

# Antagonistic modulatory influences of negative affect on cognitive control: Reduced and enhanced interference resolution capability after the induction of fear and sadness

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## ABSTRACT

The present behavioral study investigated the influence of negative affect on the neural mechanisms of cognitive control. We expected to find evidence for an antagonistic modulation of cognition by threat-relevant and threat-irrelevant negative affect (i.e. fear and sadness) that should promote bottom-up monitoring and top-down selection, respectively. Subjects performed one of three conflict tasks (Stroop, Flanker, or Simon) that tap distinct control mechanisms of conflict resolution, comprising specific attentional and motor control processes. On each task trial, target stimuli were preceded by a face stimulus exhibiting a fearful, sad, or neutral expression, providing three affect conditions. Our data provides strong evidence for substantially increased selection (attentional and motor selection) after priming of threat-irrelevant negative affect (sadness). Deviating from the results of previous studies, our analysis did not consistently yield increased monitoring after fear priming. We discuss these findings with respect to the effectiveness of different experimental affect priming procedures (i.e. stimuli) and the role of the task context, among others.

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## 1. Introduction

### 1.1. Meeting antagonistic constraints on cognitive control: the selection-monitoring balance

Adaptive goal-directed action in a changing environment can be conceived to impose antagonistic requirements on the cognitive control system. On the one hand, top-down processing should select task-relevant information whereas task-irrelevant, distracting information should be suppressed so as to prevent or minimize crosstalk and interference. On the other hand, however, goal-directed selection that suppresses irrelevant information completely would be by no means adaptive. Rather, bottom-up processing should enable an organism to recognize threats or opportunities occurring outside the current focus of attention (cf. Allport, 1989; Houghton & Tipper,

1994). Hence, adaptive action in a changing environment requires a context-sensitive “just-enough” calibration of endogenous control sufficient to protect an ongoing goal-directed operation from distraction (e.g. not looking up at every little noise in the environment), while not compromising the flexibility to rapidly execute another behavior when appropriate (e.g. when the noise appears to be a cry for help or a warning) (cf. Goschke, 2000, 2003; Gruber et al., 2009; Monsell, 2003). Here, we refer to this context-dependent calibration of cognitive processing as “selection-monitoring balance” (SMB). The basic assumption of the present work is that, besides situational requirements, affective states play an important role in the modulation of the SMB.

### 1.2. Modulation of cognition by emotion: discrepancies among theoretical accounts and empirical findings

In psychological emotion theory, the basic hypothesis has been proposed that positive and negative affect modulate the cognitive system in opposite directions, with positive affect promoting flexible and reactive information processing and negative affect leading to relatively focused and rigid information processing (e.g. Bless & Fiedler, 2006; Fiedler, 2001).

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### 1.2.1. Antagonistic cognitive styles related to positive and negative affect

More specifically, in his affect-cognition model Fiedler (2001) assumes that positive affect promotes a so-called *assimilative processing style* or *loosing style*, which is creative, intuitive, and impulsive with a tendency to transform new input information in the light of existing knowledge. There is an obvious similarity between Fiedler's assimilative processing style and cognitive symptoms of mania (e.g. flight of ideas, racing of thoughts, associative loosening) which can be considered a pathological state of positive affect. Negative affect, on the other hand, in the model of Fiedler promotes a so-called *accommodative processing style* or *tightening style* which is focused, systematically oriented, and rigid with a tendency to conserve new input information. Accommodative cognitive processing exhibits a clear overlap with cognitive symptoms in depressive disorder (e.g. perseveration, poverty of thought, circling thoughts) which can be considered a pathological state of negative affect. Importantly, Fiedler's antagonistic cognitive styles can be conclusively related to the SMB with selection (i.e. control) corresponding to accommodative cognitive processing and monitoring (i.e. flexibility) corresponding to assimilative cognitive processing.

Behavioral studies provide convincing evidence that positive affect indeed promotes cognitive flexibility or reactivity as operationalized in psychometric measures of e.g. creativity, verbal fluency and association ability (e.g. Isen, Niedenthal, & Cantor, 1992; Phillips, Bull, Adams, & Fraser, 2002; for review see Ashby, Isen, & Turken, 1999). Moreover, conform with the theoretical assumption that control strength varies in a reciprocal manner with cognitive flexibility and reactivity (also referred to as *stability-flexibility paradox* or *control-reactivity paradox*), it has been shown that enhanced cognitive flexibility under positive affect occurs at the cost of increased distractibility from task-irrelevant information as well as an impaired maintenance capability (Dreisbach, 2005; Dreisbach & Goschke, 2004). Both gains and losses in information processing related to positive affect can be plausibly explained by the same neurobiological mechanism, particularly by dopamine release in prefrontal cortices (cf. Ashby et al., 1999; Braver & Cohen, 2000).

### 1.2.2. Dopamine as mediator for the influence of emotion on cognition

It is generally accepted that there is a strong positive relationship between positive affect and neuronal (prefrontal) dopamine levels. This was repeatedly demonstrated by experiments that either manipulated (a) neural dopamine release or activity in psychopharmacological studies (Beatty, 1995; Hyman & Nestler, 1993) or (b) the affective state of subjects, e.g. in studies administering reinforcers (rewards or punishers) (e.g. Schultz, 1992, 2000). The relationship between positive affect, dopamine activity, and cognitive control processes has been described in the neuropsychological models of Ashby et al. (1999, 2002); Ashby, Valentin, and Turken (2002) as well as Braver and Cohen (2000). Both models are consistent with the assumption that increases in brain dopamine related to positive affect may be suited to weaken cognitive control and thereby shift the SMB against selection and maintenance (i.e. control) towards monitoring and switching (i.e. reactivity/flexibility).

While behavioral studies provide convincing evidence that positive affect promotes cognitive flexibility at the cost of increased distractibility, one may plausibly expect that negative affect—as antipole to positive affect—shifts the SMB in the opposite direction (towards selection/control), which may be mediated by the same or a related neurobiological (i.e. dopaminergic) mechanism (cf. Dreisbach, 2005; Dreisbach & Goschke, 2004). Contrary to this expectation, cognitive-neuroscientific (neuroimaging) studies have consistently shown that negative affect has an inhibitive influence on the neural mechanisms of cognitive control. More specifically, studies using affect priming procedures (i.e. presentation of emotion-relevant stimuli immediately before targets of a cognitive task) consistently found enhanced distractibility or interference by task-irrelevant information after negative affect priming (Blair et al., 2007; Dennis & Chen, 2007; Melcher et al., 2011). Such findings can be reasonably explained by a

basic mechanism of reciprocal inhibition between the neural systems underlying emotional and cognitive processing. In line with this explanation, it has been repeatedly shown that neural activity is reduced in areas important for higher order cognitive processes (e.g. DLPFC and dACC) during emotional processing, and inversely that areas crucially involved in emotional processing (e.g. amygdala and OFC) exhibit activation below baseline during the performance of cognitive tasks (cf. Melcher et al., 2011; Yamasaki et al., 2002; for review see Drevets & Raichle, 1998).

### 1.3. Reconciling discrepant accounts by distinguishing different kinds of negative affect according to their threat-relevance: fear vs. sadness

The outlined discrepancy between assumptions of psychological theory of emotion (strengthening of control by negative affect) on the one hand and empirical findings of cognitive neuroscience (weakening of control by negative affect) on the other, may be reconciled by assuming that different kinds of negative affect exert differential—or, more precisely, opposite—influences on the cognitive control system.

In studies showing that negative affect has an inhibitive influence on cognitive control, the adopted affect priming procedure mostly, or even exclusively, used threat-relevant stimuli, i.e. pictures of dangerous, catastrophic or harmful situations like mutilated or dead victims of war and dangerous, aggressive animals or guns that seemingly threaten the viewer (cf. Blair et al., 2007; Melcher et al., 2011). Accordingly, in the present study, we expected that specifically threat-related forms of negative affect like fear, scare, or anger exert an inhibitive influence on the cognitive control system, whereas threat-unrelated forms of negative affect like sadness or unhappiness inversely increase cognitive control mechanisms and accordingly shift the SMB in the opposite direction.

This expectation can be further corroborated by evolution-theoretical considerations as well as by consulting the cognitive concomitants of intense or pathological affective states: in threat-relevant situations (i.e. situations of potential danger), it is obviously advantageous if control (i.e. information selection) is not too rigorous. Rather, an adequate level of monitoring or vigilance should provide the required responsivity to readily adapt to significant changes in the environment (cf. Ohman, 1997; Ohman et al., 2001). In contrast, situations of sadness or grief are typically characterized by a certain cognitive rigidity or focussedness and reduced distractibility, which is arguably related to the necessity to mentally process (i.e. focus on) the related event of loss or harm (cf. Andrews et al., 2007). Moreover, patients suffering from anxiety disorder and obsessive-compulsive disorder—psychiatric disorders that share fear as core affective symptom—exhibit clear indication of enhanced monitoring or vigilance, and particularly an enhanced distractibility from task-irrelevant information (Bishop, 2007; Eysenck et al., 2007; for review see Melcher et al., 2008).

### 1.4. Scope and purpose of the present study

In the present study, we sought to directly test for an antagonistic influence of threat-relevant negative affect (i.e. fear) and threat-irrelevant negative affect (i.e. sadness) on cognitive control, particularly on the SMB. Psychological task paradigms that involve so-called *stimulus-based conflict* can be reasonably considered to provide a direct behavioral measure of the emphasis of the SMB. More specifically, during stimulus-based conflict, incompatible or incongruent task-relevant and task-irrelevant information bits compete for priority in cognitive processing (cf. Egner et al., 2007; Melcher & Gruber, 2006; Milham et al., 2003). Thus, a relatively high stimulus-based conflict (in terms of relatively high performance decrements in case of stimulus incongruency) can be considered an indication of enhanced monitoring (i.e. sensitivity for task-irrelevant information), whereas relatively low stimulus-based conflict (in terms of relatively low performance decrements in case of stimulus incongruency) can be considered as marker for enhanced selection (i.e. shielding of task-relevant information processing from distraction).

For our purpose, we adopted two interference task paradigms that involve *stimulus-based conflict*: a color word Stroop task (Stroop, 1992) and a Flanker task (Eriksen & Eriksen, 1974). Both of these tasks require increased attentional selection for conflict resolution: the Stroop task requires selecting the stimulus feature color while ignoring lexical word form (feature attention), whereas the Flanker task requires selecting stimuli in middle position while ignoring peripheral distracters (spatial attention). Moreover, we adopted a spatial conflict or Simon task (Simon, 1969) that involves so-called *response-based conflict* requiring subjects to overcome the predominant tendency to respond to stimulus location rather than stimulus identity (for a more detailed distinction between stimulus-based and response-based conflict, see also Egner et al., 2007; Kornblum, 1992; Zhang et al., 1999). The additional inclusion of a spatial conflict task should allow testing whether the influence of negative affect is equivalent across different levels of cognitive processing, i.e. whether it similarly concerns the selection of competing sensory information (attentional selection) and the selection of competing motor responses (motor selection).

For our purpose, all of the applied interference task paradigms were interleaved with an emotional priming procedure in identical manner. More specifically, on each trial immediately before the target stimulus, we presented Ekman face pictures which exhibited either a fearful, sad, or emotionally neutral expression, thus providing three affect conditions under which the cognitive tasks were performed.

## 2. Methods

### 2.1. Subjects

103 right-handed young adults (66 women; mean age  $25.0 \pm 3.8$ ; Stroop task: 25 women/16 men; mean age  $26.1 \pm 3.3$ ; Flanker task: 13 women/9 men; mean age  $22.7 \pm 2.5$ ; Simon task: 28 women/12 men; mean age  $25.3 \pm 4.4$ ) participated after they had given written informed consent. They received a monetary payment for the participation. Subjects were recruited after approval of the experimental procedure by the local university ethics committee.

### 2.2. Experimental procedure

The experimental setup was kept constant across all task paradigms including event timing parameters (presentation durations and ISIs), condition variation (created task conditions), trial number, and (counterbalanced) trial sequence as well as the applied technical (presentation and response) devices. Subjects were required to carry out speeded button press responses using either their right or left index finger during all tasks. In the Stroop task, subjects were to respond to the print color of presented word stimuli while ignoring the words' lexical identity. Blue color was mapped onto the left, yellow color onto the right response button. In the flanker task, subjects were presented with a row of five horizontally aligned arrows (one central arrow plus four peripheral flankers). The task was to respond according to the pointing direction of the central arrow whilst ignoring the laterally presented flanker stimuli. Finally, in the spatial conflict task, single arrows were presented in one of three presentation locations (left/right side of the presentation field or in center position). Subjects were required to respond to the pointing direction of the arrows while ignoring their location.

The described task paradigms allowed us to create an analogous condition variation comprising of incongruent, congruent, and neutral trials for all tasks. During (a) *incongruent trials*, the to-be-ignored task-irrelevant information—word meaning, flanker stimuli, or presentation location—was associated with the opposite button press response and, thus, was expected to induce cognitive conflict. During (b) *congruent trials*, the task-irrelevant feature value matched the response mapping of the target feature and, thus, was expected to facilitate the required response. Finally, during (c) *neutral trials*, the task-irrelevant feature was

| task / condition | Stroop | Flanker | Simon |
|------------------|--------|---------|-------|
| incongruent      | BLAU   | ←←←→←←  | →     |
|                  | GELB   | →→→←→→  | ←     |
| congruent        | GELB   | →→→→→→  | →     |
|                  | BLAU   | ←←←←←←  | ←     |
| baseline         | RUND   | —→—→—→  | →     |
|                  | RUND   | —→—→—→  | ←     |

Fig. 1. Schematic visualization of cognitive task conditions and respective target stimuli.

response-ineligible or neutral—comprising a color-unrelated word, simple line flankers without arrow head, or centered presentation position, respectively—and, thus, was expected to induce neither conflict nor facilitation, i.e. to represent a cognitive baseline condition. Fig. 1 provides a schematic visualization of the created (cognitive) task conditions and the respective target stimuli, separately for the different task paradigms.

At the beginning of each task trial, one of 27 facial expression pictures taken from the “Facial Expressions of Emotions: Stimuli and Test” (FEEST) (Young et al., 2002) was presented. Depicted faces displayed either sad, fearful, or neutral expressions providing three affect conditions under which the cognitive tasks were performed. For the neutral face condition, we used morphed images exhibiting slightly happy expression (25% happy, 75% neutral) because of evidence that 100% neutral faces may appear emotionally negative (Phillips et al., 1997). Presented pictures consisted of nine actors (five females) who evenly appeared across all affect conditions.

In their combination, cognitive and emotional conditions lead to a total of nine (three times three) experimental conditions. The experimental procedure comprised a total of 324 trials, with an equal number of congruent, incongruent, and baseline trials (108 of each). Each cognitive condition was combined with each emotional condition with equal frequency. The trial sequence was created to ensure that each trial type followed every other trial type with equal frequency. Each trial started with the presentation of a face picture which lasted for 250 ms. After a delay of either 500 or 2000 ms (presentation of a blank screen), the target stimulus of the cognitive task appeared for 750 ms and responses were registered for a further 750 ms after the stimulus offset, leading to a total response window of 1500 ms. The total trial length was either 2250 or 3750 ms. The basic trial procedure is illustrated in Fig. 2. [Annotation: the varying delay between affective stimulus and target stimulus was introduced to provide an

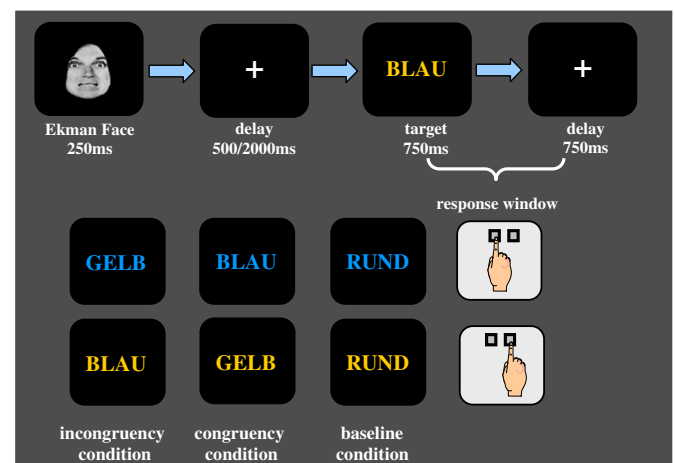


Fig. 2. Trial procedure and cognitive task conditions, exemplified for the Stroop task. The Flanker and Simon task involved an analogous condition variation. Depicted word stimuli are the German translations for the color words YELLOW and BLUE (congruency and incongruency condition) as well as for the color-neutral word ROUND (baseline condition).

event jitter to optimize data acquisition and design efficiency when the same paradigm is used in combination with functional neuroimaging (fMRI). The jitter was already inserted in the prior behavioral investigation to ensure that both behavioral and neuroimaging tests are as comparable as possible.]

### 2.3. Data analysis

Statistical analysis of the behavioral data used SPSS 16.0 for Windows. Reaction times (RTs) were aggregated across subjects and conditions, and analyzed by means of a repeated measures analysis of variance (ANOVA), thresholded at  $p < .05$ . More specifically, the ANOVA model included cognitive condition (stimulus congruency) and affect condition as within-subject factors (including three levels each), and task type (Stroop, Flanker, Simon) as additional between-subject factor. Post-hoc analyses were conducted in a hierarchical manner to further follow up significant omnibus findings. These analyses were conducted separately for the three different tasks and comprised ANOVA models of congruency effects (RT baseline–RT congruent) and incongruency effects (RT incongruency–RT congruency) with affect condition as within-subject factor. Finally single t-contrasts (one-sample t-tests) were analyzed to reveal (in-)congruency effects for different affect conditions. All tests were thresholded at  $p < .05$ . Effects of the experimental manipulation on error rates (ERs) were tested analogously to the RTs using single-subject condition-specific error percentages instead of mean RTs.

## 3. Results

### 3.1. Reaction times

RTs of the different experimental conditions are presented in Table 1 and Fig. 3, separately for the three tasks. At the descriptive level, interference effects were found across all tasks and affect conditions (i.e. increased RTs in incongruent trials compared to baseline trials). Facilitation effects (RT congruent < RT baseline), on the other hand, were present only in the Stroop and Simon task whereas congruent trials in the Flanker task exhibited an inverse effect (RT congruent > RT baseline), putatively reflecting sensory competition by the congruent arrow heads of the peripheral stimuli (see discussion). Therefore, the Flanker task was excluded from the (post-hoc) analyses of facilitation effects.

The omnibus ANOVA (affect  $\times$  cognitive condition  $\times$  task) revealed a significant main effect of factor “cognitive condition”, but not of factor “affect condition”. Moreover, confirming our basic hypothesis, there was a significant interaction “affect  $\times$  cognitive condition” indicating a significant modulation of (in-)congruency effects by the affect priming. There was no three-way interaction between task type, affect and cognitive conditions, indicating an equivalent modulation of (in-)congruency effects by affect condition across tasks (for exact statistics of the omnibus ANOVA see Table 2). This was additionally confirmed by separate two-way ANOVAs for the three

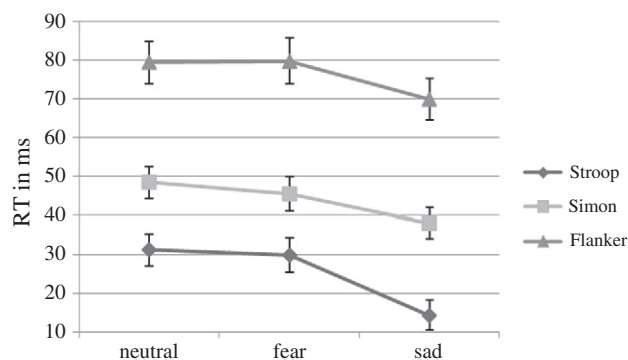


Fig. 3. Line chart of the mean interference effect scores in ms (“incongruent minus baseline”) under the different affect conditions, separately for three different tasks. Error lines represent standard errors of mean.

Table 2

Statistics (F values and p values, i.e. significance level) of the omnibus ANOVAs on the reaction time data and error rate data. For both data sets, we defined analogous  $3 \times 3 \times 2$  ANOVAs with affect and cognitive condition as within-subject factors and task as between-subject factor.

| ANOVA factor               | Reaction time |        |       | Error rate |        |       |
|----------------------------|---------------|--------|-------|------------|--------|-------|
|                            | F             | df     | p     | F          | df     | p     |
| <i>Main effects</i>        |               |        |       |            |        |       |
| (1) Affect condition       | 0.195         | 2, 200 | .823  | 0.046      | 2, 200 | .955  |
| (2) Cognitive condition    | 421.0         | 2, 200 | >.001 | 85.500     | 2, 200 | >.001 |
| <i>Interaction effects</i> |               |        |       |            |        |       |
| 1 * 2                      | 8.328         | 4, 400 | >.001 | 1.133      | 4, 400 | .341  |
| 1 * task                   | 28.713        | 4, 400 | >.001 | 1.008      | 4, 400 | .404  |
| 2 * task                   | 0.814         | 4, 400 | .518  | 5.930      | 4, 400 | >.001 |
| 1 * 2 * task               | 1.122         | 8, 800 | .347  | 2.159      | 8, 800 | .030  |

different tasks, which all revealed a significant interaction effect between affect and congruency (Stroop:  $F(4,160) = 5.156$ ;  $p = .001$ ; Flanker:  $F(4,84) = 2.647$ ;  $p = .039$ ; Simon:  $F(4,156) = 4.369$ ;  $p = .002$ ). To follow up the significant interaction effect, we specifically analyzed the modulation of congruency effects and incongruency effects by the affect condition conducting two separate two-way ANOVAs with affect as within-subject factor and task as additional between-subject factor. Regarding congruency effects, no effect of affect condition ( $F(2,158) = 1.025$ ;  $p = .361$ ) and also no interaction between affect and task was observed ( $F(2,158) = 0.909$ ;  $p = .405$ ), indicating that there was no modulation of facilitation by affect, irrespective of the specific task. Accordingly, no further post-hoc tests were conducted for facilitation effects. The same ANOVA model applied to interference effects as dependent variable, however, did show a significant effect for affect condition ( $F(2,200) = 10.001$ ;  $p = .001$ ), which occurred in absence of a significant interaction between affect condition and task ( $F(4,400) = 0.511$ ;  $p = .727$ ). Three additional one-way ANOVAs, one

Table 1

Mean reaction times and corresponding dispersion measures in the different experimental conditions, separately for the three different tasks.

| Condition           | Stroop |      |      |    | Flanker |      |     |    | Simon |      |     |    |
|---------------------|--------|------|------|----|---------|------|-----|----|-------|------|-----|----|
|                     | Mean   | sd   | se   | N  | Mean    | sd   | se  | N  | Mean  | sd   | se  | N  |
| Neutral–congruent   | 490    | 57.1 | 8.9  | 41 | 453     | 36.7 | 7.8 | 22 | 479   | 44.1 | 7.0 | 40 |
| Neutral–incongruent | 528    | 65.7 | 10.3 | 41 | 523     | 38.3 | 8.2 | 22 | 542   | 54.7 | 8.6 | 40 |
| Neutral–baseline    | 497    | 57.7 | 9.0  | 41 | 444     | 34.7 | 7.4 | 22 | 494   | 52.1 | 8.2 | 40 |
| Fear–congruent      | 492    | 56.9 | 8.9  | 41 | 453     | 34.5 | 7.4 | 22 | 484   | 45.9 | 7.3 | 40 |
| Fear–incongruent    | 528    | 68.7 | 10.7 | 41 | 520     | 36.5 | 7.8 | 22 | 537   | 51.4 | 8.1 | 40 |
| Fear–baseline       | 498    | 59.2 | 9.2  | 41 | 440     | 34.7 | 7.4 | 22 | 491   | 44.9 | 7.1 | 40 |
| Sad–congruent       | 495    | 61.9 | 9.7  | 41 | 454     | 37.7 | 8.0 | 22 | 484   | 45.3 | 7.2 | 40 |
| Sad–incongruent     | 516    | 66.4 | 10.4 | 41 | 519     | 38.1 | 8.1 | 22 | 534   | 48.5 | 7.7 | 40 |
| Sad–baseline        | 501    | 60.2 | 9.4  | 41 | 449     | 34.4 | 7.3 | 22 | 496   | 47.8 | 7.6 | 40 |



**Table 3**

Statistics (T values and two-sided p values, i.e. significance level) of post-hoc contrasts (one-sample t tests) between interference scores of different affect conditions, separately for the three different task paradigms.

| Comparison/contrast | Task    | t value | p (two-sided) |
|---------------------|---------|---------|---------------|
| Neutral–sad         | Stroop  | 3.180   | .003          |
|                     | Flanker | 2.599   | .017          |
|                     | Simon   | 2.926   | .006          |
| Fear–sad            | Stroop  | 2.671   | .011          |
|                     | Flanker | 2.487   | .021          |
|                     | Simon   | 1.786   | .082          |
| Fear–neutral        | Stroop  | 0.216   | .830          |
|                     | Flanker | −0.087  | .932          |
|                     | Simon   | 0.742   | .462          |

for each task, revealed a significant effect of affect condition on the amount of incongruity interference (Stroop:  $F(2,80) = 5.362$ ;  $p = .007$ ; Flanker:  $F(2,42) = 3.388$ ;  $p = .043$ ; Simon:  $F(2,78) = 3.817$ ;  $p = .026$ ). These results indicate a similar modulation of interference by affect across all tasks. Finally, post-hoc t-tests (one-sample t-tests) determined a consistently reduced interference effect in the sadness condition compared to the neutral affect condition and also compared to the fear condition in all three tasks. Interference effects of the fear condition and the neutral affect condition, on the other hand, did not differ to a statistically significant extent in any task (for exact statistics of the single contrasts, see Table 3).

### 3.2. Error rates

Error rates (ERs) of the different experimental conditions are listed in Table 4, separately for the three tasks. At the descriptive level, all tasks across all affect conditions exhibited incongruity interference in terms of increased ERs for incongruent trials compared to both baseline and congruent trials. In the neutral affect condition, ER of congruent trials was consistently reduced compared to ER in

**Table 4**

Error rates (percentages of wrong responses and corresponding standard errors) in the different experimental (cognitive and emotional) conditions, separately for the three different conflict task paradigms (Stroop, Flanker, and Simon).

| Task    | Affect condition | Cognitive condition | Error% | SE  |
|---------|------------------|---------------------|--------|-----|
| Stroop  | Neutral          | Congruent           | 1.2    | 0.3 |
|         |                  | Incongruent         | 3.9    | 0.6 |
|         |                  | Baseline            | 2.0    | 0.4 |
|         | Fear             | Congruent           | 1.7    | 0.4 |
|         |                  | Incongruent         | 3.3    | 0.6 |
|         |                  | Baseline            | 1.3    | 0.3 |
|         | Sad              | Congruent           | 1.8    | 0.4 |
|         |                  | Incongruent         | 3.5    | 0.6 |
|         |                  | Baseline            | 1.9    | 0.4 |
| Flanker | Neutral          | Congruent           | 0.3    | 0.2 |
|         |                  | Incongruent         | 5.1    | 1.4 |
|         |                  | Baseline            | 1.0    | 0.3 |
|         | Fear             | Congruent           | 0.8    | 0.4 |
|         |                  | Incongruent         | 5.1    | 1.5 |
|         |                  | Baseline            | 0.9    | 0.4 |
|         | Sad              | Congruent           | 0.3    | 0.2 |
|         |                  | Incongruent         | 6.05   | 1.8 |
|         |                  | Baseline            | 0.6    | 0.3 |
| Simon   | Neutral          | Congruent           | 0.4    | 0.2 |
|         |                  | Incongruent         | 5.4    | 0.9 |
|         |                  | Baseline            | 0.6    | 0.3 |
|         | Fear             | Congruent           | 0.4    | 0.2 |
|         |                  | Incongruent         | 6.0    | 0.8 |
|         |                  | Baseline            | 0.2    | 0.1 |
|         | Sad              | Congruent           | 0.8    | 0.3 |
|         |                  | Incongruent         | 3.9    | 0.6 |
|         |                  | Baseline            | 0.6    | 0.2 |

baseline trials across tasks, indicating congruity facilitation. In the negative affect conditions, however, ERs were partly increased for congruent compared to baseline trials, leading to negative facilitation coefficients.

The omnibus ANOVA (affect  $\times$  cognitive condition  $\times$  task) of the error rates revealed a significant main effect of cognitive condition, while the interaction between affect condition and cognitive condition did not reach the level of significance. Instead, there was a significant three-way interaction. This suggests that the expected interaction effect between affect condition and congruency—which was highly robust in the RT data—is additionally modulated by the task type (for exact statistics of the omnibus ANOVA, see Table 2). In order to further elucidate this effect, we conducted separate two-way ANOVAs for the three tasks. The interaction between affect and cognitive condition was only significant in the Simon task but neither in the Stroop nor in the Flanker task (Stroop:  $F(4,160) = 0.950$ ;  $p = .436$ ; Flanker:  $F(4,84) = 0.886$ ;  $p = .476$ ; Simon:  $F(4,156) = 5.261$ ;  $p = .001$ ). More specific post-hoc ANOVAs for the Simon task confirmed a significant modulation of incongruity interference by affect ( $F(2,78) = 5.371$ ;  $p = .007$ ), but not of congruity facilitation ( $F(2,78) = 1.251$ ;  $p = .292$ ). The significant ANOVA finding was further specified by post-hoc t-tests which confirmed significantly reduced interference in the sadness condition compared to both the neutral affect ( $T = 2.098$ ;  $p = .042$ ) and the fear condition ( $T = 3.066$ ;  $p = .004$ ). The difference between the fear and the neutral affect condition was not significant ( $T = 1.320$ ;  $p = .195$ ).

## 4. Discussion

### 4.1. General

In the present work, we sought to test for an antagonistic influence of threat-relevant and threat-irrelevant negative affect—fear and sadness—on the neural mechanisms of cognitive control. As theoretical framework, the study refers to the conception of adaptive goal-directed action in a changing environment as requiring a context-sensitive balance between selection (of goal-relevant information) and monitoring (for potentially significant events outside the goal-relevant attention focus), here shortly referred to as SMB (selection-monitoring-balance). We expected that fear and sadness would shift the SMB in opposite directions, emphasizing monitoring and selection, respectively. For our purpose, we adopted three different interference task paradigms, two of which—a Stroop and a Flanker task—included *stimulus-based conflict* which is resolved by selective attentional processing and, thus, provides a direct behavioral measure of the SMB's emphasis. The third interference task paradigm was a Simon task and included so-called *response-based conflict* which is resolved by primarily motor-related control processes. The parallel adoption of different conflict tasks allowed us to look whether the influence of negative affect is comparable (i.e. analogous) across different levels of cognitive processing, i.e. for the selection of sensory stimuli and the selection of motor responses. In this context, Egner et al. (2007) provided convincing evidence that the human brain is endowed with independent control mechanisms which are recruited in a context-sensitive manner for the resolution of stimulus-based and response-based conflict.

Basically, all of the adopted interference task paradigms showed reliable conflict effects (performance decrements for incongruent trials compared to congruent or baseline trials). Our results thus confirm that the tasks indeed involved the control processes of interest which we expected to be specifically modulated by the adopted affect priming procedure. Important to note, condition effects in the flanker task were partly unexpected. More specifically, we found prolonged (rather than reduced) RTs in the congruency condition compared to the baseline condition. This finding suggests that the congruent flanker stimuli of the adopted stimulus set—compared to the less complex baseline flanker stimuli consisting of “simple lines”—imposed enhanced

requirements on the visual and/or attentional neural systems. Such enhanced processing demand may have evoked interference similarly to the incongruency condition. In line with this assumption, Milham and Banich (2005) found enhanced activity in a posterior division of the ACC in relation to both incongruent and congruent trials in a Stroop task. The authors likewise concluded that attentional demands may be similarly increased on both incongruent and congruent trials as both conditions may involve attentional competition and, thus, may share substantial procedural overlap (see also Badzakova-Trajkov et al., 2009; Melcher & Gruber, 2006; Milham et al., 2003). Due to the RT prolongation during congruent flanker trials, we only considered the modulation of Flanker interference by negative affect and excluded the Flanker task from the analysis of facilitation effects.

But why expecting a differential impact of threat-relevant and threat-irrelevant negative affect on the SMB at all? Situations of threat or danger can be reasonably considered to call for an emphasis on monitoring that enables immediate redirection(s) of attention and, in turn, immediate behavioral adaptation to situational changes that might threaten an organism's well-being or survival (Ohman, 1997). On the other hand, grief or sadness that occurs in threat-irrelevant situations can be assumed to involve a need to process the respective dolorous event. This mental process could be disturbed if an adequate level of selection would not reduce distractibility (cf. Andrews et al., 2007). Basically, the present study strongly supports our expectation that threat-irrelevant negative affect (i.e. priming of sadness) specifically influences the SMB. However, the priming of threat-relevant negative affect (i.e. priming of fear) provided ambiguous findings.

#### 4.2. Effect of sadness priming

Across all task paradigms, we consistently observed a substantial reduction of RT conflict in the sadness condition compared to the neutral affect condition, while this effect was most pronounced in the Stroop task paradigm. The fact that RT conflict reduction was observed both in the Stroop and in the Flanker task suggests that the strengthening of attentional selection by sadness concerns both feature attention (i.e. the selection of feature dimensions or feature values) and spatial attention (the selection of spatial locations) which are presumably recruited to resolve stimulus-based conflict in the Stroop and Flanker task, respectively. Moreover, a statistically significant effect of conflict reduction was not only present in the adopted stimulus-based conflict tasks but also in the spatial conflict task that involves response-based rather than stimulus-based conflict. In this context, conflict reduction by sadness priming was not only observed in RTs but also in the error rate data during the Simon task.

Taken together, our findings suggest that control strengthening by sadness extends across different levels of cognitive processing and concerns both the selection of sensory stimuli (i.e. attentional control) and the selection of motor responses (i.e. motor control). This conclusion, however, may be considered slightly limited due to the stimulus set which we adopted for the spatial conflict paradigm (Simon task). More specifically, the adopted Simon stimuli included feature overlap with a varying congruity relation not only between response side and presentation location but also between arrow direction (target stimulus) and presentation location. Because these two congruity relationships were concordant (i.e. either both congruent or both incongruent), the observed interference effect in the Simon task may partly represent stimulus-based conflict, as well (cf. Hasbroucq & Guiard, 1991). Consequently, one may assume that the reduction of interference partly represents another marker of increased attentional control rather than increased motor control. Against this argument, however, prior work strongly suggests that interference effects in spatial conflict paradigms occur independently of stimulus–stimulus (i.e. stimulus–location) congruity and therefore most probably represent response-based conflict (cf. Hommel, 1995). Accordingly, the reduction

of Simon interference following sadness priming in the present study most probably reflects increased motor selection and, hence, taps a process different from the one underlying conflict reduction in the two stimulus-based conflict tasks (Stroop and Flanker), which obviously both require sensory selection. This assumption is further substantiated by the fact that specifically the Simon task (but not the Stroop neither the Flanker task) exhibited conflict reduction in the error rate data following sadness priming (in addition to the RT interference reduction which equivalently occurred across all task paradigms). Thereby, it is intuitively highly plausible that response-based or motor conflict is more tightly related to error rate than stimulus-based or sensory conflict, so that these results validate the operational distinction of conflict types in the present study.

Basically, although increased selection of relevant sensory information or motor responses reduces interference and promotes behavioral stability, it likely incurs a cost when flexible switching of goals or the detection of significant stimuli outside the current goal-related focus is required (cf. Dreisbach & Goschke, 2004; Goschke and Dreisbach, 2008). However, despite the obvious antagonisms between selection and monitoring, it may be not appropriate to assume a strict reciprocity between these processes in terms of increasing one directly decreases the other, and vice versa. Accordingly, strictly speaking, the present finding of increased selection after sadness priming does not allow to conclude—but only to tentatively conjecture—that sadness priming decreases monitoring (bottom-up processing) which thus needs own empirical evidence. This gives rise to the following two future directions. First, future studies should specifically test for an inhibitory influence of sadness priming on cognitive flexibility (and also motor flexibility) measures like e.g. set shifting ability. Second and more specifically, future studies should further elucidate the relationship between (top-down) selection and (bottom-up) monitoring (i.e. the exact characteristics of the SMB) in different contexts. This may reveal a rather unspecific antagonism or a (one- or bidirectional) reciprocity in terms of increasing one (to a certain degree) would directly decrease the other (to a similar degree).

#### 4.3. Effect of fear priming

Unlike our expectation and theoretical reasoning, we could not replicate the substantial increase of stimulus-based conflict by fear induction in the present work as it was demonstrated in prior neuroimaging studies (e.g. Blair et al., 2007; Melcher et al., 2011). In a prior study of our working group (Melcher et al., 2011), subjects were primed with threat-relevant negative affect by stimuli of the IAPS (International Affective Picture System) during the performance of a color word Stroop task. This affective priming selectively impaired performance on interference trials whereas behavioral measures of non-interference trials were roughly identical in the negative and neutral affective condition. At the same time, the negative affect condition exhibited incremental (increased and additional) interference-related brain activation in control-related regions of prefrontal and parietal cortices. We interpreted these activations as enhanced efforts to compensate for the control weakening by the affect priming. The absence of an effect for fearful faces in the present study clearly indicates that affect priming by emotional facial expressions is not comparable to affect priming by the presentation of negative-arousing IAPS stimuli. More specifically, the present findings suggest that emotional facial expressions are better suited to efficiently induce threat-irrelevant negative affect whereas threat-relevant negative affect is more efficiently elicited by stimuli that depict a proper threat or threatening situation rather than the facial response to a threat. Already in prior studies, the presentation of fearful faces appeared to be a relatively mild form of fear induction. The neuro-cognitive system may thus be endowed with effective (prefrontal) control mechanisms to completely compensate—or even overcompensate—for the putatively related inhibitive influence on the attentional system (cf.

Dennis & Chen, 2007). When more intense priming procedures or more striking emotional stimuli are applied, the effect seems to be more unitary providing a consistent and substantial impairment of selective attentional processing (Blair et al., 2007; Melcher et al., 2011).

Important to note, affective responses to observed facial expressions may be not adequately conceived as “mood contagion” in that a congruent affect is elicited in the observer, but rather as responses to the expressions’ signal value or communicative information content (cf. Hatfield et al., 1994). In this context, head orientation or gaze direction of faces has been shown to be an important moderator of the signal value of facial expressions, especially for faces expressing threat-relevant negative affect. More specifically, a fearful facial expression will elicit more fear when the head is averted from the observer rather than directed to him (e.g. Hess et al., 2007). Behind this moderator effect is the rationale that an averted fearful face signals an occurrence in the environment (located in gaze direction of the person exhibiting the fear expression) that may similarly threaten the observer, whereas a fearful face oriented head-on to the observer does not indicate such a potential threat (but probably only that the emotion expresser is startled by the observer himself). As all affect stimuli applied in the current study depicted faces in a direct angle to the observer, this might at least in part account for the weak and ambiguous effects of the fear condition. Since non-averted fearful faces do not necessarily indicate a threat to the observer, one may speculate that such stimuli rather elicit pity or compassion for the emotion expresser (who seemingly is in a miserable situation) and, hence, likewise elicit threat-irrelevant forms of negative affect. The latter might also explain why in the current work fear priming, against our expectation, was partly associated with slight conflict reduction as index of increased selection.

Important to note, there are some prior studies that—against our prior findings (Melcher et al., 2011) and expectations for the present work—showed significantly increased selection or focusing following the priming of threat-relevant negative affect by non-face stimuli (e.g. Gable & Harmon-Jones, 2010; van Steenbergen et al., 2011). More specifically, in the study by van Steenbergen et al. (2011), subjects were emotionally primed with pictures (from the IAPS) of either positive, threat-relevant negative, or neutral valence while performing a saccade task. In the negative (compared to the neutral) affect condition, the RT difference between anti-saccades and pro-saccades was significantly reduced (mainly driven by slowed pro-saccades) which can be taken as evidence for increased selectivity. Moreover, the authors showed that this effect was independent of the subjects’ arousal level (as measured by pupil dilation) suggesting its specific relation to their emotional state. RT decrements in anti-saccade trials can be reasonably considered as an instance of response-based conflict which, similar to Simon conflict, is based on the (in-)compatibility relation between (side of) the stimulus location and (side of) the required motor response. Therefore, considering the study by van Steenbergen and the present work simultaneously, one may assume that motor control is unitarily (rather than antagonistically) modulated by threat-relevant and threat-irrelevant negative affect with both increasing selectivity. However, van Steenbergen et al. presented threat-relevant negative pictures alternating with both neutral and positive pictures while we—in both, the present work and also the study by Melcher et al. (2011)—did not include positive pictures in the paradigm.

Generally, inconsistent effects of the priming of threat-relevant negative affect across studies may be due to the different task contexts due to additional affect conditions of the adopted paradigms. Likewise, similar modulation effects may be assumed for the priming of threat-irrelevant negative affect and positive affect. Such interaction or context effects could provide a highly interesting and fruitful issue for future studies, both methodologically and theoretically, as well as help to reconcile putatively contradictory findings of the literature.

## 5. Summary and conclusion

Across all adopted task paradigms, we found strong evidence for increased attentional selection (and reduced monitoring) following the priming of threat-irrelevant negative affect (i.e. sadness). Our findings suggest that increased selection in a threat-irrelevant negative affective state similarly concerns stimulus-based attention (i.e. selection of stimuli or stimulus aspects) and spatial attention (i.e. selection of spatial position or location) as well as motor control processes (i.e. selection of motor responses). While the priming of sadness lead to increased selection in the present work, prior fMRI studies provide strong evidence for an inverse effect (i.e. reduced selection and increased monitoring) of negative affect priming when using threat-relevant and arousing emotional stimuli (e.g. Blair et al., 2007; Melcher et al., 2011). Taken together, these studies support an antagonistic modulation of cognitive control (i.e. the SMB) by threat-relevant and threat-irrelevant negative affect leading to increased monitoring and selection, respectively. In the present work, however, we could not replicate findings supporting the assumption of increased monitoring related to fear priming. We explain this lack of a definite effect of fear priming by the applied affective stimulus material. More specifically, the presentation of fearful faces can be assumed to represent a relatively mild form of fear induction, particularly in comparison with the presentation of negative and arousing IAPS pictures. Moreover, head orientation of the depicted faces (i.e. their communicative value) and also the specific task context given by the other included affect conditions may play an additional modulatory role in this context. Despite a non-significant effect of fear priming in the present work, the neuroscientific and psychological literature provides ample evidence that fear as well as trait and state anxiety substantially interfere with attentional selection leading to an increased susceptibility to task-irrelevant distraction (Eastwood et al., 2003; Fox et al., 2001; Meinhardt & Pekrun, 2003; Melcher et al., 2011).

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