



How socioemotional setting modulates late-stage conflict resolution processes in the lateral prefrontal cortex

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Published online: 24 April 2018
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Abstract

The goal-directed control of behaviour critically depends on emotional regulation and constitutes the basis of mental well-being and social interactions. Within a socioemotional setting, it is necessary to prioritize effectively the relevant emotional information over interfering irrelevant emotional information to orchestrate cognitive resources and achieve appropriate behavior. Currently, it is elusive whether and how different socioemotional stimulus dimensions modulate cognitive control and conflict resolution. Theoretical considerations suggest that interference effects are less detrimental when conflicting emotional information is presented within a “positive socioemotional setting” compared with a “negative socioemotional setting.” Using event-related potentials (ERPs) and source localization methods, we examined the basic system neurophysiological mechanisms and functional neuroanatomical structures associated with interactive effects of different interfering facial, socioemotional stimulus dimensions on conflict resolution. We account for interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution, i.e., we show how the socioemotional valence modulates cognitive control (conflict processing). The data show that conflicts are stronger and more difficult to resolve in a negative emotional task-relevant setting than in a positive emotional task-relevant setting, where incongruent information barely induced conflicts. The degree of emotional conflict critically depends on the contextual emotional valence (positive or negative) in which this conflict occurs. The neurophysiological data show that these modulations were only reflected by late-stage conflict resolution processes associated with the middle (MFG) and superior frontal gyrus (SFG). Attentional selection processes and early-stage conflict monitoring do not seem to be modulated by interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution.

Keywords Conflict processing · Emotions · Faces · EEG · Source localization

Introduction

The goal-directed control of behavior critically depends on emotional regulation and constitutes the basis of mental

well-being and social interactions (Bechara, Damasio, Damasio, & Lee, 1999). Within a socioemotional setting, it is necessary to prioritize effectively the relevant emotional information over interfering (conflicting) irrelevant emotional information to orchestrate cognitive resources and achieve appropriate behavior. Difficulties with regulating emotion and impaired social cognition abilities are hallmarks of a range of clinical and neurodevelopmental disorders (Cisler, Olatunji, Feldner, & Forsyth, 2010; Etkin, Prater, Hoedt, Menon, & Schatzberg, 2010; Joormann & Gotlib, 2010; Mazefsky et al., 2013; Steinberg & Drabick, 2015; Xue, Wang, Kong, & Qiu, 2017), which may involve abnormal cognitive control processes and an inability to overcome the effects of interfering emotional information (Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). The detailed understanding of the basic neurophysiological mechanisms that underlie emotional conflict control and the specific influence of emotional task setting in which the conflict occurs are still elusive.

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Electronic supplementary material The online version of this article (<https://doi.org/10.3758/s13415-018-0585-5>) contains supplementary material, which is available to authorized users.

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Slowing down of response times and more erroneous behavior is indicative of conflict and a result of simultaneous activation of competing stimulus-response dimensions (Botvinick, Braver, Barch, Carter, & Cohen, 2001), which can reliably be reproduced in experimental settings, e.g., by using Stroop tasks. These settings require selective responses to task-relevant stimulus features over simultaneously presented task-irrelevant stimulus features (Hanslmayr et al., 2008). For example, classic *emotional* Stroop paradigms require participants to identify the ink colour of emotional and nonemotional words, thereby producing interference effects in terms of slower RTs and decreased accuracy on emotional trials (McKenna & Shamma, 1995).

Most of the research conducted has shown that emotional interference effects arise between positive and negative emotional stimuli (Etkin et al., 2006; Ma, Liu, Zhong, Wang, & Chen, 2014; Marusak, Martin, Etkin, & Thomason, 2015), as well as emotional stimuli and neutral stimuli (Padmala, Bauer, & Pessoa, 2011). As stated earlier, conflicting situations require selective responses to task-relevant stimulus dimensions over simultaneously presented task-irrelevant stimulus dimensions (Hanslmayr et al., 2008). For example, it is possible that there is a conflict between two negative emotional stimulus dimensions (e.g., disgust [task-relevant dimension] and anger [task-irrelevant dimension]) or between positive and negative emotional dimensions (e.g., happy [task-relevant dimension] and anger [task-irrelevant dimension]). In both situations, two interfering emotional dimensions simultaneously compete for cognitive resources and induce a conflict; however, the degree of interference/conflict between these dimensions may be different, because the emotional setting in which a conflict is provoked is different. Currently, it is elusive whether and how exactly that complex socioemotional stimuli (such as facial expressions) modulate cognitive control and conflict resolution processes. Yet, as outlined below, it is very likely that the emotional setting critically modulates the degree of conflicts between two interfering emotional dimensions.

For example, it has been shown that highly salient content of stimulus features seems to elicit deeper and longer lasting evaluative mechanisms (Schupp et al., 2000), which suggests that the valence of emotional stimuli influences the depth of processing of task-relevant and task-irrelevant stimulus features. Furthermore, negative emotionally salient stimuli have been shown to be processed differently compared with positive or nonemotional stimuli and seem to capture attentional resources more readily (Öhman, Lundquist, & Esteves, 2001). This is particularly important for Stroop tasks, because conflict monitoring and resolution depends on how deeply each of the stimulus features are encoded (MacLeod, 1991). In relation to that, it has been shown that “happy” emotional features elicit an “approach response” resulting in faster reaction times (RTs) (Schulz et al., 2007). This is especially true for facial emotion processing, because happy emotional expressions are

processed and categorized fastest compared with all other basic emotional expressions (Du & Martinez, 2011, 2013). It may be more demanding (i.e., require deeper processing) to differentiate accurately between two interfering negative emotional categories, which should affect conflict monitoring and resolution in Stroop tasks (MacLeod, 1991). It may be hypothesized that interference effects are less detrimental when conflicting emotional information is presented within a “positive (happy) socioemotional setting” compared with a “negative (angry, disgust) socioemotional setting.” However, contrasting findings suggest that threat-related information is computed more efficiently compared with neutral and happy emotional information (Fox et al., 2000). Particularly, threat-related stimuli, such as angry and fearful faces, seem to be detected and oriented to more quickly (Bannerman, Milders, de Gelder, & Sahraie, 2009). It also has been shown that they are perceived faster and more accurately within an array of distractors (Öhman et al., 2001), suggesting that task-irrelevant dimensions may not affect the detection of negative emotional content. Based on that, it may be reasonable to presume that interference effects of distracting emotional dimensions are diminished within a negative (e.g., angry/disgust) socioemotional setting.

The main objective of this study was the detailed investigation of the neurophysiological mechanisms and functional neuroanatomical structures associated with interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution. To examine the contrasting hypotheses about the interactive effects of different interfering socioemotional stimulus dimensions, we used an adaptation of a face-word Stroop paradigm (Chechko et al., 2009; Etkin et al., 2006; Marusak et al., 2015) in combination with high-density EEG recordings and source localization analyses.

Previous findings showed that positive and negative affective pictures have identical effects on early attentional orienting with highly similar modulation of P1 and N1 event-related potential (ERP) components (Brosch, Sander, Pourtois, & Scherer, 2008). Therefore, we expect no effects of socioemotional congruency between stimulus dimensions on P1 and N1 ERPs. In classic conflict tasks, the N2 ERP-component is more negative during conflicting/interfering trials than on nonconflicting/noninterfering trials (Beste et al., 2017; Danielmeier, Wessel, Steinhauser, & Ullsperger, 2009; Folstein & Van Petten, 2008; Gohil, Bluschke, Roessner, Stock, & Beste, 2017; Kanske & Kotz, 2011; Larson, Clayson, & Clawson, 2014; Mückschel, Stock, Dippel, Chmielewski, & Beste, 2016; Petruo, Stock, Münchau, & Beste, 2016; Stock, Friedrich, & Beste, 2016; Wolff, Roessner, & Beste, 2016). However, the majority of studies employed conflict paradigms (i.e., Simon or Flanker) in which conflict resolution is quite fast (as inferred from the response times) or focused on the influence of stimulus emotionality on conflict processing relative to nonemotional/emotionally neutral stimuli. Indeed, in emotional

Stroop paradigms, it has commonly been found that conflict effects are reflected within later stages of neurophysiological processing (Pan, Lu, Chen, Wu, & Li, 2016; Shen, Xue, Wang, & Qiu, 2013). It therefore is possible that interference effects, as modulated by the emotional category, are not evident in the N2-ERP time window, because emotional conflict detection in Stroop tasks is dependent on the level of processing of the stimulus (MacLeod, 1991). Rather, it is likely that conflict-related slow potentials (CSP) are modulated. The CSP is a late-stage, central-parietal positivity, likely reflecting a signal of increased recruitment of control. It is generally more enhanced (i.e., more positive) following conflicting trials compared with nonconflicting trials and has been associated with conflict resolution processes and post-conflict behavioural adjustment. Interestingly, enhanced CSP amplitudes on incongruent trials are more commonly observed within emotional conflict tasks while early conflict potentials remain largely unaffected by emotional interference (Larson et al., 2014; Ma et al., 2014; Zinchenko, Kanske, Obermeier, Schröger, & Kotz, 2015). Moreover, Chen et al., (2016) recently showed that the CSP was modulated by demand for emotional control using a face-word emotional Stroop task with varying degree of difficulty. We therefore hypothesized that interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution are reflected in modulations of the CSP, especially for trials that require deeper processing and increased behavioral adjustment and control (negative emotions). It also may be reasonable to assume that enhanced (i.e., more positive) CSP expression will relate compromised behavioral performance (i.e., decreased accuracy) on those emotional trials that require increased compensatory processing adjustment (i.e., interfering trials/negative emotional valence). Regarding functional neuro-anatomical structures associated with these modulations, it has been shown that the CSP is generated within subdivisions of the prefrontal cortex (PFC) (West, 2003; West, Jakubek, Wymbs, Perry, & Moore, 2005). Furthermore, imaging studies have reported superior frontal gyrus (SFG) and medial frontal gyrus (MFG) to be activated in association with CSP following Stroop effects, suggesting an involvement of these region in conflict resolution and behavioral adjustment following high-control settings (Banich et al., 2000; Kerns et al., 2004; Milham et al., 2001). We therefore hypothesized to find activation differences in emotion- and conflict-related areas, specifically PFC subregions, such as SFG and MFG.

Materials and Methods

Participants

Twenty-four healthy participants (21 females/3 males) between ages 18 and 30 years (mean age 24.13 years \pm 0.72) were tested. All participants had normal or corrected-to-

normal vision and were screened on personal health background to ensure that our sample was free of individuals previously diagnosed with any psychiatric or neurological disorders or taking regular medication. The data set of one participant had to be excluded because of their psychiatric background and another due to insufficient quality of the EEG data, resulting in a total of 21 participants considered for analysis. All participants gave written, informed consent before the experiment and received payment (7.50 €/h) or participation credits (TU Dresden students) after completion of the study. The study was approved by the institutional review board of the medical faculty of the TU Dresden and was conducted in accordance with the Declaration of Helsinki.

Task and Procedure

We employed a new version of the emotional Stroop paradigm in which conflict effects are produced by incompatibility between two conflicting emotional dimensions of one presented stimulus. The paradigm was a German adaptation of the emotional Stroop design used by Etkin et al. (2006); trials were combinations of an emotional face (happy, disgust, or angry expression) and the words “FREUDE,” “EKEL,” or “ÄRGER” (German for happiness, disgust, and anger) printed across in red capital writing (Figure 1). The faces with socially relevant emotional expression represented the target dimension (i.e., emotional valence) of the stimulus.

Stimuli constituted of four different male Caucasian faces, which expressed each of the three emotions. Emotional face stimuli were selected from the NimStim, MacBrain Face Stimulus Set (Nim Tottenham supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development, open source available on <http://www.macbrain.org/resources.htm>). The faces were rendered in greyscale using XNView (for windows) and the words FREUDE, EKEL, or ÄRGER (German for Happiness, Disgust and Anger) were printed across the center of the face in red, bold capital letters. There were equal proportions of congruent and incongruent stimuli for each emotion adding up to a total of 32 different stimuli. These stimuli were pseudo-randomly presented in four blocks of 216 trials each (i.e., 864 trials in total). In each block, the same number of congruent and incongruent stimuli was presented, and it was ensured that the same proportion of the different stimuli was presented.

Participants were encouraged to make use of the allocated breaks and to proceed with the experiment in their own time. During the experiment, responses were given via the arrow keys of a conventional computer keyboard. The stimuli (face target/task relevant dimension and emotional word/ task irrelevant dimension) were presented for 450 ms and then were succeeded by the presentation of the fixation cross for the rest of the trial. Participants were instructed to identify the correct

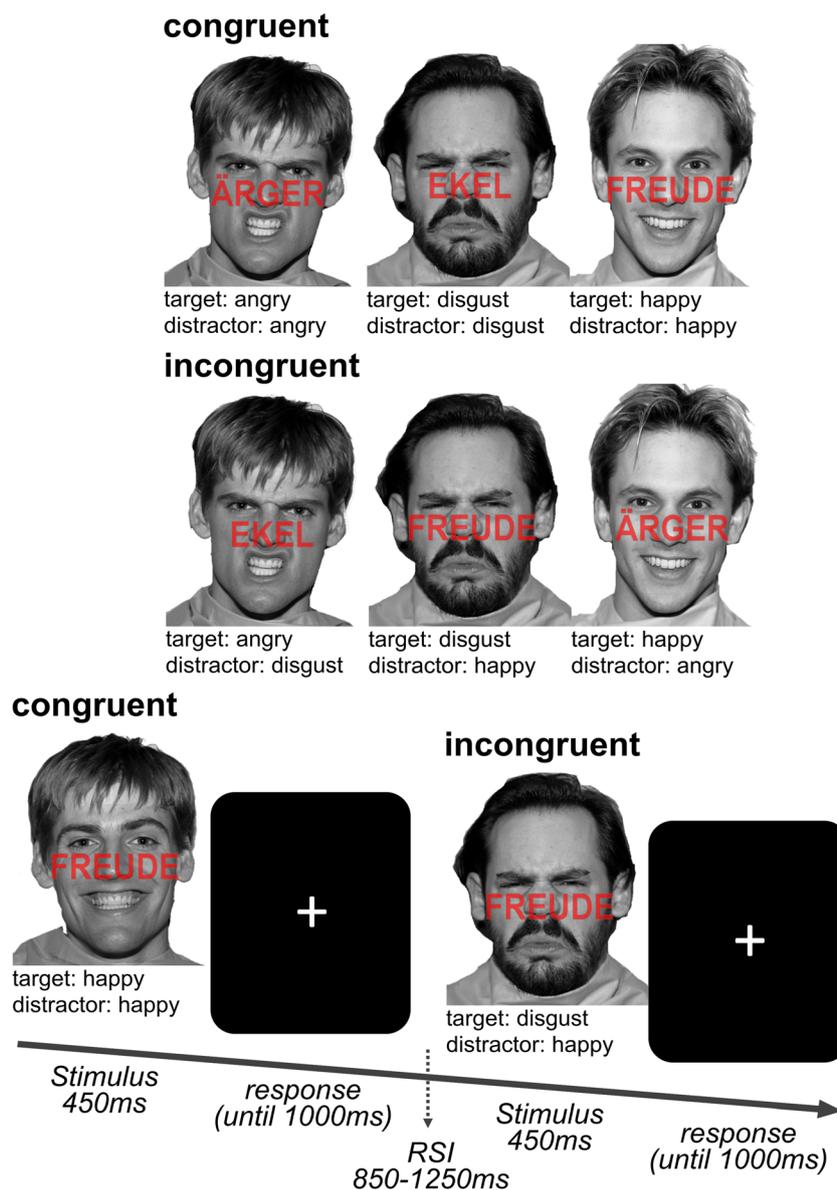


Figure 1 Example stimuli and experimental paradigm of the emotional Stroop task. Participants were instructed to classify the emotional expression of the face (i.e., angry, disgust, or happy) that had an emotional word (angry, disgust, or happy) written across them. Stimuli

were either congruent or incongruent with respect to facial expression (emotional target) and word (emotional distractor), which created emotional conflict.

facial emotional expression as quickly as possible for each trial, giving responses by pressing the cursor keys using only their right hand. For stimuli depicting happy facial emotional expressions, participants were required to press the left-arrow key, for disgust the down-arrow, and for angry emotions the right-arrow key. If participants did not respond within 1,000 ms of target onset, the trial was treated as a miss. After the response was executed, a variable response stimulus interval (RSI), jittered between 850 and 1250 ms was included, in which a central fixation cross was presented. Participants were instructed not to double-press a button and to avoid missing responses as much as possible.

EEG Data processing and source localization analysis

EEG data were recorded with a sampling rate of 500 Hz using a 60-channel system (BrainAmp, Brain Products Inc.). Passive Ag/AgCl-electrodes (60 recording electrodes) were mounted in an elastic cap (EasyCap Inc.) and arranged in equidistant positions approximating the positions of the 10/20 system. The ground and reference electrode were placed at coordinates theta = 58, phi = 78, and theta = 90, phi = 90, respectively. Electrode impedances were kept under 5 k Ω . Subsequent data analysis was performed in the Brain Vision Analyzer 2 software package (BrainProducts, Inc.): Offline, a

band pass filter from 0.5 to 20 Hz (with a slope of 48 dB/oct each) and a notch filter of 50 Hz were applied. It needs to be noted that the results reported below remained the same when a less steep slope of the filter (e.g., 16 dB/oct) was used. Subsequently, the data were down-sampled from 500 to 256 Hz. Following that, a raw data inspection was conducted manually to reject technical artifacts from the EEG. Following that, independent component analysis (ICA; Infomax algorithm) was conducted on the data to remove artifacts. ICA components revealing horizontal and vertical eye movement, blinks, and pulse artifacts were manually discarded (number of discarded ICs: 4 ± 1.5). The data were then segmented for each distinct emotion condition (angry, disgust, happy) for congruent and incongruent trials. Trials were only considered when the correct response was given within 1,000 ms of target onset. The segmentations were locked to target stimuli starting 250 ms before target onset and finishing 1,000 ms after its onset. Afterwards, an automated artifact rejection was applied for all the segments. Activity below $0.5 \mu\text{V}$ in a 100-ms period and a maximal value difference of $200 \mu\text{V}$ in 200 ms within the epoch were used as rejection criteria. If an artifact was detected in a trial, the trial was discarded. Overall, $\sim 1.6\%$ of trials had to be discarded due to these issues. To eliminate the reference potential from the data and to re-reference the data, we applied a current source density (CSD) transformation (Nunez & Pilgreen, 1991), which also serves as a spatial filter resulting in values for amplitudes in $\mu\text{V}/\text{m}^2$. A baseline correction from -200 ms to 0 before target onset was applied and the relevant ERP components, P1 (at P7 & P8: 100–130 ms after target presentation onset), N1 (at P7 & P8: 150–170 ms), N2 (at Cz: 220–300 ms), P3 (at PO1 & PO2: 520–680 ms), and conflict-related slow potential (CSP; at P3: 660–800 ms) were identified by means of scalp topography. Within these search intervals, a semiautomatic peak detection was conducted for the ERP components P1, N1, and N2. For the P3 and the CSP, an area export was conducted for each corresponding search interval. The choice of these search intervals for ERP quantification was validated using a statistical approach outlined in Mückschel, Stock, and Beste (2014). Doing so, the above-mentioned time intervals were taken and the mean amplitude within the defined search intervals was determined for each of the 60 electrode positions. To compare each electrode against an average of all other electrodes, Bonferroni correction for multiple comparisons (critical threshold, $p = 0.0007$) was used. Only electrodes that displayed significantly larger mean amplitudes (i.e., negative for the N-potentials and positive for the P-potentials) compared with other electrodes were chosen. This procedure revealed the same electrodes as those chosen by visual inspection.

For the source localization analyses, sLORETA (standardized low-resolution brain electromagnetic tomography) was

used, which provides a single solution to the inverse problem (Marco-Pallarés, Grau, & Ruffini, 2005; Pascual-Marqui, 2002). For sLORETA, the intracerebral volume is partitioned into 6,239 voxels at 5-mm spatial resolution. Then, the standardized current density at each voxel is calculated in a realistic head based on the MNI152 template. It has been mathematically proven that sLORETA provides reliable results without a localization bias (Sekihara, Sahani, & Nagarajan, 2005). Moreover, there is evidence from EEG/fMRI and neuro-navigated EEG/TMS studies underlining the validity of the sources estimated using sLORETA (Dippel & Beste, 2015; Hoffmann, Labrenz, Themann, Wascher, & Beste, 2014). The voxel-based sLORETA images were compared between groups and experimental conditions using the sLORETA built-in voxel-wise randomization tests with 2,000 permutations, based on statistical nonparametric mapping (SnPM). Voxels with significant differences ($p < 0.01$, corrected for multiple comparisons) between contrasted conditions and groups were located in the MNI-brain.

Statistical analysis

Correct responses (%) and reaction times (RTs) were analysed using dependent-samples *t* tests and repeated-measures ANOVAs using the within-subject factors “congruency” (congruent vs. incongruent) and “emotional target dimension” (happy, anger, and disgust). For the neurophysiological data, the factors congruency, emotion, and electrode (for P1, N1, P3, and CSP) were included in the model. Greenhouse-Geisser correction was applied where appropriate, and post-hoc tests were Bonferroni-corrected. Additionally, correct responses (%) and RTs as well as the EEG-data were analysed considering the impact of the “emotional distractor dimension,” which is provided in the [supplementary material](#).

Results

Accuracy

A summary of the behavioural data, i.e., mean reaction times (ms) and accuracy (%) for the congruency conditions and each emotion conditions is shown in Figure 2. The mean and standard error of the mean (SEM) are reported for the descriptive data.

Concerning accuracy, the repeated-measures ANOVA revealed a main effect of “congruency,” ($F(1,20) = 60.54$; $p < 0.001$; $\eta_p^2 = 0.752$). Participant’s performance was significantly more accurate on congruent ($91.02\% \pm 0.94$) trials than on incongruent trials ($85.58\% \pm 1.36$). Furthermore, there was a main effect of “emotional target dimension,” ($F(2,40) = 23.32$; $p < 0.001$; $\eta_p^2 = 0.538$). Participants performed more

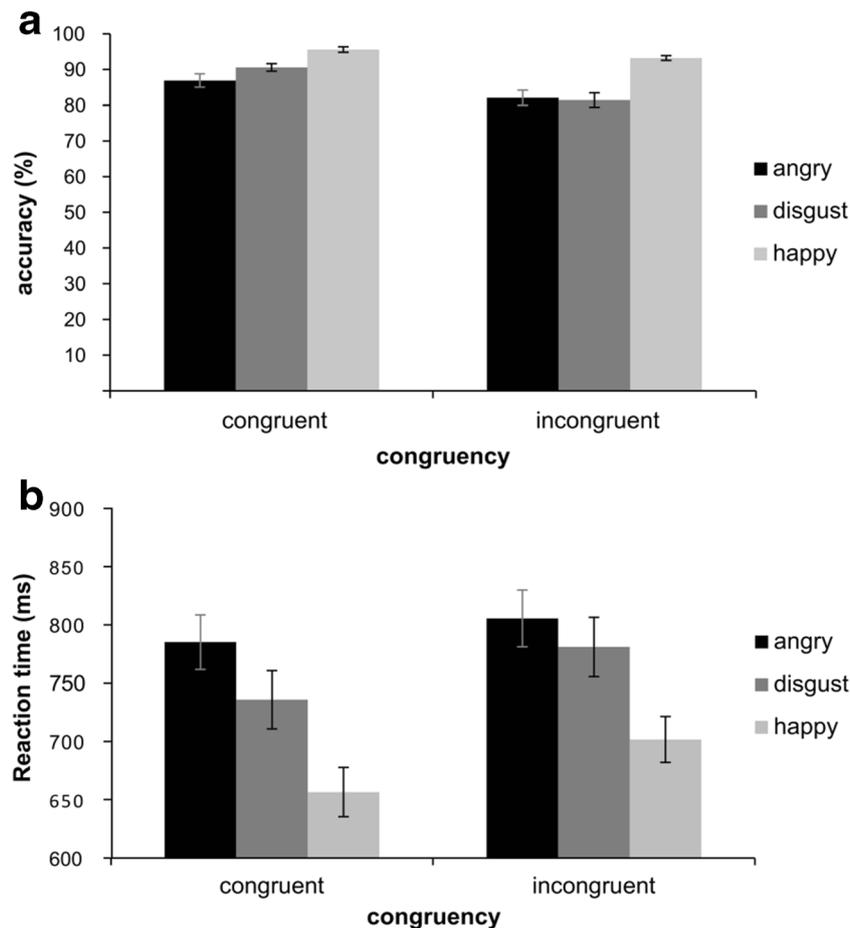


Figure 2 Summary of the behavioral results. (a) Accuracy (%) and (b) reaction times (in ms) data (mean \pm SEM) for congruent and incongruent trials for each target emotion. Incongruent trials elicited slower RTs and

less accurate responses than congruent trials. Happy target trials resulted in smaller conflict effect than disgust and angry trials.

accurately when happy emotions had to be detected ($94.4\% \pm 0.64$), compared with the other two emotions (all $t \geq 5.38$; $p < 0.001$), while accuracy between angry ($84.50\% \pm 1.91$) and disgust conditions ($86.01\% \pm 1.47$) did not differ ($t(20) = 1.19$; $p = 0.248$).

Most importantly, there was a significant interaction “congruency \times emotional target dimension” ($F(2,40) = 10.94$; $p < 0.001$; $\eta_p^2 = 0.35$). We further analyzed this interaction by means of repeated-measures ANOVAs for each congruency condition separately. For the congruent condition a main effect of “emotional target dimension” was observed ($F(2,40) = 15.17$; $p = 0.001$; $\eta_p^2 = 0.43$). Accuracy was highest for happy emotions ($95.60\% \pm 1.53$) and further decreased for disgust ($90.58\% \pm 1.1$) and angry ($86.91\% \pm 1.87$) emotions (all $t \geq 2.40$; $p \leq 0.027$). Similarly, for incongruent trials, we detected a main effect of accuracy depending on emotion condition ($F(2,40) = 25.41$; $p < 0.001$, $\eta_p^2 = 0.56$), although effect sizes were increased in this condition. For incongruent trials, performance accuracy only differed between the happy ($93.20\% \pm 0.680$) and the other two emotions (all $t \geq 5.68$; $p \leq 0.001$), whereas angry ($82.09\% \pm 2.12$) and disgust

emotions ($81.45\% \pm 2.03$) did not differ ($t(20) = 0.432$; $p = 0.670$). A post-hoc power analysis revealed that the power was above 99% given the obtained effect size.

Reaction times

In the repeated-measures ANOVA for reaction times (RTs), there was a main effect of “congruency” ($F(1,20) = 49.34$; $p < 0.001$; $\eta_p^2 = 0.712$). On congruent trials, mean RTs ($725\text{ ms} \pm 21$) were significantly faster than on incongruent trials ($762\text{ ms} \pm 21$). Moreover, a significant main effect of “emotional target dimension” was observed ($F(2,40) = 48.47$; $p < 0.001$; $\eta_p^2 = 0.708$), indicating that “emotional target dimension” differently affected RTs. Post-hoc paired t tests showed RTs were increased on happy emotion trials ($795\text{ ms} \pm 23$) compared with the disgust ($758\text{ ms} \pm 24$) and the angry condition ($679\text{ ms} \pm 20$) (all $t \geq 3.61$; $p \leq 0.002$).

Most importantly, we found a significant interaction “congruency \times emotional target dimension” ($F(2,40) = 5.24$; $p = 0.01$; $\eta_p^2 = 0.207$). To further analyze this

interaction, we conducted repeated-measures ANOVAs for each congruency condition separately. The repeated-measures ANOVA for the congruent condition revealed a main effect of “emotional target dimension” $F(2,40) = 63.84$; $p < 0.001$; $\eta_p^2 = 0.761$, showing RTs to increase from the happy emotion (656 ms \pm 21) to the disgust (735 ms \pm 24) and the angry emotion condition (785 ms \pm 23) (all $t \geq 4.80$; $p \leq 0.001$). Similarly, within the

incongruent condition, a main effect of “emotional target dimension” was detected $F(2,40) = 29.63$; $p < 0.001$; $\eta_p^2 = 0.597$, even though the effect size was decreased compared with the congruent condition. For incongruent trials, post-hoc paired t tests indicated that RTs were highly significantly decreased in the happy emotion condition (701 ms \pm 19) compared with the other two emotions (all $t \geq 5.43$; $p \leq 0.001$). Differences between the angry

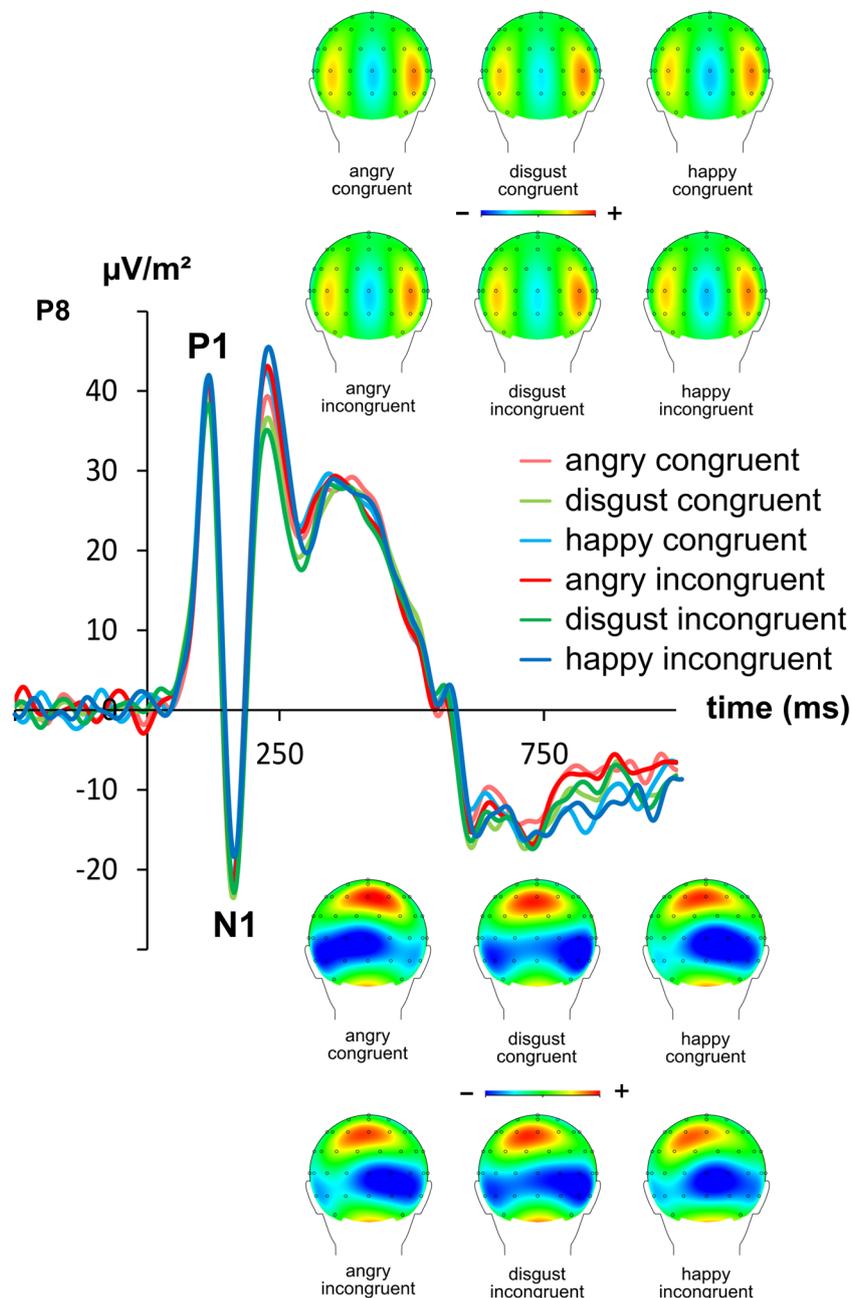
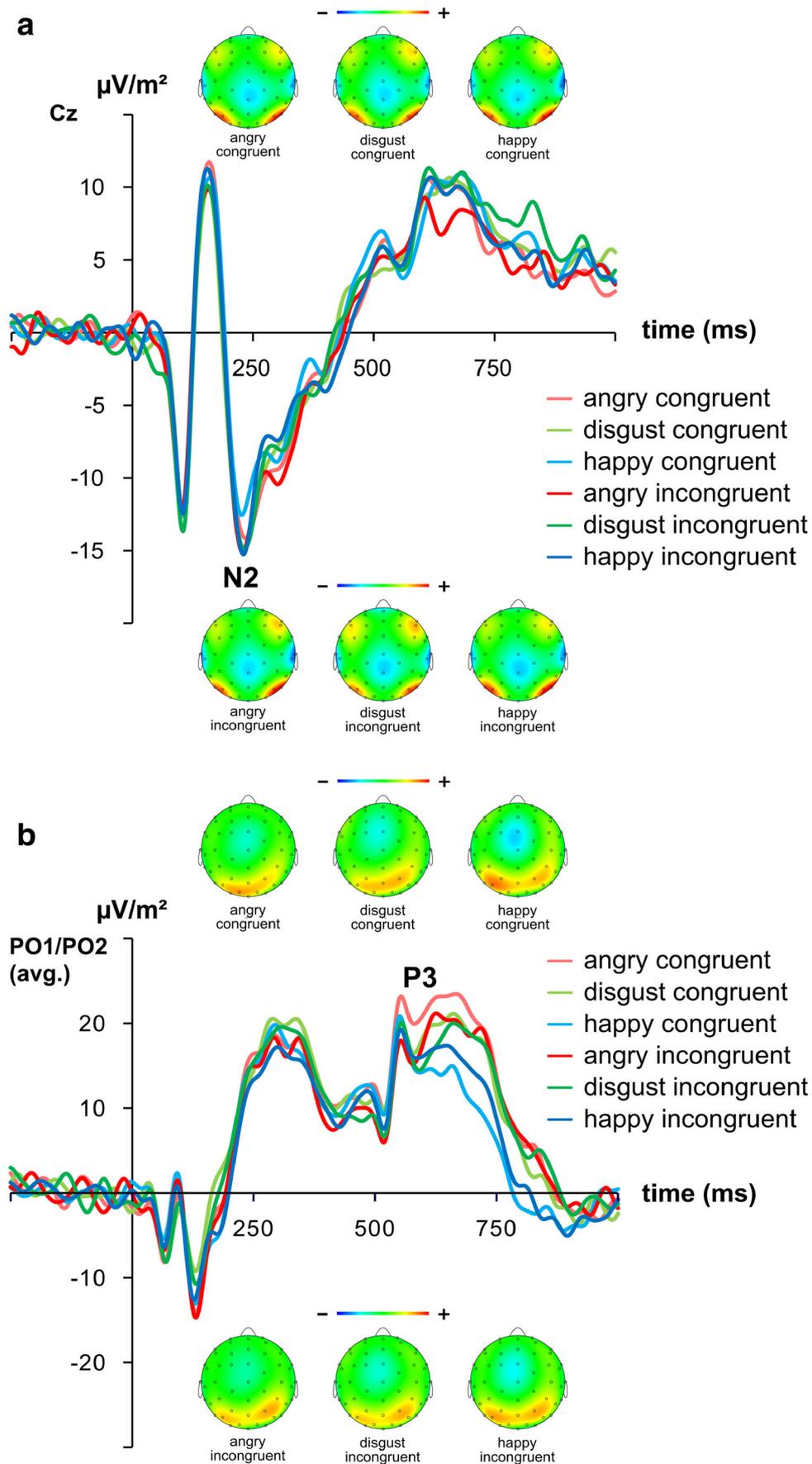


Figure 3 P1 and N1 ERP components shown for electrode P8 and corresponding topography maps of the scalp electrical potential for P1 and N1 at the peak of each ERP-component. In the topographies, red colours denote positivity and blue colours negativity.

The lines represent congruent/incongruent angry (pink/red), congruent/incongruent disgust (light green/dark green), and congruent/incongruent happy (light blue/dark blue) emotion conditions. Time point zero denotes onset of the target stimulus.



◀ **Figure 4 (a) N2 ERP-component at electrode Cz and (b) P3 ERP-component averaged across electrodes PO1 and PO2.** The corresponding topography maps of the scalp electrical potential are shown for the peak of each ERP-component. In the topographies, red colours denote positivity and blue colours negativity. Time point zero denotes onset of trial stimulus. The lines represent congruent/incongruent angry (pink/red), congruent/incongruent disgust (light green/dark green), and congruent/incongruent happy (light blue/dark blue) emotion conditions.

(805 ms \pm 24) and the disgust emotion condition (781 ms \pm 25), however, barely reached significance ($t(20) = 2.09$; $p = 0.049$). A post-hoc power analysis showed that the power was above 99% given the obtained effect size.

Neurophysiological Analysis

The P1 and N1 ERP-components are shown in Figure 3. The N2 ERP-component is shown in Figure 4a.

In regard to the P1, we found a significant main effect of “electrodes” (P8/P7), ($F(1,20) = 13.51$; $p = 0.002$; $\eta_p^2 = 0.403$) in the repeated-measures ANOVA, showing the P1 amplitude to be increased in the electrode P8 ($38.64 \mu\text{V}/\text{m}^2 \pm 4.46$) compared with P7 ($26.76 \mu\text{V}/\text{m}^2 \pm 4.28$). No other significant main effects or interactions were observed (all $F \leq 2.22$; $p \geq 0.101$). Concerning the repeated-measures ANOVA for N1 amplitudes, there were no significant main or interaction effects (all $F \leq 3.25$; $p \geq 0.052$). Similarly, in the repeated-measures ANOVA for the N2 amplitudes, there were neither main, nor interaction effects (all $F \leq 2.74$; $p \geq 0.077$). The P3 ERP-component is shown in Figure 4b.

In the repeated-measures ANOVA for the P3 ERP-component, a main effect of congruency was observed ($F(1,20) = 7.90$; $p = 0.011$; $\eta_p^2 = 0.283$), showing P3 amplitudes to be increased on congruent trials ($18.13 \mu\text{V}/\text{m}^2 \pm 2.56$) compared with incongruent trials ($16.65 \mu\text{V}/\text{m}^2 \pm 2.69$). Moreover, a main effect of “emotional target dimension” was observed ($F(2,40) = 6.02$; $p = 0.005$; $\eta_p^2 = 0.231$). Post-hoc paired t tests

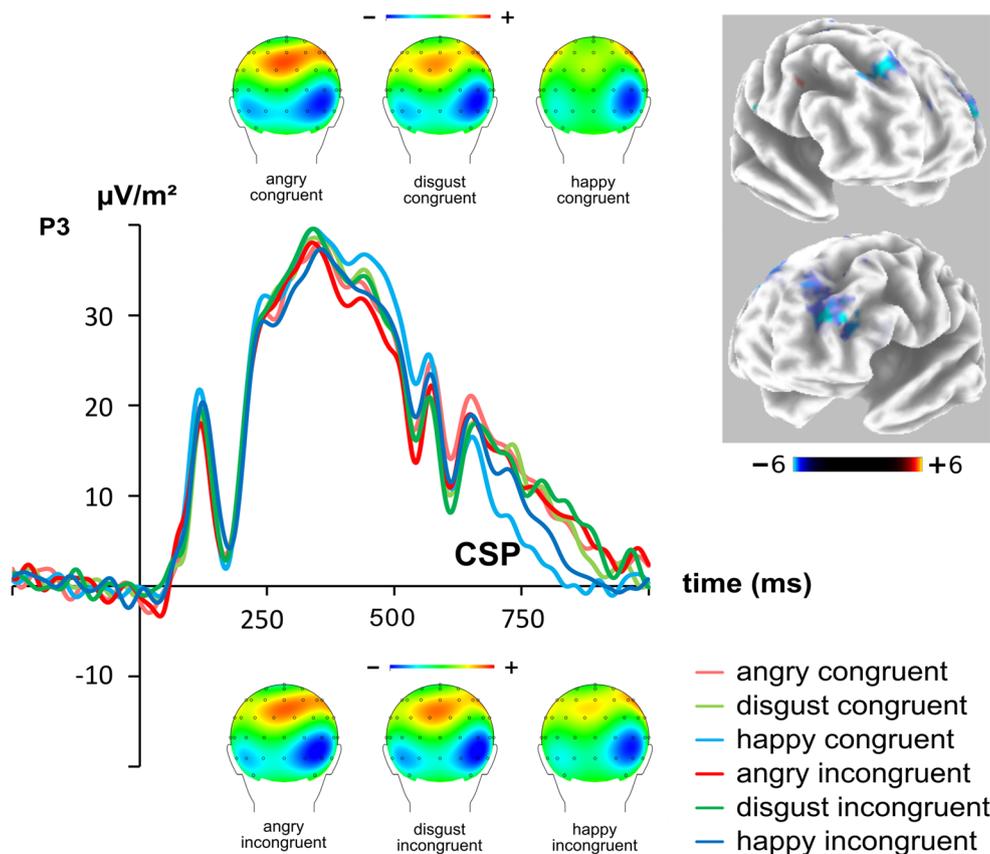


Figure 5 The conflict related slow potential (CSP) is shown at electrode P3 and the corresponding topography maps show the topography of the CSP in the entire analyzed time window. In the topographies, red colours denote positivity and blue colours negativity. Time point zero denotes onset of trial stimulus. The lines represent congruent/incongruent angry (pink/red), congruent/incongruent disgust (light green/dark green), and congruent/incongruent happy (light blue/dark blue) emotion conditions. Moreover, the differences waves between

congruent and incongruent happy target emotion trials are shown (happy congruent trials light blue and happy incongruent trials blue). The sLORETA source localization results show a differential activation within superior (BA8) and middle frontal gyrus (BA46) contrasting happy target emotion with disgust and angry target emotions. Only significant voxels corrected for multiple comparisons using SnPM are shown ($p < 0.01$). The sLORETA colour scale shows the critical t -values.

showed that P3 amplitudes only differed between the angry ($19.10 \mu\text{V}/\text{m}^2 \pm 2.69$) and the other two emotions (all $t \geq 2.36$; $p \leq 0.029$), whereas the disgust ($17.48 \mu\text{V}/\text{m}^2 \pm 2.89$) and the happy emotion ($15.6 \mu\text{V}/\text{m}^2 \pm 2.43$) conditions did not differ ($t(20) = 1.54$; $p = 0.140$).

Most importantly, the interaction “congruency x emotional target dimension” ($F(2,40) = 6.71$; $p = 0.003$; $\eta_p^2 = 0.251$), as shown in Figure 5, reached significance. We further analyzed this interaction by means of repeated-measures ANOVAs for each congruency condition separately. For congruent trials a main effect of “emotional target dimension” was observed ($F(2,40) = 11.75$; $p < 0.001$; $\eta_p^2 = 0.370$). Post-hoc paired t tests for congruent trials revealed P3 amplitudes to increase from the happy ($15.10 \mu\text{V}/\text{m}^2 \pm 2.42$), to the disgust ($18.42 \mu\text{V}/\text{m}^2 \pm 2.84$), to the angry ($20.89 \mu\text{V}/\text{m}^2 \pm 2.68$) emotions (all $t \geq 2.33$; $p \leq 0.030$). The repeated-measures ANOVA for incongruent trials, however, did not reach significance ($F(2,40) = 0.53$; $p < 0.593$; $\eta_p^2 = 0.026$). The conflict-related slow potential (CSP) is shown in Figure 5.

In the repeated-measures ANOVA for the CSP, a main effect of “emotional target dimension” was obtained ($F(2,40) = 8.05$; $p = 0.001$; $\eta^2 = 0.287$), showing that the CSP was less pronounced for the happy trials ($9.87 \mu\text{V}/\text{m}^2 \pm 2.33$) compared with the angry ($13.94 \mu\text{V}/\text{m}^2 \pm 2.46$) and disgust ($13.98 \mu\text{V}/\text{m}^2 \pm 2.12$) trials (all $t \geq 3.03$; $p \leq 0.007$), whereas the disgust and angry trials did not differ ($t(20) = 0.04$; $p = 0.972$). The main effect of congruency did not reach significance ($F(1,20) = 2.22$; $p = 0.152$; $\eta_p^2 = 0.100$).

Most importantly, there was a significant interaction “congruency x emotional target dimension” ($F(2,40) = 10.31$; $p < 0.001$; $\eta_p^2 = 0.340$). A post-hoc power analysis showed that the power was above 99% given the obtained effect size. To further analyze this interaction, we compared each emotion between congruent and incongruent trials. Post-hoc paired t tests revealed this interaction to be based on significant differences between the congruent ($7.76 \mu\text{V}/\text{m}^2 \pm 2.48$) and incongruent trials ($11.98 \mu\text{V}/\text{m}^2 \pm 2.25$) in the happy emotion condition ($t(20) = 4.67$; $p < 0.001$), whereas congruent and incongruent trials in the angry (congruent: $14.51 \mu\text{V}/\text{m}^2 \pm 2.55$; incongruent: $13.37 \mu\text{V}/\text{m}^2 \pm 2.44$) or disgust (congruent: $14.21 \mu\text{V}/\text{m}^2 \pm 2.05$; incongruent: $13.75 \mu\text{V}/\text{m}^2 \pm 2.30$) conditions did not differ significantly (all $t \leq 1.39$; $p \geq 0.179$). A subsequent sLORETA analysis for contrasting the happy congruent emotion condition with the incongruent happy emotion condition revealed these differences to be based on an increased activation of the superior (BA8) and middle frontal gyrus (BA46) in the incongruent happy emotion condition.

Discussion

The purpose of this study was to clarify the basic system neurophysiological mechanisms and functional neuroanatomical

structures associated with interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution. While recent research has either focused on the impact of emotion on cognitive control mechanisms or the effects of the emotional valence of target dimensions (emotionally valent vs. neutral) on conflict processing (Kanske, 2012; Ma et al., 2014; Zinchenko et al., 2015), the effects of socially relevant emotional categories on emotional conflict processing and the neurophysiological mechanisms involved in resolving emotional conflict remained to be elucidated.

We employed a version of the Emotional Stroop paradigm and EEG-recordings in combination with source localization analyses. This approach was chosen to investigate the underlying system neurophysiological mechanisms involved. In the applied paradigm, a conflict processing was examined presenting a picture showing a task-relevant facial emotional dimension (happy, angry, disgust) that was combined with the presentation of an emotional word (happy, angry, disgust) in the middle of the face, which reflected the task-irrelevant emotional dimension.

Our results show that incompatibility between task-irrelevant emotional content (carried by the word) and the task-relevant socioemotional content (carried by the facial expression) differentially affects performance depending on the valence of the facial emotion expression (happy, angry, disgust). The power calculations show that this was a robust effect. Emotional conflict arises when interfering streams of emotional information occur, which is reflected in notable interference effects in RTs and accuracy (Egner, Etkin, Gale, & Hirsch, 2008; Fonzo, Huemer, & Etkin, 2016; Ma et al., 2014; Ma, Liu, & Chen, 2015, 2016; Meeren, van Heijnsbergen, & de Gelder, 2005; Zinchenko et al., 2015). Our behavioral data show that, when the facial emotion expression and the emotional word were congruent, performance on happy faces was improved (i.e., RTs decreased and accuracy increased), whereas it was decreased on disgust and angry facial emotion expressions. Importantly, on incongruent trials, performance was strongly affected on angry and disgust emotion expressions, whereas it was barely compromised in the happy emotion condition. This suggests that interference effects of conflicting information are less striking in a positive task-relevant socioemotional task setting than in a negative socioemotional task setting. Moreover, the degree to which an interfering emotion dimension influences control processes is dependent on the valence emotional category of the target stimulus. To elucidate which specific cognitive sub-processes were modulated and underlie the observed interactive emotional interference effects, ERP data were analyzed.

Because no differential modulations in line with the behavioral data were observed for the N1- or P1 ERP amplitudes, perceptual and attentional processes reflected by these ERP components (Beste, Baune, Falkenstein, & Konrad 2010; Fu, Caggiano, Greenwood, & Parasuraman, 2005; Han, He, &

Woods, 2000; Herrmann & Knight, 2001; Hillyard & Anllo-Vento, 1998; Petruo et al., 2016; Schneider, Beste, & Wascher, 2012a, b) are unlikely to underlie the observed changes on the behavioral level. For the P3 amplitude, we found that a main effect of emotion showing P3 was modulated (i.e., was larger) in negative emotional settings (i.e., angry and disgust facial expressions) (Kaestner & Polich, 2011; Schupp et al., 2000). This may reflect an intensified allocation of processing resources to threat-related emotional events, which has previously been described (Meinhardt & Pekrun, 2003). In this light, our results support the idea that the processing of negative target emotions (or negative emotional settings) may capture larger amounts of processing resources compared with the classification of happy target emotions. There was a congruency \times target emotion' interaction, which was only based on the differences between the congruent trials (happy < disgust < angry) in consistence with the pattern of congruent trials in the behavioral data. However, because no differences were found for the incongruent trials, this suggested that emotional conflict effects are reflected in neuropsychological processes in later processing stages.

Interestingly, the N2 ERP-component, often referred to as reflecting conflict detection processes (Chmielewski, Roessner, & Beste, 2015; Danielmeier, Wessel, Steinhauser, & Ullsperger, 2009; Folstein & Van Petten, 2008; Kanske, 2012; Larson et al., 2014; Mückschel, Chmielewski, Ziemssen, & Beste, 2017; van Veen & Carter, 2002; Zhang, Stock, Fischer, & Beste, 2016), was not differentially modulated by interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution. However, compared with nonemotional conflict paradigms, which typically evoke short RTs, the employed paradigm used rather complex emotional stimuli. The results show that RTs were around 650 to 800 ms and thus clearly exceeded the N2 time window. Stimulus complexity and emotional intensity likely also account for why we do not see exactly the same pattern of modulation for the accuracy and RTs in terms of congruency effects. The lack of N2 modulation may be because emotional expressions require deeper processing and therefore, conflicts are not detected within the time window of the N2. This suggests that N2 amplitude is not a signal of conflict processing per se and only reflects conflict if stimulus dimensions can be encoded early. Particularly in Stroop-tasks, conflict detection seems to rely on the level of processing and the time needed to encode the stimulus (MacLeod, 1991). This is coherent with results from studies using more complex emotional Stroop-stimuli, such as mismatching facial expressions and bodily postures, where early potentials appeared not to be sensitive to conflict between the stimuli dimensions (Meeren et al., 2005).

Thus, interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution in line with the behavioral data were reflected in the

conflict-related slow potential (CSP). The generally stronger CSP amplitudes for negative emotions is in line with other studies, suggesting prolonged evaluative mechanisms following the presentation of highly emotionally salient content (Schupp et al., 2000). More importantly, only for happy facial emotions, an enhanced (i.e., more positive) CSP was detected on incongruent trials compared to congruent trials. A more pronounced CSP following conflict trials has been reported in a number of cognitive and emotional conflict Stroop studies (Ma et al., 2014; Zinchenko et al., 2015) and likely reflects a signal of increased recruitment of control and has been associated with conflict resolution or evaluation processes (West, 2003). This is in line with findings showing the CSP to be modulated by the demands for cognitive control (Chen et al., 2016; Larson, Kaufman, & Perlstein, 2009). Our results suggest that trials in which positive facial emotions (task-relevant dimensions) are presented induce a setting that requiring low levels of cognitive control. It has been shown that visual expressions of happy emotions are faster and more reliably computed than the other basic emotions (Du & Martinez, 2011, 2013). Therefore, following the detection of positive target emotions, sufficient processing capacities may be available to evaluate the conflicting information and to resolve interference effects induced by the task-irrelevant but incongruent emotional dimension. This is reflected in the behavioral data and the differences in CSP amplitudes between congruent and incongruent conditions. Furthermore, it has been shown that negative emotional categories are generally computed slower (Du & Martinez, 2011). On a neuroanatomical level, the source localization analysis shows that the effects observed are due to modulations of neuronal activity in middle frontal gyrus (MFG) and superior frontal gyrus (SFG) following incongruent trials with angry and disgust target emotions compared with happy target facial emotions expressions. When trying to relate ERP data to a specific area, the accuracy of the source localization cannot be entirely certain, due to the inverse problem. Nonetheless, our findings are very much in line with the existing literature. Activation of these areas has been associated with post-conflict evaluation processes in response to complex stimuli with great demand for higher level control functions (Banich et al., 2000; Boissgueheneuc et al., 2006; Kerns et al., 2004). Moreover, reactions to complex personal moral dilemmas have been associated with increased RTs and increased activity in the MFG in other regions linked to emotion (Greene, Nystrom, Engell, Darley, & Cohen, 2004). Most importantly, Kerns et al. (2004) observed that activation of MFG went along with the greatest degree of behavioral adjustment following highly conflicting trials. This is in line with the general idea that activation of subregions within the PFC (such as MFG and SFG) reflect recruitment of higher cognitive function in response to complex stimuli that require deeper processing and high levels of

executive control (Damasio, Everitt, & Bishop, 1996; MacDonald, Cohen, Stenger, & Carter, 2000; Miller & Cohen, 2001). Together, the neurophysiological results suggest that the degree to which higher regions of PFC are implicated in the control of complex conflicting emotional situations, and thus how strongly emotional interference exerts an effect on behavior is dependent on the complexity of the emotional valence of the stimulus. Angry and disgust target emotions may represent high-control setting and do not permit for clear representation of emotional interference effects within CSP because of a markedly increased activation of SFG and MFG in these conditions. This suggests that processing of negative emotions inherently evokes a greater demand for control, which may reduce the capacity to resolve emotional conflict efficiently.

Within healthy populations, it would be interesting to investigate the specific influence of distractor valence on conflict processing using paradigms with sufficient number of trials per condition to allow analysis of neurophysiological data. Furthermore, our findings invite future investigations to examine trial-by-trial adjustment and recruitment of cognitive control in emotional paradigms. Considering the present findings, future studies examining sequential manipulation of conflict effects (CSE) may be particularly interesting within the setting of emotional interference effects. CSE describes the effect of conflict adaptation dependent on previous-trial congruency shown in numerous studies and putatively related to enhancement of control following high conflict. High-conflict trials (i.e., incongruent trials) preceded by another incongruent trial seem consistently to result in faster RTs and higher accuracy, as well as attenuated N2 amplitudes compared with incongruent trials that are preceded by congruent (low-conflict) trials (Larson et al., 2014). Our findings show that processing of negative emotional valence elicits longer lasting evaluative mechanisms (i.e., enhanced CSP). Thus, the emotional valence of a preceding trial (in particular, negative/aversive states) may exert rather specific effects on trial-by-trial conflict adjustment and resulting behavioral responses to the target emotion presented within the *current* trial.

The current findings also have implications for examining affective control in psychiatric disorders. Studies have shown that individuals with Generalized Anxiety Disorder (Etkin et al., 2010), or treatment-resistant depression (Xue et al., 2017), show impairments in emotional conflict monitoring and behavioral adjustment (Holmes & Pizzagalli, 2008). Furthermore, individuals with Autism Spectrum Disorder exhibit a specific attentional bias towards emotional expressions compared with non-social objects and have been shown to perform worse in face-processing tasks (Ashwin, Wheelwright, & Baron-Cohen, 2006). Thus, within these patient groups, it might be important to consider the specific impact of emotional

valence on conflict control because of known differences in processing of social and emotional stimuli. Hence, decreased efficacy in processing socioemotional stimuli (i.e., facial emotions) would lead to decreased conflict processing and resolution reflected in later stages of neurophysiological processing (Fonzo et al., 2016; Groenewold, Opmeer, de Jonge, Aleman, & Costafreda, 2013; Shafritz, Bregman, Ikuta, & Szeszko, 2015; Sladky et al., 2015).

In summary, we show what system neurophysiological mechanisms and functional neuroanatomical structures are associated with interactive effects of different interfering socioemotional stimulus dimensions on conflict resolution; i.e., we show how the socioemotional setting modulates cognitive control (conflict processing). Conflicts are stronger and more difficult to resolve in a negative emotional task-relevant valence. Opposed to this, incongruent information barely induced conflicts in a positive emotional task-relevant setting. The neurophysiological data show that these modulations were only reflected by late-stage conflict resolution processes associated with the middle (MFG) and superior frontal gyrus (SFG). The degree of emotional conflict therefore critically depends on the emotional setting in which this conflict occurs.

Acknowledgements This work was partly supported by a grant from the Deutsche Forschungsgemeinschaft (DFG) SFB 940 project B8.

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