



# Neurophysiological processes and functional neuroanatomical structures underlying proactive effects of emotional conflicts

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## ARTICLE INFO

### Keywords:

Emotion  
Faces  
Conflict  
Proactive control  
EEG  
Source localization

## ABSTRACT

There is a strong inter-relation of cognitive and emotional processes as evidenced by emotional conflict monitoring processes. In the cognitive domain, proactive effects of conflicts have widely been studied; i.e. effects of conflicts in the  $n-1$  trial on trial  $n$ . Yet, the neurophysiological processes and associated functional neuroanatomical structures underlying such proactive effects during emotional conflicts have not been investigated. This is done in the current study combining EEG recordings with signal decomposition methods and source localization approaches.

We show that an emotional conflict in the  $n-1$  trial differentially influences processing of positive and negative emotions in trial  $n$ , but not the processing of conflicts in trial  $n$ . The dual competition framework stresses the importance of dissociable 'perceptual' and 'response selection' or cognitive control levels for interactive effects of cognition and emotion. Only once these coding levels were isolated in the neurophysiological data, processes explaining the behavioral effects were detectable. The data show that there is not only a close correspondence between theoretical propositions of the dual competition framework and neurophysiological processes. Rather, processing levels conceptualized in the framework operate in overlapping time windows, but are implemented via distinct functional neuroanatomical structures; the precuneus (BA31) and the insula (BA13). It seems that decoding of information in the precuneus, as well as the integration of information during response selection in the insula is more difficult when confronted with angry facial emotions whenever cognitive control resources have been highly taxed by previous conflicts.

## Introduction

The last years have witnessed a vast increase in studies dealing with the inter-relation of cognitive and emotional processes. For example, a great deal of effort has been devoted to study emotional conflict monitoring processes, i.e. by employing facial expressions in emotional Stroop tasks (Egner et al., 2008; Etkin et al., 2006). In these tasks, emotional faces are presented together with an emotional word that is either congruent or incongruent with the expressed facial emotion. Most studies have focused on identifying the neural mechanisms involved in emotional conflict resolution or response inhibition to emotional stimuli (Kanske and Kotz, 2011a; Zinchenko et al., 2015). However, it is necessary to distinguish this form of reactive control from proactive control processes as it has been shown that the ability to ignore an emotional distractor dimension depends on the type of cognitive control that is

exerted (Botvinick et al., 2001; Grimshaw et al., 2017; Kar et al., 2017; Padmala et al., 2011). Proactive control is the ability to increase behavioral monitoring as a consequence of a conflict in a preceding trial: According to the 'conflict monitoring theory' (Botvinick et al., 2001) a conflict in trial  $n-1$  enhances the processing of task-relevant information in the forthcoming trial  $n$ . These effects are also known as 'Gratton-effect' or 'congruency-sequence effect (CSE)' (Gratton et al., 1992). This kind of proactive control during emotional conflicts has only been studied recently in the context of emotional processes using behavioral experiments (Kar et al., 2017; Padmala et al., 2011). Yet, the neuro- or electrophysiological processes and associated functional neuroanatomical structures underlying such proactive effects during emotional conflicts have not been investigated. This is the goal of the current study.

A conceptual basis for an interaction between emotion and executive function (e.g. during conflict monitoring) has been put forward in the

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'dual competition framework' (Pessoa, 2008). According to this view, cognitive–emotional behavior has its basis in dynamic coalitions of brain networks making it impossible to classify behavior into either cognitive or emotional categories (Pessoa, 2008). Hence, the concept assumes that resources needed for conflict processing are shared with resources needed for emotional processing (Padmala et al., 2011; Pessoa, 2008). In a (facial-emotional) Stroop task, conflict emerges between task-relevant emotional stimulus features (e.g. facial emotion) and simultaneously presented task-irrelevant emotional stimulus features (e.g. emotional word) (Hanslmayr et al., 2008). Conflict monitoring theory assumes that  $n-1$ -trial effects are only important for the *task-relevant* information in trial  $n$  (Botvinick et al., 2001). Thus, if the task-relevant information in the current  $n$  trial is the facial emotion it may be hypothesized, that conflicts in trial  $n-1$  influence processing of the *emotional facial expression* in trial  $n$ . Crucially, it has also been suggested that especially intense negative emotions engage large amounts of processing resources (Padmala et al., 2011) and it has been suggested that the existence of an incongruent stimulus in itself is registered an aversive signal (Dreisbach and Fischer, 2012). Therefore, it is hypothesized that the  $n-1$  trial has different effects depending on the emotional valence of the facial expression presented in trial  $n$  (positive or negative). So, we hypothesize that there are interactive effects between  $n-1$  trial congruency and the facial emotion shown in trial  $n$ :  $n-1$  trial congruency should have strong effects whenever there is a negative facial emotion expression in trial  $n$ . Moreover, there shall be less or even no effects of  $n-1$  trial congruency when there is positive facial emotion in trial  $n$ . That is, if the  $n-1$  trial is incongruent (i.e. conflicting), responses in the current trial  $n$  are expected to be slower and less accurate when an angry facial emotion is presented, compared to trials in which a happy facial emotion is shown.

On a neurophysiological (EEG) level, conflict effects have been suggested to be reflected by the N2 event-related potential (ERP) component originating within the anterior cingulate cortex (ACC) (Beste et al., 2012; Beste et al., 2010; Folstein and Van Petten, 2008; van Veen and Carter, 2002; Willemsen et al., 2011). The N2 has consistently been shown to be more negative during conflicting/interfering trials than on non-conflicting/non-interfering trials (Chmielewski et al., 2016; Danielmeier et al., 2009; Folstein and Van Petten, 2008; Gohil et al., 2017; Kanske and Kotz, 2011b; Larson et al., 2014; Mückschel et al., 2016; Stock et al., 2016; Wolff et al., 2016). Based on this it is reasonable to predict that N2-ERPs are more negative following incongruent  $n-1$  trials, which is line with findings showing that the N2 in trial  $n$  is modulated by the degree of conflict in the  $n-1$  trial (Chmielewski et al., 2015; Clayson and Larson, 2013; Spapé et al., 2011; Winkel et al., 2009). Yet, it has recently been shown that the N2 ERP-component contains dissociable fractions of 'stimulus codes' (perceptual/attentional processing) and 'response selection/executive control codes' (Mückschel et al., 2017a). Emotionally complex conflicting stimuli are thus, likely to modulate both sub-processes reflected within the N2 signal which would prevent congruency effects to be clearly represented within the classic N2 amplitude. The idea that dissociable fractions of perceptual and cognitive processes needed for emotional conflict adaptation (i.e. proactive control) may exist at overlapping time frames is of particular relevance for the dual competition framework providing a conceptual basis for an interaction between emotion and executive function (Pessoa, 2008). This is because shared processes needed for conflict and emotional processing are assumed to exist at dissociable levels - a perceptual level and a response selection or cognitive control level (Pessoa, 2008). Thus, the dual competition framework stresses dissociable roles of processing levels known to be intermingled in the N2 electrophysiological correlate of conflict processing (Folstein and Van Petten, 2008; Mückschel et al., 2017a). As a consequence, it is crucial to dissociate these levels in neurophysiological signals when studying the neural mechanisms associated with proactive effects during emotional conflicts. This is possible applying an EEG temporal decomposition method, i.e. residue iteration decomposition (RIDE) (Mückschel et al., 2017a; Ouyang et al., 2011). Although, RIDE was developed to account for intra-individual variability

within EEG data (Ouyang et al., 2011, 2015a), it has been shown that it can be applied to distinguish co-existing coding levels that occur during conflict monitoring B (Mückschel et al., 2017a, 2017b; Wolff et al., 2017). RIDE decomposes EEG data into several component clusters with dissociable functional relevance (Ouyang et al., 2011; 2015a). The S-cluster refers to stimulus-related processes (like perception and attention), the R-cluster refers to response-related processes (like motor preparation/execution) and the C-cluster refers to intermediate processes between S and R (like response selection and executive control) (Ouyang et al., 2011; 2017). Grounded within the dual competition framework (Pessoa, 2008), we hypothesize that especially the S-cluster and C-cluster in the N2 time window should reflect interactive effects between  $n-1$  trial congruency and the facial emotion expressed in trial  $n$ , as hypothesized for the behavioral level. More specifically, due to the complex nature of the task relevant stimulus dimension (i.e. emotional facial expression), it is to be expected that sub-processes at a perceptual/attentional coding level (i.e. the S-cluster), are more strongly modulated by the presentation of an emotional conflict in the preceding trial  $n-1$  compared to congruent  $n-1$  trials. It has been suggested that threat-related emotional stimuli engage greater amounts of processing resources. Therefore, we expect amplitudes to be more negative within the S-cluster (perceptual/attentional processing) following the presentation of an angry target emotion in (in trial  $n-1$ ) reflecting an enhanced allocation of processing resources. Similarly, incongruent preceding  $n-1$  trials should affect sub-processes relating to response selection/cognitive control and therefore, be reflected in the C-cluster. Following propositions of the dual competition framework (Pessoa, 2008), it is possible that these dissociable sub-processes exist at overlapping time frames.

Concerning the question which functional neuroanatomical structures may be modulated, it is possible that medial frontal regions play a role, because dissociable fractions of 'perceptual' and 'response selection codes' in the N2 ERP-component are both processed in the medial frontal cortex (Mückschel et al., 2017a). According to the conflict monitoring theory of anterior cingulate cortex (ACC) function the deployment of cognitive control resources is triggered by the detection of conflict. Thus, given the important role of the ACC for monitoring negative decision outcomes in response to conflict and for the detection of aversive signals for future action selection (Botvinick, 2007; Dreisbach and Fischer, 2012), it is reasonable to predict its activation particularly in response to conflict following incongruent  $n-1$  trials. However, it is also possible that there are distinct functional neuroanatomical structures associated with modulations in the S-cluster and the C-cluster. Using fMRI, it has been shown that emotion decoding at the perceptual level is mediated via four brain regions: the posterior cingulate cortex, the precuneus, the medial prefrontal cortex, and the angular gyrus (Kim et al., 2015). Especially the precuneus has repeatedly been shown to be involved in the decoding of facial emotions (Cheng et al., 2017; Zhang et al., 2016; Zhao et al., 2017). We therefore hypothesize that modulations in the S-cluster may be associated with the precuneus, as the S-cluster reflects perceptual and attentional stimulus-related processes. However, for the C-cluster this may be different. As outlined above, several lines of evidence suggest that the C-cluster reflects neurophysiological processes involved in the mapping of a stimulus on the appropriate response (Ouyang et al., 2017; Verleger et al., 2014; Wolff et al., 2017), i.e. processes that integrate information for the purpose of cognitive control. The insular cortex is involved in the interpretation of emotional information (Manoliu et al., 2013; Sprengelmeyer et al., 2011) and has been shown to be involved in emotional and non-emotional interference processing (Xu et al., 2016). Thus, we predict involvement of the insula particularly for the C-cluster given its importance for emotion regulation and decision making especially, under circumstances of uncertainty and affective ambiguity (Simmons et al., 2008). Anatomically, the insula is ideally placed to monitor current environment and emotional states and to predict future outcomes based on previous experience by determining the valence of internal and external stimuli (Gogolla, 2017). This previous experience is what is central for proactive control effects. This makes the insula cortex

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