Trait anxiety and the dynamics of attentional control

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\section*{Abstract}

According to recent theoretical approaches dispositional anxiety is fundamentally linked to neural mechanisms of cognitive control (Braver et al., 2007; Eysenck et al., 2007). The present study was conducted to further investigate this topic by focusing on the relation between trait anxiety, conflict-processing and dynamic adjustments in attentional allocation. Participants completed a modified version of the face–word Stroop task while an electroencephalogram was recorded. We analyzed behavioral and electrophysiological correlates of conflict processing and conflict-driven modulations in target and distractor processing. Anxiety was not related to general conflict-sensitivity but to individual differences in conflict-driven adjustments in attentional allocation: following a high level of stimulus–response conflict, highly anxious participants allocated more attentional resources to the processing of predominantly task-relevant information and withdrew attention from the processing of predominantly task-irrelevant information. Thus, trait anxiety appears to be closely related to individual differences in dynamic adjustments of attentional control.

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\section*{1. Introduction}

In their influential attentional control theory (ACT), Eysenck and colleagues (Derakshan and Eysenck, 2009; Eysenck et al., 2007) have recently claimed that anxiety as personality trait is closely related to individual differences in higher-order functions of cognitive control. Specifically, high trait anxiety is thought to bias the balance between a goal-directed attention system and a stimulus-driven attention system in favor of the latter (also see, Corbetta and Shulman, 2002). Consequently, task-irrelevant information should be more intrusive in highly anxious compared to low anxious individuals. Moreover, Eysenck et al. hypothesize that the deficit in attentional control should affect processing efficiency (as typically indexed by reaction times [RTs]) rather than effectiveness (as typically indexed by error-rates), especially in tasks requiring inhibitory control (i.e., inhibiting the distracting influence of task-irrelevant information) and/or attentional set shifting (i.e., shifting attention between multiple task rules). A further postulate of the ACT is that anxious subjects can compensate for the deficiencies in attentional control by recruiting additional cognitive resources. On the neuronal level this should lead to an enhanced activity of brain circuits involved in cognitive control.

By now these theoretical assumptions have received considerable empirical support by studies using behavioral indices of attentional processing. For instance, there is a large body of research, demonstrating that emotionally arousing but task-irrelevant stimuli are more intrusive in highly compared to low anxious subjects (Bar-Haim et al., 2007). Other findings indicate that high anxiety is indeed associated with a general deficit in inhibitory control and attentional set-shifting (e.g., Ansari et al., 2008; Derakshan et al., 2009b; Fox, 1993, 1994; Wieser et al., 2009; Wood et al., 2001) and that these deficits affect processing efficiency rather than processing effectiveness (Derakshan et al., 2009a).

In contrast to this rather homogeneous picture of behavioral findings, prior studies investigating the link between anxiety and neural correlates of attention and cognitive control have yielded more inconsistent results. While some authors report an increased recruitment of neural control mechanisms in highly trait anxious subjects (e.g., Ansari and Derakshan, 2011; Basten et al., 2011; Gray and Braver, 2002; Telzer et al., 2008) others report the opposite (e.g., Bishop, 2009; Bishop et al., 2004; Klumpp et al., 2011). Recent theoretical and empirical works suggest that these inconsistencies are partly caused by disregarding the temporal dynamics of cognitive control. For instance, Braver et al. (2007) postulated that low and highly anxious individuals generally differ in the
way they exert top–down control. Specifically, highly anxious subjects are proposed to recruit neurocognitive control resources in a transient and reactive manner (i.e., only when control is needed) whereas low anxious subjects are thought to engage control in a rather sustained and proactive way (also see, Fales et al., 2008). The assumption of a reactive recruitment of cognitive-control in highly anxious subjects is also supported by data from our group (Osinsky et al., 2010). In this study, we investigated dynamic adjustments in conflict-processing, measuring event-related potentials (ERP) of the electroencephalogram (EEG) while subjects performed a face–word version of the Stroop task. Results of this study indicate that highly anxious subjects only more strongly engage neural mechanisms of conflict-monitoring when previously exposed to a high level of stimulus–response conflict. Similarly, findings from two other recent studies suggest that highly anxious subjects more strongly recruit mechanisms of conflict-monitoring (Dennis and Chen, 2009) and inhibitory control (Hardin et al., 2009) after seeing fearful faces. In sum these studies indicate that highly anxious subjects especially show a reactive and compensatory recruitment of control resources and goal-directed attention when previously exposed to a highly cognitive demanding or distracting event.

The present study was conducted to further investigate the link between anxiety and dynamic adjustments in attentional processing. Our main purposes were (1) to investigate the potential relation between anxiety and sensitivity for distracting and task-irrelevant information and (2) to examine how a potential reactive recruitment of cognitive control in highly anxious individuals affects dynamic adjustments in attentional processing. We recorded EEG while subjects performed a modified version of the face–word Stroop task (see Fig. 1). In most trials of this task, a single female or male face was combined with the word man or woman written across the face, resulting in a congruent or incongruent face–word pairing (hereafter ‘face–word stimuli’). In these trials, subjects were asked to discriminate the gender of the face by button-press. In the remaining infrequent trials only a single face (hereafter ‘face-only stimuli’) or word (hereafter ‘word-only stimuli’) was presented, requiring the same discrimination as in the frequent face–word trials. This task allows for testing several predictions of the ACT.

First, highly anxious subjects should be more sensitive to distracting and task-irrelevant information, resulting in higher behavioral interference effects in the face–word trials. This should especially be seen in RTs as an index of processing efficiency but not in hit rates (HRs) as an index of processing effectiveness. Moreover, conflict-related brain potentials should increase with the level of anxiety. We therefore analyzed the so-called conflict-N450 and the conflict-SP (sustained potential) which are typically observed in the Stroop task. The conflict-N450 is a negative-going ERP deflection, typically observed at central scalp sites. It occurs about 450 ms after the onset of an incongruent stimulus and probably reflects processes of conflict-monitoring in the anterior cingulate cortex (Badzakova-Trajkov et al., 2009; Bruchmann et al., 2010; Hanslmayr et al., 2008; Liotti et al., 2000; Rebai et al., 1997; West, 2003; West et al., 2005). It is directly followed by the more parietal positive going conflict-SP which has also been linked to conflict-monitoring and to the execution of top–down control (Liotti et al., 2000; West, 2003; West et al., 2005).

To investigate the link between anxiety and dynamic adjustments in attentional processing we analyzed behavioral indices and ERPs in the face-only and word-only trials. Using similar conflict-evoking tasks, previous studies have demonstrated that, following a high level of conflict between task-relevant and task-irrelevant stimuli, attention is more strongly oriented toward target stimuli and/or away from distractor stimuli (e.g., Egner and Hirsch, 2005; Scerif et al., 2006). According to the ACT (Eysenck et al., 2007) and prior findings from our group (Osinsky et al., 2010), such reactive recruitment of attentional resources should be increased in highly trait anxious subjects. In our task, this should result in a facilitated processing of the predominantly task-relevant face dimension and/or a suppressed processing of the predominantly task-irrelevant word-dimension. We therefore analyzed two frequently studied ERP deflections related to face- and word-processing, namely the N170 and the N400, respectively. The N170 is a negative-going deflection which peaks about 170 ms after stimulus onset and is especially pronounced for face stimuli (Bentin et al., 1996). It probably reflects processes of structural face encoding in temporo-occipital brain areas and is sensitive to attentional processes (Hole and Bourne, 2010; Holmes et al., 2003; Mohamed et al., 2009). After a high level of conflict, a top–down attentional amplification in processing of the predominantly task-relevant face dimension should therefore lead to an elevated N170 and this effect should be increased in highly anxious subjects. The N400 has been classically observed in sentence reading tasks as a relative negative-going deflection about 400 ms after the onset of a word that does not match its preceding semantic context (Kutas and Hillyard, 1980). This ERP component is inversely related to the ease of accessing semantic memory representations and, consequently, to the ease of processing a word’s meaning (Federmeier, 2007; Kutas and Federmeier, 2000). Accordingly, the N400 can be used as an index for the depth of word processing (i.e., the smaller the N400 amplitude the easier word processing; see, e.g., Stewart et al., 2010). In our task, a reactive suppression of the predominantly task-irrelevant word dimension may therefore lead to an N400 effect, that is, more negative amplitudes when words are
preceded by a high level of conflict. Again, this effect should be especially pronounced when trait anxiety is high.

In sum our hypotheses were as follows:

i. Highly compared to low anxious subjects should be more sensitive to distracting information as indicated by higher behavioral interference effects (in RTs rather than in HRs) and higher magnitudes of the conflict-N450 and the conflict-SP.

ii. Following a stimulus–response conflict in the face–word trials highly compared to low anxious subjects should show a reactive recruitment of top–down control as indexed by a facilitated processing of face-only stimuli (higher N170, faster face discrimination) and a suppressed processing of word-only stimuli (higher N400, slower word discrimination).

2. Methods

2.1. Participants and general procedure

Initially, 36 students of the University of Giessen participated in this study. For 5 participants not enough artifact-free trials per condition (>20) were available. The final sample therefore consisted of 31 participants (18 female) with a mean age of 24.6 years (SD = 2.6). All were right-handed, native German speakers with a normal or corrected to normal vision and reported to be free of any diagnosed mental or neurological disorder. Participants gave informed written consent before completing a questionnaire for anxiety assessment. Afterwards they performed the behavioral task while an EEG was recorded. Finally, they either received a monetary compensation of 15€ or course credit. The study was approved by the ethics committee of the German Psychological Society.

2.2. Anxiety assessment

Dispositional anxiety was measured with the German trait scale of Spielberger’s Trait State Anxiety Inventory (Laux et al., 1981). This scale comprises 20 items for which respondents rate their anxiety on a four-point format, resulting in a maximum score of 80 and a minimum score of 20. In our sample, scores ranged between 27 and 62 with a mean score of 38.9 (SD = 9.7). These values are similar to those previously found in other student samples (e.g., Ansari et al., 2008) and much lower than those found in clinical samples (e.g., Fisher and Durham, 1999).

2.3. Behavioral task and analyses

In the behavioral task (see Fig. 1) three types of stimuli were centrally presented on a computer screen: face-only stimuli (a single male or female face), word-only stimuli (the word “Mann” or “Frau” in red font; German words for man or woman, respectively), or face–word pairs (a combination of both face and word with the word being written across the face). In the latter, the face–word combination could either be congruent or incongruent. For the face–word pairs and face-only stimuli subjects were instructed to discriminate the sex of the presented faces (6 male and 6 female greyscale neutral faces, taken from the Karolinska Directed Emotional Faces Database (Lundqvist et al., 1998)). In contrast, participants should react to the word meaning of the word-only stimuli.

In total, 960 critical trials were presented in 10 blocks. Each block comprised 72 face–word stimuli (36 congruent, 36 incongruent), 12 face-only stimuli (6 male and 6 female), and 12 word-only stimuli (6 “Mann” and 6 “Frau”). Thus, the face-dimension was predominantly task-relevant whereas the word-dimension was predominantly task-irrelevant. Preceding each word-only or face-only stimulus a sequence of at least two but not more than five congruent or incongruent face–word stimuli was presented, resulting in the following four trial categories: word-only trials preceded by congruent face–word pairs, word-only trials preceded by incongruent face–word pairs, face-only trials preceded by congruent face–word pairs, and face-only trials preceded by incongruent face–word pairs. Each of these categories comprised 60 trials (6 trials per block) which were balanced for the current and preceding response-hand (25% left–left; 25% left–right; 25% right–right; 25% right–left). The average number of preceding congruent or incongruent face–word pairs was equal for the four categories (2.33). There were no direct repetitions of the same face. At the beginning of each block, 16 (block one) or four face–word practice trials (block 2–10) were presented. For these practice trials two separate faces (one male and one female) were chosen. The same automatically generated pseudorandom trial-order was used for all participants.

In each trial the stimulus lasted until the response was given. In the 1500 ms inter-trial-interval a white fixation cross appeared at the center of the screen. Reactions were given with two response buttons (male = left index finger; female = right index finger) on a Cedrus RB730 response box (Cedrus Corp., San Pedro, CA, USA). All stimuli were presented on a 17-in. monitor with a black background. Stimulus presentation and response recording was performed by a Pentium [Intel Corp., Santa Clara, CA, USA] based PC and Presentation software (Neurobehavioral Systems, Albany, CA, USA).

All error- and post-error trials were excluded from RT analyses to control for confounding effects of post-error slowing (Laming, 1968; Rabbit and Rogers, 1977). The same applied for all trials with response latencies below 200 ms or above 2 s. For statistical analyses, individual mean RTs as well as mean HRs (percentage of correct responses) were calculated for word-only, face-only and face–word trials. All statistical analyses were conducted with PASW 18 software (IBM Corp., Somer, NY, USA).

2.4. EEG recordings and ERP analyses

EEG (analogue band-pass: 0.1–250 Hz; sampling rate: 1000 Hz) was recorded at 29 scalp sites, using Ag/AgCl electrodes (ActiCap, Brain Products, Gilching, Germany) and a BrainAmp DC amplifier (Brain Products). Impedances were kept below 5 kΩ. All channels were referenced online to the nose tip. The horizontal and vertical electrooculograms were recorded to detect ocular artifacts. Offline analyses were conducted with Brain Vision Analyzer 2 software (Brain Products). Channels were referenced to the averaged mastoids and filtered with a 30 Hz low-pass and a 0.15 Hz high-pass filter. Stimulus-locked epochs (~200 to 800 ms) were built for face–word, face-only, and word-only stimuli. These epochs were automatically scanned for artifacts and excluded from further analyses if necessary (exclusion criteria: max. voltage differences within epoch > 100 µV, max. allowed voltage step of 20 µV/ms, minimal activity of 0.5 µV). Finally, individual average waves were calculated.

For face–word stimuli the conflict-N450 and the conflict-SP were quantified at electrodes Fz, Cz and Pz as the mean-amplitudes in the time-windows between 350–450 ms and 500–800 ms post-stimulus, respectively. These time-windows and electrodes were chosen based on previous studies (e.g., Lioi et al., 2000; Osinsky et al., 2010) and visual inspection of the grand average waves. For the face-only stimuli the N170 was quantified as the most negative individual peak amplitude in the time-window between 120 and 220 ms post-stimulus at electrodes P7, P8, P09, and P10 (Rossion and Jacques, 2008). For one male participant no clear negative peak could be detected. This participant was therefore excluded from N170 analyses. Based on visual inspection and previous research (Kutas and Federmeier, 2011) we analyzed the N400 for the word-only stimuli as the mean amplitude between 400 and 500 ms post-stimulus at centro-parietal electrodes C3, C4, CP1, CP2, P3 and P4.

3. Results

3.1. Behavioral results

Descriptive statistics of RTs and HRs are listed in Table 1. The high HRs in the face–word (minimum = 81.0 percent, maximum = 98.0 percent) and face-only condition (minimum = 85.0 percent, maximum = 100 percent) indicate that participants were generally able to correctly discriminate the face stimuli.

3.1.1. Face–word stimuli

t-Tests were conducted to compare congruent and incongruent face–word pairs with respect to RTs and HRs. Responses in congruent compared to incongruent face–word trials were significantly faster, t(30) = 14.67, p < .001, Cohen’s d = .80. Moreover, participants committed fewer errors in congruent compared to incongruent trials, χ²(30) = 7.11, p < .001, d = 1.38. To analyze the relation between trait anxiety and the magnitude of behavioral interference effects, we calculate individual difference scores (incongruent minus congruent). Neither for RTs (Pearson product–moment correlation r = −.10, p = .60) nor for HRs (r = −.07, p = .72) were these scores significantly correlated with anxiety.

3.1.2. Face-only stimuli

Across all participants there was a trend for faster discrimination of face-only stimuli when these were preceded by congruent compared to incongruent face–word pairs, t(30) = 1.88, p = .07, d = .09. There was no effect of preceding face–word congruency on HRs, t(30) = 0.25, p = .80. Again, we calculated individual difference scores (preceding incongruent minus preceding congruent) to quantify the size of the context effect. Interestingly, there was a negative correlation between anxiety and the context-effect in RTs (r = −.36, df = 29, p = .05) but not in HRs (r = .13, p = .48). As illustrated in Fig. 2, an increase in anxiety was associated with a...
relative speeding in face-discrimination in the context of preceding incongruent compared to congruent face–word pairs.

3.1.3. Word-only stimuli

Word discrimination was significantly slower in the context of a preceding sequence of incongruent compared to congruent face–word pairs, t(30) = 4.53, p < .001, d = 0.26. Moreover, participants tended to respond less accurate when the current word-only stimulus was preceded by incongruent compared to congruent face–word trials, t(30) = 1.72, p = .096, d = .26. Neither for RTs (r = .10, p = .58) nor for accuracy (r = .08, p = .66) was the preceding context effect significantly correlated with anxiety.

3.2. ERP results

3.2.1. Conflict-N450 and conflict-SP

Grand-average waveforms for face–word trials are plotted in Fig. 3. To analyze the conflict-N450 and conflict-SP we conducted 3 × 2 repeated measure ANOVAs with the within-subject factors ‘electrode’ (Fz, Cz, and Pz) and ‘congruency’ (congruent and incongruent). We observed the typical conflict-N450 as a more negative-going amplitude to incongruent compared to congruent trials in the time-window between 350 and 450 ms after the onset of the face–word stimulus, F(1,30) = 41.66, p < .001, n²p = .58. Moreover, there was a significant ‘electrode’×‘congruency’ interaction, F(2,60) = 19.76, p < .001, n²p = .40. In detail, the size of the N450 congruency-effect increased from frontal (mean difference = −0.73 µV, SD = 1.22; t(30) = 3.31, p < .01) over central (mean difference = −1.56 µV, SD = 1.63; t(30) = 5.33, p < .001) to parietal sites (mean difference = −2.06 µV, SD = 1.41; t(30) = 8.16, p < .001).

In the 500–800 ms time-window the conflict-SP was evident as more positive amplitude to incongruent compared to congruent face–word stimuli, F(1,30) = 13.04, p < .001, n²p = .30. Again there was a significant ‘electrode’×‘congruency’ interaction, F(2,60) = 11.46, p < .001, ε = 0.67, n²p = .28. Post hoc comparisons revealed that the SP increased from frontal (mean difference = 0.58 µV, SD = 1.68, t(30) = 1.94, p = .06) over central (mean difference = 0.88 µV, SD = 1.83, t(30) = 2.67, p < .05) to parietal sites (mean difference = 1.62 µV, SD = 1.69, t(30) = 5.31, p < .001).

Finally, we calculated a conflict-N450 and conflict-SP difference-score (incongruent minus congruent) at electrode Pz (where effects of face–word congruency were largest). The correlations between these scores and anxiety (conflict-N450: r = .24; conflict-SP: r = −.14) as well as behavioral interference in RTs (conflict-N450: r = −.09; conflict-SP: r = .04) and HRS (conflict-N450: r = .05; conflict-SP: r = −.03) were all small and statistically not significant (all p > .24).

3.2.2. N170

N170 peak amplitudes for the face-only stimuli were entered into 2 × 2 × 2 repeated measure ANOVA with the within-subject factors ‘hemisphere’ (left and right), ‘electrode’ (P7/P8 and PO9/PO10) and ‘preceding context’ (congruent and incongruent). The N170 was larger over the right hemisphere, F(1,29) = 11.29, p < .01, n²p = .28, and tended to be larger at electrodes P09/P010 compared to electrodes P7/P8, F(1,29) = 3.20, p = .08. Moreover, there was a significant ‘electrode’×‘preceding context’ interaction, F(1,29) = 4.54, p < .05, n²p = .14. As illustrated in Fig. 4A, the N170 at electrodes P7/P8 was larger when the preceding face–word pairings were incongruent compared to congruent, mean difference = −0.36 µV, SD = 0.93, t(29) = 2.14, p < .05. This effect was much smaller and statistically not significant at electrode P09/P010, mean difference = −0.06 µV, SD = 1.01, t(29) = 0.32, p = .75.

Table 1
Mean reaction times in ms and hit rates in percent (standard deviations in parentheses) for the three stimulus types.

<table>
<thead>
<tr>
<th></th>
<th>Face–word stimuli</th>
<th>Face-only stimuli</th>
<th>Preceded-congruent</th>
<th>Preceded-incongruent</th>
<th>Word-only stimuli</th>
<th>Preceded-congruent</th>
<th>Preceded-incongruent</th>
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<tbody>
<tr>
<td>Reaction times (ms)</td>
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<td>615 (86)</td>
<td>555 (73)</td>
<td>561 (66)</td>
<td>596 (70)</td>
<td>615 (79)</td>
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<tr>
<td>Hit rates (percent)</td>
<td>96.8 (3.1)</td>
<td>91.6 (5.3)</td>
<td>96.8 (4.3)</td>
<td>96.9 (4.0)</td>
<td>95.3 (6.0)</td>
<td>93.8 (5.4)</td>
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![Fig. 2. Scatter-plot with linear regression line for the relation between anxiety and the RT context effect (preceding incongruent minus preceding congruent) in the in the face-only condition.](image1)

![Fig. 3. Stimulus-locked grand-average waveforms at electrode Pz for the face–word stimuli as a function of face–word congruency. Voltage distributions are shown for the difference between incongruent minus congruent in the time-windows between 350–450 ms (conflict-N450) and 500–800 ms (conflict-SP).](image2)
We calculated an individual difference score (preceding incongruent minus preceding congruent), reflecting the size of the context effect at a pooling of P7/P8. As shown in Fig. 4B, this score was significantly correlated with anxiety ($r = -.36$, df = 28, $p < .05$), indicating that an increase in anxiety was associated with an increase of the N170 context effect. This pattern cannot be attributed to a single condition alone since anxiety did not significantly correlate with the absolute N170 peak amplitudes in the context of preceding congruent ($r = -.04$, $p = .84$) or incongruent face-word pairs ($r = -.16$, $p = .41$). There were no significant relations between the N170 context effect and the behavioral context effects for face-only trials (RT: $r = -.03$, $p = .88$; HR: $r = -.06$, $p = .74$). Moreover, the correlation between anxiety and the RT context effect remained stable ($r = -.36$) when partialing out the influence of the N170 context effect.

3.2.3. N400

ERP waves for word-only stimuli are plotted in Fig. 5A. Mean amplitudes between 400 and 500 ms post-stimulus were entered into a $2 \times 3 \times 2$ repeated measure ANOVA with the within-subject factors ‘hemisphere’ (left and right), ‘electrode’ (C3/C4, CP1/CP2, P3/P4) and ‘preceding context’ (incongruent and congruent). There was a significant ‘electrode’ × ‘preceding context’ interaction, $F(2,60) = 4.75$, $p < .05$, $\eta^2_p = .14$. Post hoc comparisons indicated that a relative negativity in the context of preceding incongruent compared to congruent face-word stimuli was higher at CP1/CP2 (mean difference = −0.41 µV, SD = 2.20) and P3/P4 (mean difference = −0.38 µV, SD = 1.92) compared to C3/C4 (mean difference = 0.06 µV, SD = 2.04; CP1/CP2 vs. C3/C4: $t(30) = 3.47$, $p < .01$; P3/P4 vs. C3/C4: $t(30) = 2.18$, $p < .05$). There was no significant difference in context effect between CP1/CP2 and P3/P4, $t(30) = 0.17$, $p = .87$.

We calculated a difference score (preceding incongruent minus preceding congruent) for the N400 context effect at a pooling of CP1/CP2 (where the context effect was descriptively highest). A negative correlation between this score and anxiety was observed, such that greater anxiety was associated with a larger effect of preceding context on the N400 ($r = -.36$, df = 29, $p < .05$; see Fig. 5B).
The N400 context effect was not significantly correlated with the behavioral context effects in the word-only condition (RT: \( r = -0.16, p = 0.38 \); HR: \( r = 0.07, p = 0.72 \)). Again, analyses for the absolute mean amplitudes in the N400 time window revealed that the relation between anxiety and the N400 context effect cannot be attributed to a single condition since anxiety did not significantly correlate with the mean amplitude in the context of preceding congruent (\( r = -0.15, p = 0.43 \)) or incongruent face-word stimuli (\( r = 0.03, p = 0.88 \)).

4. Discussion

According to the ACT (Derakshan and Eysenck, 2009; Eysenck et al., 2007), highly trait anxious individuals are characterized by a general deficit in goal-directed attention, leading to a higher sensitivity for distracting information. However, they may compensate for this deficit by recruiting additional cognitive resources in a reactive manner. A similar assumption has been put forward by Braver et al. (2007) who postulate that low anxious subjects exert cognitive control in a sustained and proactive mode whereas highly anxious subjects rather engage top-down control in a reactive way. Based on these theoretical assumptions, the present study was conducted to further elucidate the link between trait anxiety and the recruitment of cognitive control by investigating behavioral and neural correlates of conflict processing as well as conflict-driven adjustments in attentional allocation.

One of the main hypotheses of the ACT is that task-irrelevant and distracting information should be more intrusive in highly compared to low anxious subjects. In Stroop like tasks, this should result in an increased conflict between task-relevant and task-irrelevant information, leading to higher behavioral interference effects and increased activity of neural modules involved in conflict-monitoring. In the present study, however, trait anxiety did neither significantly correlate with behavioral interference nor with the magnitude of the conflict-N450 and the conflict-SP in the face-word condition. Thus, our findings appear to be in contrast with predictions of the ACT and previous studies indicating such link between anxiety and inhibitory control (e.g., Derakshan et al., 2009a; Eysenck and Byrne, 1992; Fox, 1993, 1994; Wieser et al., 2009; Wood et al., 2001). It should be noted, however, that in some of these prior reports highly anxious subjects were only more sensitive to distracting stimuli which were emotionally high-arousing (experiment 2 in Derakshan et al., 2009b; Eysenck and Byrne, 1992; experiment 3 in Fox, 1994) whereas the distractors applied in the present study were neutral and non-arousing. Another important factor to mention is the level of cognitive load during task performance. Although we found strong behavioral interference effects in RTs and HRs across all participants, the cognitive demand during our task is probably rather low to moderate. Therefore, highly anxious subjects may have been able to directly compensate for their potential deficit in inhibitory control within incongruent trials by recruiting additional cognitive resources. Certainly more research is needed to uncover the moderating effect of cognitive load on the link between anxiety and inhibitory control, especially since previous studies on this particular topic are highly inconsistent (e.g., Bishop, 2009; Wood et al., 2001). At this point, however, we must conclude that the data for the face-word condition in our task do not support the assumption of a deficit in inhibitory control in highly anxious subjects.

A second theoretical prediction that we aimed to test in the present study is that highly compared to low anxious subjects reactively recruit attentional resources (Braver et al., 2007; Eysenck et al., 2007). Indeed, our findings point to a modulatory effect of trait anxiety on dynamic adjustments in attention following a high level of stimulus-response conflict. In detail, a high level of anxiety was associated with a relative speeding to face-only trials preceded by incongruent compared to congruent face-word pairs. This pattern may indicate a facilitation in face-processing following incongruent trials in anxious individuals. Moreover, high anxiety was linked to a conflict-driven increase in the N170 for the face-only stimuli. Such increases in N170 amplitude have been previously interpreted as indicating attentional gain in sensory processing in early stages of face perception (e.g., Holmes et al., 2003; Mohamed et al., 2009). Hence, following a sequence of conflict between task-relevant and task-irrelevant stimuli highly compared to low anxious subjects appear to allocate more processing resources to the predominant task-relevant face dimension.

Moreover, an increase in participants’ anxiety was associated with a N400 to word-only stimuli preceded by incongruent compared to congruent face-word pairs, presumably indicating a conflict-driven diminished processing of the predominant irrelevant word-dimension. However, it might be argued that the observed N400 pattern may also reflect differences between low and highly anxious participants in the P300 component. In fact, the N400 effect is typically observed in the same time range and at similar posterior electrodes as the P300 (Kutas and Federmeier, 2011). For the word-only trials we therefore conducted post hoc analyses of the P300 peak amplitude and latency in the time window between 300 and 600 ms post-stimulus at electrode CP1/CP2 (where we observed a significant relation between anxiety and, what we interpreted as, N400). Overall, there was no significant effect of preceding context on P300 latency (\( F(1,30) = 0.02, p = 0.88 \)) or peak amplitude (\( F(1,30) = 0.01, p = 0.94 \)). Moreover, there was no relation between anxiety and the individual context effect (preceding incongruent minus preceding congruent) in P300 peak latency (\( r = 0.04, p = 0.85 \)). Although the correlation between anxiety and the context effect in P300 peak amplitude was also statistically not significant (\( r = -0.29, p = 11 \)), the size and direction of this coefficient may imply that our findings do indeed reflect a mixture of N400/P300 effects. However, this does not generally challenge our argumentation since a relative decrease in P300 amplitude has also been frequently interpreted as an indication of reduced resource allocation (Polich, 2007). Thus, a negative correlation between anxiety and the context effect in the P300 peak amplitude would also point to a conflict-driven suppression of word processing in highly anxious subjects. In sum, our findings for the face-only and word-only stimuli indicate that high trait anxiety is linked to a reactive and compensatory recruitment of attentional control resources following a conflict between task-relevant and task-irrelevant stimuli. This is consistent with prior studies also demonstrating that anxious subjects especially show a reactive recruitment of top-down control when previously exposed to a highly cognitive-demanding or arousing event (Dennis and Chen, 2009; Hardin et al., 2009; Osinsky et al., 2010).

However, Etkin et al. (Etkin et al., 2010; Etkin and Schatzberg, 2011) recently reported that patients with a generalized anxiety disorder (GAD) do not show the typical pattern of emotional conflict-adaptation in performance after being exposed to conflicting emotional information. Moreover, their fMRI data indicate that this behavioral deficit is partly caused by a GAD specific lack of compensatory activation of the lateral prefrontal cortex, a brain area which has been repeatedly linked to the execution of top-down control. Thus and in contrast with prior studies (Dennis and Chen, 2009; Hardin et al., 2009; Osinsky et al., 2010) and the present one, the results of Etkin and colleagues rather point to a diminished reactive recruitment of cognitive control in highly anxious subjects. These inconsistencies between studies may partly result from sample differences. While Etkin et al. (2010) and Etkin and Schatzberg (2011) investigated GAD patients, healthy students with rather moderate trait anxiety scores participated in the studies by Dennis and Chen (2009), Osinsky et al. (2010) and in the present one. It is very likely that young healthy students
with increased but non-pathologic trait anxiety possess compensatory cognitive mechanisms and strategies that are absent in GAD patients. By using these compensatory mechanisms they may be able to overcome deficits in attentional control that play a causal and maintaining role in GAD (e.g., Bradley et al., 1999; MacNamara and Hajcak, 2010; Olatunji et al., 2011). With respect to the study by Hardin et al. (2009) it should be noted that their high anxiety group consisted of adolescents with a primary diagnosis of social phobia or GAD but it is not reported whether the results are equal for both subgroups. Since GAD and social phobic patients strongly differ in their clinical symptoms it is not implausible that they also differ in certain aspects of cognitive-affective processing. Moreover, there are crucial differences between studies in the applied experimental tasks and, consequently, neurocognitive processes engaged. For instance, while we used neutral material to induce stimulus–response conflicts, Etkin and colleagues applied emotional stimuli. Importantly, different neural systems have been identified in the processing of emotional and neutral conflicts (Egner et al., 2008; Whalen et al., 1998) and it is possible that anxiety is differentially linked to these distinct circuits. Future studies investigating the link between anxiety and cognitive control should therefore also consider the dissociation between emotional and neutral conflicts. For the moment we can conclude that findings from the present study argue for a conflict-driven reactive recruitment of cognitive control in highly compared to low anxious subjects.

It is tempting to speculate which neural circuits underlie the observed effects in the ERPs. Previous work has demonstrated that conflict-driven adjustments in attentional allocation are mediated by interconnections between lateral prefrontal areas and sensory-perceptual cortex. For instance, using a similar behavioral task as in the present study, Egner et al. (Egner and Hirsch, 2005; Egner et al., 2008) reported that conflicts between the task-relevant face dimension and the task-irrelevant word dimension lead to an increase in activity in the fusiform face area. This brain area is crucially involved in face perception (Kanwisher et al., 1997) and generation of the N170 (e.g., Deffke et al., 2007; Halgren et al., 2000; Rossion et al., 2003). Moreover, the results of Egner et al. indicate that the conflict-driven increase in the activity of fusiform face area is presumably caused by biasing signals of the dorsolateral prefrontal cortex (DLPFC). The DLPFC, in turn, has been frequently identified as one of the main executing modules of cognitive control, being crucially involved in the creation, manipulation and implementation of attentional sets (e.g., Banich et al., 2000; Hajcak et al., 2010; Kerns et al., 2004; MacDonald et al., 2000). While Egner et al. (Egner and Hirsch, 2005; Egner et al., 2008) did not consider individual differences in top-down modulation our data strongly suggest that the patterns of neural activity observed by these authors are influenced by dispositional anxiety. Accordingly, in our study highly anxious subjects may have reactively recruited the DLPFC in the trial following a face–word conflict. Via interconnections between the DLPFC and temporoparietal sensory areas (e.g., the fusiform gyrus) this could have led to a facilitated face-processing, finally resulting in an increase in N170 amplitude. A similar network could underlie the observed N400 effect. For instance, the DLPFC has been shown to exert inhibitory control over semantic word processing in temporal brain regions (Hoenig and Scheef, 2009) and the N400 has also been interpreted to reflect such processes of semantic inhibition (Debruelle, 2007). Interestingly, two recent fMRI studies investigating the link between anxiety and activation of the DLPFC in conflict-inducing tasks have reported contrary results: while Basten et al. (2011) found a positive correlation between anxiety and conflict-elicited DLPFC recruitment, Bishop (2009) observed the opposite. In both studies, however, analyses are restricted to first-order congruency effects (i.e., contrasting currently congruent vs. incongruent conditions) and, therefore, miss dynamic variations and adjustments in DLPFC activity as a function of preceding conflict level. Since our findings argue for the importance of considering such dynamic adjustments in cognitive control, future fMRI studies on the link between anxiety and prefrontal activity should also take this issue into account. Moreover, highly and low anxious subjects may use qualitatively distinct neuronal modes of cognitive control (i.e., reactive control vs. proactive control) as has been indicated by a recent fMRI study by Fales et al. (2008). Since in the present study we have primarily focused on ERP indices of reactive control, the question for future studies arises of how proactive control can also be quantified in EEG research. Generally, it appears advisable for future research in this area to regard cognitive control as a multiphasic and dynamic process rather than a temporally invariant entity.

Some limitations of the present study should be noted. The size of our sample was rather small, limiting the statistical power. Moreover, we did not control for potential confounding effects of affective dimensions other than anxiety (e.g., depression). It should also be noted that task-switching was needed in the word-only condition but not in the face-only condition. As the ACT makes specific predictions in this regard it would have been interesting to investigate the relation between anxiety and deficits in task-switching. However, since the tasks in both conditions are completely different (i.e., reading vs. face-identification) an adequate quantification of switching–costs is not possible.

In summary, our data only partially support the assumptions put forward in the ACT: while we found no evidence for diminished inhibitory control in highly anxious subjects, higher values in anxiety were linked to a reactive and conflict-driven recruitment of attentional control resources. Thus, trait anxiety appears to be closely related to the way the cognitive system adapts to recent demands.

References


