences, while the yellow-to-back window highlights significantly differing topographies (p < 0.01).*



- Between 538 and 742 ms, the incongruent condition was characterized by a more negative potential over frontal-central electrodes and a more diffused positive potential localized over posterior and occipital regions (Fig.3A).
- A cluster of 41 adjacent voxels localized in the ACC (BA 24 and 33) and in adjacent regions of the cingulate gyrus (BA 24 and 32), showed significantly higher activity in the incongruent condition as compared to the congruent condition (Fig. 3B)

Figure 3: *(A) ERP mean topographies computed for the congruent and incongruent condition between 538 and 742 ms. Also shown is a standard t-map contrasting congruent and incongruent topographies. (B) Voxel-wise t values comparing sLORETA source density between the incongruent and congruent condition. All voxels reaching the thershold for p <0.05 (corrected for multiple comparison, t > 3.66) are color-coded in red.*



- The difference in ACC activity between 538 and 742 ms (Fig.4B & 3B) was due to a significant ACC activity reduction in the congruent condition from the time period between 500 and 538 ms (Fig.4A) to the time period between 538 and 742 ms ($p = 0.003$)
- The difference in ACC activity between congruent and incongruent condition disappeared when ACC activity was computed between 538 and the offset of MS8 in both conditions (Fig.4C)

Figure 4: *From voxels showing a significant effect of congruency (incongruent > congruent) in the time period between 538 and 742 ms, average source activity is computed (A) before and (B) during the time period of observed topographic differences described in Fig.3B. Also shown is the (C) activity corrected for the offset of MS8 in the congruent and incongruent condition, respectively.*

4 Conclusions

(I) Our findings support the hypothesis of a longer neuronal activity of the ACC in the incongruent condition. By contrast, they give less support to a conflict monitoring specificity of the ACC predicting a higher neuronal activity in the incongruent condition

(II) To interpret the change in the duration of ACC activation at this stage of processing, we hypothesize that it reflects non-specific sensory, attentional, memory, and motor processes involved in the release of a response when facing competing stimuli

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