Modulation of the conflict monitoring intensity: The role of aversive reinforcement, cognitive demand, and trait-BIS

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Abstract According to Botvinick's (Cognitive, Affective, & Behavioral Neuroscience 7, 356–366, 2007) integrative account, conflict monitoring is aversive because individuals anticipate cognitive demand, whereas the revised reinforcement sensitivity theory (rRST) predicts that conflict processing is aversive because individuals anticipate aversive reinforcement of erroneous responses. Because these accounts give different reasons for the aversive aspects of conflict, we manipulated cognitive demand and the aversive reinforcement as a consequence of wrong choices in a go/no-go task. Thereby, we also aimed to investigate whether individual differences in conflict sensitivity (i.e., in trait anxiety, linked to high sensitivity of the behavioral inhibition system [trait-BIS]) represent the effects of aversive reinforcement and cognitive demand in conflict tasks. We expected that these manipulations would have effects on the frontal N2 component representing activity of the anterior cingulate cortex. Moreover, higher-trait-BIS individuals should be more sensitive than lower-trait-BIS individuals to aversive effects in conflict situations, resulting in a more negative frontal N2 for higher-trait-BIS individuals. In Study 1, with $N = 104$ students, and Study 2, with $N = 47$ students, aversive reinforcement was manipulated in three levels (within-subjects factor) and cognitive demand in two levels (between-subjects factor). The behavioral findings from the go/no-go task with noncounterbalanced reinforcement levels (Study 1) could be widely replicated in a task with counterbalanced reinforcement levels (Study 2). The frontal mean no-go N2 amplitude and the frontal no-go N2 dipole captured predicted reinforcement-

related variations of conflict monitoring, indicating that the anticipation of aversive reinforcement induces variations in conflict monitoring intensity in frontal brain areas. The aversive nature of conflict was underlined by the more pronounced conflict monitoring in higher- than in lower-trait-BIS individuals.

Keywords Conflict monitoring · Aversive reinforcement · Cognitive demand · Dipole modeling · Trait-BIS

Many situations in everyday life require executive control. One mechanism that serves to detect the need for executive control has been described as the *conflict monitoring system* (e.g., Brown, 2009). Recent theoretical accounts of conflict monitoring, especially the integrative account of Botvinick (2007) and the revised reinforcement sensitivity theory (rRST; Corr, 2008; Gray & McNaughton, 2000), have suggested that conflict registers as an aversive or negatively reinforcing event. In his integrative perspective, Botvinick suggested that conflict information is aversive because the processing of conflict information requires cognitive demand and because individuals aim at minimizing this demand (Balle, 2002). Botvinick's perspective allows for an integration of two accounts on anterior cingulate cortex (ACC) functioning: The common idea of the conflict monitoring theory (Botvinick, Cohen, & Carter, 2004) and of decision-making models (e.g., Rushworth, Walton, Kennerley, & Bannerman, 2004) is that the ACC response to conflict serves as a teaching signal, driving a form of avoidance learning.

According to rRST, conflict information is aversive because of anticipated aversive consequences that might result from wrong choices or erroneous responses (Corr, 2008). Briefly, the rRST relates the activity of neural systems to individual differences in reinforcement-related withdrawal

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and approach behavior. The behavioral inhibition system (BIS) has been described as a conflict detection and conflict resolution device that is sensitive to conflict-related information (Gray & McNaughton, 2000). The BIS mechanism sends signals to the behavioral approach system (BAS) and to the fight/flight/freezing system (FFFS), where the BAS is sensitive to appetitive reinforcement and is responsible for approach behavior, and the FFFS is sensitive to aversive reinforcement and is responsible for withdrawal behavior (Corr, 2008; Gray & McNaughton, 2000). When the BIS detects conflict information, the approach tendencies that are initiated by the BAS will be stopped and the withdrawal tendencies of the FFFS facilitated, to allow for a more detailed stimulus analysis and BIS-related conflict resolution (cf. Corr, 2008). All three neural mechanisms have been related to individual differences (Corr, 2004, 2008). High sensitivity of the BIS mechanism has been associated with trait anxiety (also known as *trait-BIS*), increased BAS sensitivity has been linked to trait impulsivity, and a sensitive FFFS has been related to fear.

In Botvinick's (2007) integrative account, variations of conflict monitoring intensity are primarily conceived as effects of cognitive variables—namely, of cognitive demand. Effects of aversiveness are just a consequence of the cognitive demand that is required in order to get along in a conflict situation. In rRST, variations of conflict monitoring intensity are primarily linked to the effects of anticipation of aversive reinforcement. The activation of the cognitive system that underlies conflict processing is a consequence of the affective–motivational processes that are activated when individuals are confronted with conflict information (cf. Corr, 2008). Beyond these conceptual differences, Botvinick's integrative account and the rRST (Gray & McNaughton, 2000, Appx. 3) have in common that the ACC should be primarily involved in processes during conflict monitoring. Because Botvinick's account and the rRST are both related to the aversive aspects of conflict, we aimed to investigate the conjoint effects of aversive reinforcement and cognitive demand on variations of conflict monitoring intensity in individuals with higher versus lower trait-BIS. This would allow us to understand whether the effects of trait-BIS in conflict tasks (e.g., Amodio, Master, Yee, & Taylor, 2008; Leue, Lange, & Beauducel, *in press*) primarily represent effects of aversive reinforcement, or whether they are also related to the cognitive demand of conflict tasks.

Study 1

Cognitive demand has been described as an intrinsic cost that is associated with the investment of mental effort (see Botvinick & Rosen, 2009). Referring to the law of least

mental effort (Balle, 2002), Botvinick and Rosen argued that individuals would have “a bias against tasks and strategies carrying high levels of cognitive demand” (p. 835). Accordingly, the anticipation of higher cognitive demand should be aversive to an individual. The prediction that conflict is aversive because of the required cognitive demand has been tested in go/no-go tasks by means of varying the go and no-go probabilities (e.g., Schacht, Nigbur, & Sommer, 2009; see also Table 1) and in decision-making tasks by means of varying stimulus complexity (Botvinick & Rosen, 2009). In go/no-go tasks, a conflict is expected to emerge in no-go trials between the requirements to inhibit responses and to respond to go trials. Especially when no-go trials occur less frequently and responses to go trials are predominant or have a high priority, the intensity of conflict monitoring should be particularly pronounced (Band, Ridderinkhof, & van der Molen, 2003; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Thus, in go/no-go tasks, the anticipated cognitive demand might refer to the requirement to inhibit responses to less frequently occurring no-go stimuli but to respond quickly and accurately to go stimuli.

Botvinick and Rosen (2009) reported larger skin conductance responses (SCRs) following a high-demand (i.e., high stimulus complexity) than following a low-demand (i.e., low stimulus complexity) condition in a demand-selection task. More intense SCR responses to high-demand stimuli were interpreted as a more intense anticipation of demand. Schacht et al. (2009) reported larger SCR responses for no-go than for go trials in a task with less frequent no-go trials. The larger SCR has been interpreted as suggesting that higher cognitive demand intensifies the aversive nature of the conflict task (e.g., Botvinick & Rosen, 2009). However, SCRs are sensitive to a variety of psychological processes (e.g., arousal and cognitive load), whereas other physiological variables, such as ACC-related event-related potentials (ERPs), are probably more directly associated with processes like conflict monitoring and cognitive control. In this respect, the N2 amplitude has been shown in a couple of studies to indicate variations of conflict monitoring intensity. N2 amplitudes were more negative to less frequently occurring stimuli than to more frequently occurring stimuli, indicating that the intensity of conflict monitoring depends on the frequencies of the go and no-go stimuli (e.g., Amodio et al., 2008; Nieuwenhuis et al., 2003). In these studies, the N2 has been regarded as an indicator of conflict monitoring intensity that is probably generated in the ACC.

Studies applying one or more levels of go:no-go probability (Table 1) have reported a more negative N2 amplitude to less frequently occurring stimuli (e.g., Amodio et al., 2008; Nieuwenhuis et al., 2003). Like Schacht et al. (2009), we regard variations of go:no-go trial probability as variations of cognitive demand. As becomes apparent from Table 1, some studies have investigated N2 variations

Table 1 N2 studies investigating the modulation of conflict monitoring by means of cognitive demand, aversive reinforcement, and individual differences

Authors	Sample Size	Treatment			Individual Differences
		Type of Go/No-Go Stimuli	Go:No-Go Ratio	Type of Reinforcement	
Albert et al. (2010)	30 (16 f)	M, W Emotional context ¹	70:30	—	—
Amodio et al. (2008)	48 (32 f)	M, W	80:20	Written: “Too slow”, feedback to errors	Trait-BIS, trait-BAS
Bruin & Wijers (2002)	12 (8 f)	M, W	75:25 50:50 25:75	—	—
Eimer (1993, I)	6 (2 f)	M, W	75:25	—	—
Eimer (1993, II)	6 (2 f)	M, W	50:50	—	—
Lavric, Pizzagalli, & Forstmeier (2004)	30 (14 f)	Rectangles, circle	50:50	Written: “Error”, “no response”	—
Leue et al. (in press)	94 (40 f)	M, W	80:20	Written: “Error”, “Too slow”, “Error: −3 Ct”, “Too slow: −3 Ct”, Correct: +3 Ct	Trait-BIS, trait-BAS
Nieuwenhuis et al. (2003)	12 (9 f)	M, W	80:20 50:50 20:80	Written: Blockwise mean RT, error rate	—
Righi, Mecacci, & Viggiano (2009)	18 f	Digits	89:11	—	STAI-S, STAI-T
Schacht et al. (2010)	20 (10 f)	M, W	50:50	—	—
Sehlmeyer et al. (2010)	54 (39 f)	2 words	50:50	Auditory: “RT interval exceeded”	ASI, STAI-T

¹ The letters M and W were presented in an emotionally aversive, an emotionally appetitive, or an emotionally neutral context. f, female participants. ASI, Anxiety Sensitivity Index. STAI-S, State–Trait Anxiety Inventory: State. STAI-T, State–Trait Anxiety Inventory: Trait. The go:no-go ratio was used to modulate the intensity of cognitive demand. Although such verbal feedback as “Error” or “Too slow” is not very aversive, we have assumed that, especially in the performance context of the task, it is at least slightly aversive for the participants.

in a go/no-go task that provided written negative feedback, which might be an aversively reinforcing stimulus for the participants. However, these studies have not disentangled the effects of cognitive demand and aversive reinforcement on conflict monitoring, because these variables have not been independently manipulated.

In line with this perspective, we predicted that the frontal N2 component would also capture those aspects of conflict monitoring that are related to negatively reinforcing events. These negatively reinforcing events during conflict monitoring could derive from anticipated aversive reinforcement in the case of erroneous responses, but they might also derive from the anticipation of the cognitive demand that would be required in order to successfully monitor for conflict information. In consequence, negatively reinforcing aspects of anticipated negative feedback and anticipated cognitive demand could be represented in one and the same neural source. This might suggest that not cognitive demand itself, but the aversive nature of cognitive demand enhances the conflict monitoring intensity in ACC-related areas of the brain. If this were true, the effects of the anticipation of cognitive demand on the frontal N2 could be regarded as the effects of aversiveness. In this respect, the predictions of

rRST (Corr, 2008) and Botvinick’s (2007) integrative account on conflict monitoring would converge. In accordance with Shackman et al. (2011), we assumed that affect and cognition are closely related in the ACC and during conflict monitoring. To sum up, we expected that aversive treatments such as negative reinforcement and the anticipation of cognitive demand would result in a more negative frontal ACC-related N2 component.

In prior studies, personality has been shown to modulate ACC functioning (Segalowitz & Dywan, 2009; Sehlmeyer et al., 2010; Yücel et al., 2007). More specifically, the ACC has been related to the processing of negative affect, pain, and cognitive control (Shackman et al., 2011). It has been shown that individuals who express more negative affect, indexed by the emotion-modulated startle reflex, show larger ERP indices of conflict (Hajcak & Foti, 2008). Furthermore, several studies have provided evidence supporting a relation between the error-related negativity (ERN) and individual differences in emotionality: Individuals who report more anxiety and sensitivity to punishment have more pronounced ERNs (e.g., Boksem, Tops, Wester, Meijman, & Lorist, 2006; Hajcak, McDonald, & Simons, 2003, 2004; Luu, Collins, & Tucker, 2000). Segalowitz and Dywan

(2009) argued that individuals high in conscientiousness appeared to be more concerned with errors, because they responded equally to minor and more severe errors (Gehring, Himle, & Nisenson, 2000).

According to a meta-analysis (Leue & Beauducel, 2008), individuals with higher trait-BIS scores are more sensitive toward aversive reinforcement in conflict and nonconflict tasks than are individuals with lower trait-BIS scores. If trait-BIS differences are generally related to the aversive nature of a conflict situation, a trait-BIS main effect should occur in the frontal N2 in a go/no-go task across varying levels of cognitive demand and aversive reinforcement. Indeed, higher-trait-BIS individuals showed more pronounced conflict monitoring intensity (represented by a more negative no-go N2) than did lower-trait-BIS individuals in conflict tasks with aversive reinforcement (e.g., Amodio et al., 2008; Leue, Chavanon, Wacker, & Stemmler, 2009; Leue et al., *in press*). This suggests that the increased conflict sensitivity of higher- relative to lower-trait-BIS individuals results from a more intense anticipation of aversive reinforcement, and possibly of cognitive demand. This would be in line with rRST, but it would also be compatible with Botvinick's (2007) account of conflict monitoring, because it would underline the aversive effects of cognitive demand from the perspective of individual differences. If the idea is correct that cognitive demand is aversive, we would expect that higher-trait-BIS individuals would have more negative frontal N2 amplitudes in a high-cognitive-demand condition than would lower-trait-BIS individuals. In contrast, if trait-BIS differences are more specifically related to the aversive consequences of erroneous responses in a conflict task, but not to cognitive demand, an interaction of trait-BIS and reinforcement-related conflict level should be observed in the frontal N2 component. This would be in line with the rRST, which postulates that higher- as compared to lower-trait-BIS individuals should be more sensitive to reinforcement-related conflict information (Corr, 2008), but it would not support the idea of the aversive effects of cognitive demand, as postulated in Botvinick's account of conflict monitoring. Briefly, we investigated trait-BIS differences in conflict monitoring in this study because it has not been clear whether the effects of trait-BIS in prior conflict tasks (see Table 1) represented the effects of aversive reinforcement or were also related to the anticipated cognitive demand of conflict tasks.

The evidence on the aversiveness of conflict monitoring until now has primarily been based on correlations with trait-BIS or trait anxiety (Table 1). Since prior studies on individual differences in conflict monitoring did not manipulate cognitive demand, the correlations between the no-go N2 amplitude and trait-BIS or trait anxiety have not necessarily represented the aversiveness effects of cognitive demand. Consequently, a direct confirmation of Botvinick's (2007) idea of the aversiveness of cognitive demand could not be derived from correlations with trait-BIS or trait anxiety in prior studies. Moreover,

the roles of cognitive demand, aversive reinforcement, and individual differences in conflict monitoring until now have not been clear, especially because prior studies on individual differences in conflict monitoring (Table 1) did not simultaneously manipulate the effects of aversive reinforcement and cognitive demand during conflict monitoring. Accordingly, the simultaneous manipulation of aversive reinforcement and cognitive demand would allow for a more direct test of the aversiveness effects of cognitive demand on conflict monitoring than do the correlations between trait-BIS and conflict monitoring intensity (indicated by the N2 component). Therefore, we aimed at investigating the conjoint effects of cognitive demand and aversive reinforcement on conflict monitoring intensity, as well as trait-BIS related differences in conflict monitoring, within one study.

Study aims

In the present study, reinforcement was manipulated as a within-subjects factor with three levels (nonreinforcement, aversive verbal–nonmonetary reinforcement, and aversive verbal–monetary reinforcement). Cognitive demand was manipulated as a between-subjects factor with two levels of go:no-go probability (80:20 go:no-go ratio, inducing higher cognitive demand, vs. 65:35 go:no-go ratio, inducing lower cognitive demand). First of all, we expected that reinforcement-related variations of conflict monitoring intensity would be reflected in anterior ERP components thought to be associated with activity of the ACC. Therefore, a more negative frontal N2 was hypothesized for conflict conditions that provided aversive reinforcement relative to a condition without any reinforcement. Second, aversive aspects of cognitive demand should also result in a more negative frontal N2, with a more negative frontal N2 for high than for low cognitive demand. Third, individual differences in trait-BIS scores have been shown to modulate ACC functioning and conflict monitoring intensity mostly in frontal areas of the brain (see, e.g., Amodio et al., 2008; Leue et al., 2009). In accordance with rRST, we predicted more intense conflict monitoring, indicated by a more negative frontal N2 amplitude, for individuals with higher trait-BIS scores relative to individuals with lower trait-BIS scores. Fourth, if cognitive demand has aversive effects on conflict monitoring intensity, as predicted by Botvinick (2007), the increase of cognitive demand should especially lead to a more negative frontal N2 in higher-trait-BIS individuals.

Method

Participants A total of 114 right-handed students at a German university gave written informed consent and participated voluntarily in this study. According to our artifact rejection criterion (see below), participants with less than 25

electroencephalogram (EEG) epochs to no-go trials per task condition were eliminated from statistical analysis ($n = 10$), leaving a final sample of 104 participants (55 female, 49 male; age: $M = 23.68$ years, $SD = 3.51$, range 19–35 years) for statistical analysis. All participants had normal or corrected-to-normal vision. Independent-samples t tests indicated that trait-BIS scores did not differ substantially between the cognitive demand groups (see below), $t(102) = 0.45$, n.s. Moreover, chi-square tests indicated that the numbers of men and women assigned to the low- or the high-cognitive-demand group did not differ substantially, $\chi^2 = 0.05$, n.s.

Measures Participants performed the German version of the BIS/BAS scales (Strobel, Beauducel, Debener, & Brocke, 2001). The BIS/BAS scales consist of a 7-item BIS scale and a 13-item BAS scale (see Carver & White, 1994). All of the items have a 4-point Likert-type answer format. In this study, the internal consistency coefficients of the BIS scale (Cronbach's $\alpha = .74$) and the BAS scale (Cronbach's $\alpha = .65$) were moderate and were widely comparable to those found in validation studies (Carver & White, 1994; Strobel et al., 2001). Handedness was measured with the Edinburgh Handedness Inventory (Oldfield, 1971).

Go/no-go task The go/no-go task included go and no-go trials. The trial sequences of correct go trials, slow go trials, and erroneous no-go trials, along with the different kinds of feedback, are presented in Fig. 1. Each trial of the go/no-go task began with a fixation cross that was presented for 500 ms in the center of the screen. Subsequently, again in the center of the screen, either the capital letter “M” or “W” (72-point Arial font) was presented for 100 ms. Participants were instructed to respond exclusively on go trials as quickly as possible within a 500-ms interval. As in Amodio et al. (2008), responses to go trials were recorded up to 1,000 ms after stimulus onset. Trial-by-trial feedback was provided for 1,000 ms. The intertrial interval was 1,000 ms.

The go/no-go task consisted of three blocks providing three different levels of aversive reinforcement. Each task block consisted of 250 trials. In the first task block, participants did not receive any reinforcement. In the second task block, aversive verbal–nonmonetary reinforcement was provided following erroneous responses to no-go stimuli (“Error!”) or when responses to go trials came between 500 and 1,000 ms post-stimulus (“Too slow!”). During the last block, aversive verbal–monetary reinforcement occurred when participants erroneously responded to no-go trials (“Error: –3Ct!”) or when go trial responses came too slowly (“Too slow: –3Ct!”). No reinforcement was applied to correct responses in any task block. A 2 min break was inserted after each task block (i.e., after 250 trials). The go and no-go letters were counterbalanced across all three task blocks. The trial sequence was similar to those of prior studies (e.g., Amodio et al., 2008). All participants

performed the nonreinforcement task block first, followed by the verbal–nonmonetary and the verbal–monetary task blocks. The probabilities of go and no-go trials were varied by means of a 80:20 ratio of go versus no-go trials and a 65:35 ratio of go versus no-go trials. Since go responses were required in either 80% (= 200 stimuli) or 65% (= 162 stimuli) of all trials in a task block, go responses were predominant. Consequently, withholding predominant responses, especially on the more rarely occurring no-go trials (20% = 50 stimuli; 35% = 88 stimuli), should increase the cognitive demand of conflict monitoring. Assignment to one cognitive demand level was counterbalanced (every second participant performed the lower-cognitive-demand condition). It should be noted that the go/no-go task is rather monotonous, so that it seemed reasonable to keep the task duration within 45 min. In order to realize a task design that did not demotivate participants because of its length (6 conditions $\times$ 15 min = 90 min task, excluding breaks), cognitive demand was manipulated as a between-subjects factor.

Procedure About one week before the examination date, participants were instructed by telephone to omit alcohol use, to avoid unusual caffeine and nicotine consumption, and to avoid taking other stimulating substances the day before the examination. After arriving, participants gave written informed consent. They were then prepared for physiological recording. Participants were seated in a comfortable chair approximately 95 cm from the 20-in. TFT computer screen. The room was sound-attenuating and well-lit. Presentation software (version 12.1; Neurobehavioral Systems, Albany, NY) was used to present the go/no-go task. Before the start of the experiment, participants performed 10 practice trials. EEGs were recorded during each 15-min-long task block. During task performance, the experimenter sat in an adjacent room, where the data were recorded. Each examination lasted approximately 1.5 h. After finishing the task, participants received a basic payment of €15 (about USD20). For the aversive verbal–monetary task condition, participants received an additional starting bonus of €7. Each too-slow go response and each erroneous no-go response resulted in a loss of 3 cents. Participants were told that these losses would be subtracted from their bonus. If no errors or too-slow responses occurred in the monetary loss condition, participants received the complete starting bonus of €7 in addition to the basic payment, resulting in a maximum payment of €22 (about USD30). Participants did not receive trial-by-trial monetary gains following correct go responses in this task condition.

EEG recording and processing EEG recording, quantification, and analysis were conducted in line with the guidelines for the study of human ERPs (Picton et al., 2000). The EEG equipment was used from the ActiveTwo BioSemi system

Fig. 1 Trial sequences of go and no-go trials. During the nonreinforcement condition and following correct go responses during the other task conditions, the feedback screen remained black. ITI, intertrial interval

(BioSemi, Amsterdam, Netherlands). EEG was recorded with 64 active scalp electrodes placed according to the extended 10/20 system (Jasper, 1958). An electrooculogram (EOG) was recorded from two horizontal electrodes placed at the epicanthi of both eyes and one vertical electrode located approximately 1 cm below the right eye. As per BioSemi's design, the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode. All bioelectric signals were digitized on a laboratory computer using ActiView software (BioSemi). The impedances were below 30 k Ω during EEG recording. The EEGs were sampled at 512 Hz. Offline analysis was performed by using EEGLab (version 9.0.0.2; Delorme & Makeig, 2004), based on MATLAB 7.10.0 (The MathWorks, Natick, MA). All data were band-pass filtered (1–30 Hz) and were rereferenced to averaged mastoids. Independent-components analysis (ICA; an automated infomax decomposition) was applied to correct for ocular artifacts. Further technical and muscle artifacts were rejected when the EEG signal exceeded ± 75 μ V. Prior to the statistical analysis of the ERP data, all data were filtered at 1–12 Hz (cf. Amodio et al., 2008; Donkers & van Boxtel, 2004; Nieuwenhuis et al., 2003). Artifact-free epochs were separately segmented for go and no-go trials, with a window for

correct responses 700 ms after stimulus onset and a prestimulus baseline of 100 ms. All participants included into the statistical analysis had at least 50% artifact-free epochs on the no-go trials. The rejection of EEG epochs varied between 7.6% and 9.2% among the task conditions, indicating good quality of the EEG data.¹ Grand averages of the ERPs indicated one no-go N2 amplitude at central and parietal sites between 150 and 250 ms poststimulus (subsequently referred to as the *posterior N2*) and a second no-go N2 amplitude between 250 and 350 ms, which was most pronounced at frontal sites (subsequently referred to as the *frontal N2*; see Fig. 2a and b). Our main analysis was of the frontal N2

¹ The mean numbers of artifact-free EEG epochs for go stimuli for the high- versus the low-cognitive-demand conditions were 182.85 ($SD = 23.45$) versus 150.81 ($SD = 14.30$) in the nonreinforcement block, 182.47 ($SD = 25.81$) versus 149.08 ($SD = 16.13$) in the aversive verbal-nonmonetary reinforcement block, and 181.54 ($SD = 22.09$) versus 149.73 ($SD = 17.47$) in the aversive verbal-monetary reinforcement block. For no-go stimuli, the mean number of artifact-free EEG epochs for high versus low cognitive demand were 41.70 ($SD = 6.64$) versus 80.45 ($SD = 8.33$) in the nonreinforcement block, 41.23 ($SD = 6.92$) versus 77.71 ($SD = 10.66$) in the aversive verbal-nonmonetary reinforcement block, and 39.94 ($SD = 6.98$) versus 79.31 ($SD = 9.46$) in the aversive verbal-monetary reinforcement block.

component, which has also been observed in prior studies (Amodio et al., 2008; Donkers & van Boxtel, 2004; Leue et al., 2009; Nieuwenhuis et al., 2003; Schacht, Dimigen, & Sommer, 2010). The mean amplitude of the N2 components was used for the statistical analysis (cf. Luck, 2005).

Dipole modeling was performed with the source localization software BESA 5.3 (MEGIS Software GmbH, Graefelfing, Germany). We applied 62 electrodes to the source localization analysis (excluding three EOG channels and two reference

channels). To fit the source model, the ERPs of correct no-go stimuli were averaged across the two cognitive demand conditions (80:20 vs. 65:35) and across the three aversive reinforcement levels for 104 participants. Source analysis was performed exclusively to correct no-go stimuli to prevent motor processes that might be associated with the go stimuli (cf. Jonkman, Sniedt, & Kemner, 2007). Then, a Fourier filter was applied to the averaged ERPs (high pass, 1 Hz, 12 dB/oct, zero phase; low pass, 12 Hz, 48 dB/oct, zero phase). The

(A) High cognitive demand (80:20 go – nogo ratio)

Fig. 2 a Raw waveforms and difference waveforms for high cognitive demand and the three levels of aversive reinforcement with go and no-go stimuli ($n = 55$). **b** Raw waveforms and difference waveforms for low

cognitive demand and the three levels of aversive reinforcement with go and no-go stimuli ($n = 49$). Difference waveforms have been computed as the no-go waveform minus the go waveform

(B) Low cognitive demand (65:35 go – nogo ratio)

Fig. 2 (continued)

topographical decomposition of the N2 component was performed in BESA on data across a time window of 100 ms around the N2 peak (using an average reference). Among different strategies that are available for decomposing spatial ERP components, we decided to use BESA in order to isolate spatial ERP components that are associated with N2-related conflict monitoring by means of principal components analysis (PCA; Luck, 2005). Two principal components explained 98.5% of the data variance (Component 1, 88.4%; Component 2, 10.1%). Because even the second component explained a substantial amount of variance, we aimed at fitting two dipoles to the source model. These two dipoles were fitted to the source

model (Fig. 3a) according to existing literature on N2-related dipoles (Amodio et al., 2008; Nieuwenhuis et al., 2003). In accordance with prior studies, we defined one frontal and one posterior dipole, along with their orientations, as starting points in the source model (Talairach coordinates: frontal dipole, $x = 3.8$, $y = 10.7$, $z = 37.9$, energy, 53.7 nA; posterior dipole, $x = -3.4$, $y = -42.8$, $z = 25.7$, energy, 47.1 nA). Data were fitted to a four-shell ellipsoidal model. Thus, in our BESA analysis, we focused on the separation of relevant N2 variances by means of dipoles that were localized and oriented according to prior studies. We did not aim to probe different starting points of the dipoles in an exploratory manner. After fitting the two

dipoles, the residual variance was rather small (4.19%, $SD = 2.28$). The source model was then applied to each individual data file. The time interval around the N2 peak and the orientations of the two dipoles were individually fitted (cf. MEGIS Software GmbH, Graefelfing, Germany). The grand averages of the dipoles are presented in Fig. 3b and c. The N2 dipoles were located in a time window (between 250 and 350 ms poststimulus) similar to the window of the frontal N2 component in the raw waveforms (Fig. 2).

Statistical analysis Using SPSS 16.0, the initial repeated measures ANCOVA for the mean N2 amplitude was conducted with Region (frontal: F3, Fz, F4; central: C3, Cz, C4; and parietal: P3, Pz, P4), Laterality (left: F3, C3, P3; middle: Fz, Cz, Pz; and right: F4, C4, P4), Go–No–Go Stimulus, and Reinforcement Level Condition as repeated factors (within-subjects factors). Dipole Source (frontal vs. posterior) was entered as a repeated factor in a subsequent repeated measures ANCOVA. Cognitive Demand, manipulated by means of the go:no-go ratio (80:20 vs. 65:35), and Gender were applied as between-subjects factors. The high-cognitive-demand (80:20 ratio) group included $n = 55$ participants, and the low-cognitive-demand (65:35 ratio) group included $n = 49$ participants. To investigate the modulation of conflict monitoring intensity by means of trait-BIS and trait-BAS (Kolmogorov–Smirnov test, $ps < .10$), normalized (Blom, 1958) trait-BIS and trait-BAS sum scores were applied as covariates in the repeated measures ANCOVAs for the behavioral data and the N2 data. The Blom transformation fits the inverse normal density function to the rank data. The normalized trait-BIS and trait-BAS sum scores were normally distributed (all $ps > .10$) and mean-centered. For response times, a violation of the normal distribution was also observed (Kolmogorov–Smirnov test, $ps < .10$). As in other studies, response times were therefore transformed using the natural logarithm (e.g., Wilkowski, Robinson, & Troop-Gordon, 2010). Violations of sphericity were Greenhouse–Geisser corrected whenever necessary. Sensitivity (d') was computed according to Stanislaw and Todorov (1999).

Results

Behavioral data A paired t test revealed that the commission error rate ($M = .25$, $SD = .23$) was significantly higher than the omission error rate ($M = .08$, $SD = .12$) across all three task conditions, $t(103) = 7.49$, $p < .01$. The analysis of sensitivity revealed a significant cognitive demand main effect, with a higher d' in the low-cognitive-demand (65:35) condition than in the high-cognitive-demand (80:20) condition, $F(1, 87) = 10.41$, $p < .01$, $\eta^2 = .11$ (for descriptive statistics, see Table 2). The main effect of reinforcement level was significant for d' , $F(1.98, 186.24) = 10.84$, $p < .01$, $\eta^2 = .10$, with a higher d' with aversive verbal–monetary reinforcement than with aversive

verbal–nonmonetary reinforcement, $F(1, 94) = 21.60$, $p < .01$, $\eta^2 = .19$, and with nonreinforcement, $F(1, 94) = 6.73$, $p < .01$, $\eta^2 = .07$ (for descriptive statistics, see Table 2). For sensitivity, a tendency toward a trait-BIS main effect occurred, $F(1, 94) = 3.33$, $p = .07$, $\eta^2 = .03$, with higher-trait-BIS individuals showing higher sensitivity, $r = .23$, $p < .05$ (two-tailed).

For the mean go response times, a main effect of reinforcement level occurred, $F(1.73, 150.79) = 44.47$, $p < .01$, $\eta^2 = .34$. Simple contrasts revealed longer response times to go trials in the nonreinforcement condition than with either aversive verbal–nonmonetary reinforcement, $F(1, 94) = 34.80$, $p < .01$, $\eta^2 = .27$, or aversive verbal–monetary reinforcement, $F(1, 87) = 60.33$, $p < .01$, $\eta^2 = .39$. Moreover, mean go response times were shorter in the aversive verbal–monetary condition than in the aversive verbal–nonmonetary condition, $F(1, 94) = 20.43$, $p < .01$, $\eta^2 = .18$ (for descriptive statistics, see Table 2). There was no cognitive demand main effect for go response times and no interaction of cognitive demand and reinforcement level, $F_s < 1$, n.s. For the mean no-go response times, neither the reinforcement level main effect nor the cognitive demand main effect was significant, $F_s < 1$, n.s. The Reinforcement Level $\times$ Cognitive Demand interaction was also not significant for mean no-go response times, $F(1.98, 130.37) = 2.23$, n.s. With the exception of sensitivity, no personality main effects and no substantial interaction with reinforcement level or cognitive demand was observed for any further performance parameters, $F_s < 1$, n.s.

Results of the mean N2 amplitude for cognitive demand and reinforcement level The grand averages indicated a no-go N2 in the time window between 250 and 350 ms poststimulus for high cognitive demand (Fig. 2a) and for low cognitive demand (Fig. 2b). This N2 time window is similar to those found in prior studies (e.g., Donkers & van Boxtel, 2004; Eimer, 1993). The no-go N2 was more pronounced at frontal than at parietal sites. Because the go N2 showed no clear peak, we decided to report mean amplitude results of that frontal N2 (cf. Luck, 2005). In a subsequent analysis, we explored the effects on the posterior mean no-go N2 amplitude at central (C3, Cz, C4) and parietal (P3, Pz, P4) positions, occurring between 150 and 250 ms poststimulus.

For the frontal N2, a repeated measures ANCOVA suggested a significant region main effect on the mean N2 amplitude, $F(1.26, 113.50) = 111.63$, $p < .01$, $\eta^2 = .55$ (Table 3). Deviation contrasts indicated a more negative mean N2 amplitude at frontal positions (including F3, Fz, F4) than at central positions (including C3, Cz, C4) and parietal positions (including P3, Pz, P4), $F(1, 90) = 143.32$, $p < .01$, $\eta^2 = .61$. The go–no-go stimulus main effect suggested a more negative no-go N2 amplitude, as compared to the go N2 amplitude, $F(1, 90) = 370.88$, $p < .01$, $\eta^2 = .81$ (Table 3). The Region $\times$ Go–No–Go Stimulus $\times$ Cognitive Demand interaction, $F(1.27, 114.60) = 17.25$, $p < .01$, $\eta^2 = .16$, could be traced back to a significant

(A) Source model

(B) High cognitive demand (80:20 go-nogo ratio)

(C) Low cognitive demand (65:35 go-nogo ratio)

Fig. 3 **a** Two-dipole source model of the no-go N2 effect ($N = 104$), averaged across three reinforcement levels and two cognitive demand conditions. The red dipole represents the frontal N2 component. The blue dipole represents the posterior N2 component. **(b** and **c**) Grand averages of the frontal and posterior no-go N2 dipoles separately for **(b)** high

cognitive demand and **(c)** low cognitive demand. The gray rectangles in the time window between 250 and 350 ms represent the time interval around the N2 dipoles from which the N2 dipoles were computed. The individual N2 dipoles were computed as mean N2 dipoles ± 50 ms around the N2 dipole peak ($N = 104$)

Table 2 Descriptive statistics of behavioral parameters with regard to reinforcement levels and cognitive demand

	Study 1						Study 2					
	Across Cognitive Demand Levels ($N = 104$)			Low Cognitive Demand ($n = 49$)			High Cognitive Demand ($n = 55$)			Across Cognitive Demand Levels ($N = 47$)		
	<i>M</i>	<i>SE</i>		<i>M</i>	<i>SE</i>		<i>M</i>	<i>SE</i>		<i>M</i>	<i>SE</i>	
Number of Correct Responses												
Nonreinforcement	177.25	1.98		157.29	1.09		195.04	0.86		180.06	2.82	
Aversive verbal–nonmonetary	177.30	1.99		157.27	0.92		195.15	1.04		179.28	2.79	
Aversive verbal–monetary	179.60	1.86		159.92	0.47		197.13	0.47		180.64	2.80	
Commission Errors												
Nonreinforcement	4.62	0.42		4.39	0.67		4.82	0.54		6.30	1.39	
Aversive verbal–nonmonetary	5.84	0.48		5.18	0.67		5.85	0.70		4.91	0.56	
Aversive verbal–monetary	5.21	0.47		4.31	0.59		6.02	0.71		3.44	0.52	
Omission Errors												
Nonreinforcement	6.30	0.82		6.24	1.35		6.35	1.00		2.74	0.45	
Aversive verbal–nonmonetary	5.94	0.81		5.95	1.08		5.93	1.21		3.17	0.44	
Aversive verbal–monetary	3.75	0.43		3.78	0.71		3.74	0.55		1.62	0.22	
Sensitivity (d')												
Nonreinforcement	3.94	0.87		4.16	0.88		3.73	0.82		4.59	0.13	
Aversive verbal–nonmonetary	3.78	0.95		3.92	0.96		3.65	0.93		4.15	0.14	
Aversive verbal–monetary	4.12	1.03		4.44	1.00		3.84	0.99		4.97	0.15	
Go Response Times (in ms)												
Nonreinforcement	289.91	3.52		284.78	5.59		294.49	4.37		266.39	3.54	
Aversive verbal–nonmonetary	277.98	2.91		276.48	4.51		279.32	3.79		270.20	3.47	
Aversive verbal–monetary	269.86	2.71		267.57	3.96		271.90	3.72		267.31	3.00	
No-Go Response Times (in ms)												
Nonreinforcement	246.31	6.55		235.94	10.92		254.14	7.90		235.97	10.32	
Aversive verbal–nonmonetary	241.59	6.08		240.90	10.18		242.12	7.51		223.99	6.98	
Aversive verbal–monetary	238.74	6.20		239.21	8.51		238.38	8.87		225.29	8.17	
High Cognitive Demand ($n = 24$)												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												
Commission Errors												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												
Omission Errors												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												
Sensitivity (d')												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												
Go Response Times (in ms)												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												
No-Go Response Times (in ms)												
Nonreinforcement												
Aversive verbal–nonmonetary												
Aversive verbal–monetary												

Descriptive statistics for response times are not natural-log-transformed. In Study 1, the order of the reinforcement-related task conditions was constant, whereas in Study 2 this order was randomized. No-go response times were observed for $n = 96$ participants in the nonrandomized nonreinforcement condition, $n = 97$ in the nonrandomized aversive verbal–nonmonetary reinforcement condition, and $n = 89$ in the nonrandomized aversive verbal–monetary reinforcement condition in Study 1. In Study 2, we recorded no-go response times from $n = 34$ participants in the randomized nonreinforcement condition, $n = 44$ in the randomized aversive verbal–nonmonetary reinforcement condition, and $n = 36$ in the randomized aversive verbal–monetary reinforcement condition. Errors of omission were recorded from $n = 23$ participants in the nonreinforcement condition, $n = 30$ in the aversive verbal–nonmonetary reinforcement condition, and $n = 21$ in the aversive verbal–monetary reinforcement condition in Study 2.

Region $\times$ Cognitive Demand interaction for no-go stimuli, $F(1.24, 111.13) = 4.16$, $p < .05$, $\eta^2 = .04$, but not for go stimuli, $F < 1$, n.s. A tendency toward a cognitive demand main effect was observed at parietal sites for the no-go N2, $F(1, 90) = 3.68$, $p = .06$, $\eta^2 = .04$. The parietal mean no-go N2 amplitude was less positive (indicating more intense conflict monitoring) for higher cognitive demand ($M = 1.23 \mu\text{V}$, $SE = 0.41$) than for lower cognitive demand ($M = 2.38 \mu\text{V}$, $SE = 0.44$).

Because reinforcement condition effects were expected in particular for the no-go N2 amplitude, further analysis focused on the mean no-go N2 amplitude. A Region $\times$ Reinforcement Condition interaction occurred for no-go trials, $F(2.55, 229.23) = 5.04$, $p < .01$, $\eta^2 = .05$. Deviation contrasts revealed that the decrease of the N2 amplitude from nonreinforcement to aversive verbal–nonmonetary reinforcement was more pronounced at frontal sites (F3, Fz, F4) than at centro-parietal sites (C3, Cz, C4, P3, Pz, P4), $F(1, 90) = 10.44$, $p < .01$, $\eta^2 = .10$ (Table 3). No main effect of reinforcement level was observed for the frontal mean go N2 amplitude, $F < 1$, n.s. Repeated measures ANCOVAs did not reveal any substantial main effect or interaction of trait-BIS and trait-BAS with electrode sites, reinforcement level, or cognitive demand for the mean no-go N2 amplitude.

To investigate whether cognitive demand modulates the no-go N2 amplitude, irrespective of aversive reinforcement

following erroneous responses, we performed a repeated measures ANCOVA of the no-go N2 amplitude in the nonreinforcement condition. The cognitive demand main effect, $F(1, 92) = 0.42$, n.s., and the Region $\times$ Cognitive Demand interaction, $F(1.25, 112.05) = 1.78$, n.s., were nonsignificant.

For the posterior mean no-go N2 amplitude, the region main effect was significant, $F(1, 90) = 4.23$, $p < .05$, $\eta^2 = .05$, with a more negative mean N2 amplitude at parietal ($M = 1.36 \mu\text{V}$, $SE = 0.21$) than at central sites ($M = 1.79 \mu\text{V}$, $SE = 0.29$). The go–no-go main effect, $F(1, 90) = 48.91$, $p < .01$, $\eta^2 = .35$, and the Region $\times$ Go–No–Go $\times$ Cognitive Demand interaction were significant, $F(1, 90) = 32.89$, $p < .01$, $\eta^2 = .27$. The go–no-go main effect indicated a more pronounced mean no-go N2 ($M = 1.04 \mu\text{V}$, $SE = 0.25$) as compared to the mean go N2 ($M = 2.11 \mu\text{V}$, $SE = 0.24$). The three-way interaction could be traced back to a significant Go–No–Go $\times$ Cognitive Demand interaction at parietal sites, $F(1, 90) = 6.87$, $p < .05$, $\eta^2 = .07$. Separate analyses for the posterior go N2 and the posterior no-go N2 at parietal sites (P3, Pz, P4) revealed a significant cognitive demand main effect exclusively for the no-go N2 amplitude, $F(1, 90) = 5.25$, $p < .05$, $\eta^2 = .06$, with a more pronounced posterior no-go N2 for high cognitive demand ($M = 0.28 \mu\text{V}$, $SE = 0.32$) than for low cognitive demand ($M = 1.36 \mu\text{V}$, $SE = 0.34$). In contrast to the frontal mean no-go N2 amplitude, the Region $\times$ Reinforcement Level interaction of the posterior mean no-go N2 amplitude was not significant, $F(1.97, 176.94) = 1.14$, $p = .32$. The reinforcement level main effect for the posterior mean no-go N2 amplitude was significant, $F(1.91, 172.23) = 8.24$, $p < .01$, $\eta^2 = .08$. Deviation contrasts revealed a more pronounced posterior mean no-go N2 amplitude for nonreinforcement ($M = 0.54 \mu\text{V}$, $SE = 0.26$) than for the two aversive reinforcement conditions (average $M = 1.29 \mu\text{V}$, $SE = 0.28$), $F(1, 90) = 13.93$, $p < .01$, $\eta^2 = .13$. In conclusion, the posterior no-go N2 amplitude did not capture effects of aversive reinforcement during conflict monitoring, but rather attention-related aspects of conflict monitoring.

Table 3 Descriptive statistics of the mean N2 amplitude (in μV) for electrode positions, go–no-go stimuli, and aversive reinforcement

	<i>M</i>	<i>SE</i>
Region		
Frontal positions (F3, Fz, F4)	−0.44	0.41
Central positions (C3, Cz, C4)	1.74	0.40
Parietal positions (P3, Pz, P4)	3.64	0.29
Go–No–Go Stimuli		
Go stimuli	3.55	0.35
No-go stimuli	−0.25	0.34
Aversive Reinforcement Frontal Sites (F3, Fz, F4), No–Go N2		
Nonreinforcement	−0.35	0.44
Aversive verbal–nonmonetary	−0.58	0.44
Aversive verbal–monetary	−0.38	0.43
Aversive Reinforcement Central Sites (C3, Cz, C4), No–Go N2		
Nonreinforcement	1.32	0.41
Aversive verbal–nonmonetary	1.77	0.43
Aversive verbal–monetary	2.12	0.43
Aversive Reinforcement Parietal Sites (P3, Pz, P4), No–Go N2		
Nonreinforcement	3.24	0.31
Aversive verbal–nonmonetary	3.70	0.31
Aversive verbal–monetary	3.99	0.34

$N = 104$.

Dipole modeling of the no-go N2 component In a subsequent repeated measures ANCOVA using frontal and posterior no-go N2 dipole scores as dependent variables, a significant Dipole $\times$ Reinforcement Level interaction was observed, $F(1.99, 180.97) = 6.49$, $p < .05$, $\eta^2 = .05$. For the frontal no-go N2 dipole, but not for the posterior no-go N2 dipole, a significant reinforcement level main effect was observed, $F(1.94, 176.60) = 14.49$, $p < .01$, $\eta^2 = .14$. Relative to nonreinforcement ($M = 15.46 \text{ nA}$, $SE = 2.73$), a less positive frontal N2 dipole was observed for the aversive verbal–monetary reinforcement ($M = 4.12 \text{ nA}$, $SE = 2.59$), $F(1, 91) = 18.68$, $p < .01$, $\eta^2 = .17$, and for the aversive verbal–nonmonetary reinforcement ($M = 4.78 \text{ nA}$, $SE = 2.75$), $F(1, 91) = 21.24$, $p < .01$, $\eta^2 = .19$. A Dipole $\times$ Cognitive Demand interaction, $F(1, 91) = 16.79$, $p < .01$, $\eta^2 = .16$, could be traced

back to a cognitive demand main effect for the frontal N2 dipole, $F(1, 91) = 7.84, p < .01, \eta^2 = .08$, with a more positive frontal N2 dipole for higher cognitive demand ($M = 14.59$ nA, $SE = 3.15$) than for lower cognitive demand ($M = 1.64$ nA, $SE = 3.40$), $F(1, 91) = 7.84, p < .01, \eta^2 = .08$, suggesting that lower cognitive demand resulted in more intense conflict monitoring than did higher cognitive demand. In contrast, the cognitive demand main effect at the posterior N2 dipole indicated a tendency for a more negative posterior N2 dipole in the higher-cognitive-demand condition ($M = 9.27$ nA, $SE = 2.67$) than in the lower-cognitive-demand condition ($M = 16.06$ nA, $SE = 2.88$), $F(1, 91) = 3.03, p < .09, \eta^2 = .03$.

A Dipole $\times$ Reinforcement Level $\times$ Cognitive Demand interaction, $F(1.99, 180.97) = 4.54, p < .05, \eta^2 = .05$, could be traced back to a Reinforcement Level $\times$ Cognitive Demand interaction only for the frontal N2 dipole, $F(1.94, 176.60) = 6.35, p < .01, \eta^2 = .07$. Separate analyses for low versus high cognitive demand revealed significant reinforcement level main effects for low cognitive demand, $F(1.95, 83.97) = 19.50, p < .01, \eta^2 = .31$, and high cognitive demand, $F(1.98, 97.21) = 5.30, p < .01, \eta^2 = .10$. Simple contrasts of the reinforcement level main effect for low cognitive demand suggested a substantial decrease of the frontal no-go N2 dipole from nonreinforcement to aversive verbal–nonmonetary reinforcement, $F(1, 43) = 20.84, p < .01, \eta^2 = .33$, and to aversive verbal–monetary reinforcement, $F(1, 43) = 31.58, p < .01, \eta^2 = .42$. The decrease from aversive verbal–nonmonetary reinforcement to aversive verbal–monetary reinforcement was marginally significant, $F(1, 43) = 2.96, p = .09, \eta^2 = .06$ (see Fig. 4). For high cognitive demand, simple contrasts of the reinforcement level main effect suggested a substantial decrease of the frontal no-go N2 dipole (i.e., the N2 dipole became more negative) from nonreinforcement to aversive verbal–nonmonetary reinforcement, $F(1, 49) = 9.20, p < .01, \eta^2 = .16$, but the no-go N2 dipole was less pronounced for aversive verbal–monetary reinforcement, $F(1, 49) < 1$, n.s. (Fig. 4). For the nonreinforcement condition, the effect of

cognitive demand was significant for neither the frontal N2 dipole nor the posterior N2 dipole, $F_s < 1.93$, n.s.

With regard to individual differences, a significant trait-BIS main effect occurred, $F(1, 91) = 5.46, p < .05, \eta^2 = .06$, indicating more intense conflict monitoring (i.e., a more negative N2 dipole) in individuals with higher trait-BIS scores than for those with lower trait-BIS scores, especially for the frontal no-go N2 dipole. The Reinforcement Level $\times$ Trait-BIS interaction was marginally significant, $F(1.89, 172.22) = 2.73, p = .07, \eta^2 = .03$. Pearson correlations of trait-BIS and the frontal no-go N2 dipole showed a tendency toward significance across all three reinforcement levels, $r = -.16, p = .10$ (Fig. 5a). Trait-BIS did not substantially correlate with the frontal no-go N2 dipole for the nonreinforcement condition, $r = -.07$, n.s., or for the aversive verbal–nonmonetary reinforcement condition, $r = -.12$, n.s. (Fig. 5b and c). The Pearson correlation indicated a more negative frontal no-go N2 dipole for individuals with higher trait-BIS scores than for those with lower trait-BIS scores exclusively following aversive verbal–monetary reinforcement, $r = -.25, p < .05$ (all p s two-tailed; Fig. 5d). Partial correlations (correcting for the posterior no-go N2 dipole scores of the corresponding reinforcement level) of trait-BIS and the frontal no-go N2 dipole were nonsignificant for nonreinforcement, $r = -.11$, and for aversive verbal–nonmonetary reinforcement, $r = -.04$, but were significant for aversive verbal–monetary reinforcement, $r = -.21, p < .05$ (all p s two-tailed).

Pearson correlations were observed in particular between the behavioral parameters and the frontal no-go N2 dipole (Table 4). In the aversive verbal–nonmonetary reinforcement, a more negative frontal no-go N2 dipole (i.e., more pronounced conflict monitoring intensity) was associated with a lower error-of-commission rate, a higher sensitivity, and shorter go and no-go response times (particularly in the low-cognitive-demand condition). In the aversive verbal–monetary reinforcement condition, similar associations were found for the error-of-commission rate, sensitivity, and response times to no-go and

Fig. 4 Modulation of the frontal no-go N2 dipole by means of aversive reinforcement and cognitive demand ($N = 104$). Error bars represent the standard errors

go trials. Substantial correlations in the nonreinforcement condition were exclusively observed for the error-of-commission rate. Altogether, these Pearson correlations illustrate that the frontal no-go N2 dipole was predictive for the behavioral parameters within the corresponding reinforcement levels. Moreover, these findings facilitate a differentiation of the three reinforcement levels, because substantial correlations occurred in particular for aversive verbal–nonmonetary reinforcement and for aversive verbal–monetary reinforcement.

Discussion

With regard to the question of how aversive reinforcement and cognitive demand modulate conflict monitoring intensity, we

observed a more negative frontal no-go N2 dipole for task conditions with more intense aversive reinforcement (i.e., aversive verbal–nonmonetary or aversive verbal–monetary reinforcement) and lower cognitive demand. Main effects of cognitive demand were captured by a posterior mean no-go N2 amplitude and a posterior no-go N2 dipole indicating a more pronounced posterior no-go N2 dipole following high versus low cognitive demand. Moreover, the decrease of the mean no-go N2 amplitude from nonreinforcement to aversive verbal–nonmonetary reinforcement was more pronounced on frontal than on parietal sites. Thus, more frontal sites reflected the expected increase in conflict monitoring. In line with our prediction, the frontal no-go N2 dipole was more negative in higher- than in lower-trait-BIS individuals, indicating more pronounced conflict monitoring in higher-trait-BIS individuals,

Fig. 5 Scatterplots of the association between trait-BIS scores ($N = 104$) and the frontal no-go N2 dipole (in nanoamperes), collapsed across all three reinforcement levels (a) and separately for the three reinforcement levels (b to d)

Table 4 Pearson correlations (correcting for the posterior no-go N2 dipole in corresponding reinforcement levels) between behavioral parameters and the frontal no-go N2 dipole, with regard to reinforcement levels and cognitive demand (Study 1)

Reinforcement Level	Across Cognitive Demand Levels ($N = 104$)	High Cognitive Demand ($n = 55$)	Low Cognitive Demand ($n = 49$)
Nonreinforcement			
EOC rate, frontal no-go N2 dipole	.19[†]	.10	.28[†]
d' , frontal no-go N2 dipole	-.01	.16	-.15
No-go RT, frontal no-go N2 dipole	.07	.09	.12
Go RT, frontal no-go N2 dipole	.05	.03	.03
Aversive Verbal–Nonmonetary			
EOC rate, frontal no-go N2 dipole	.30[*]	.27[†]	.20
d' , frontal no-go N2 dipole	-.24[*]	-.18	-.24[†]
No-go RT, frontal no-go N2 dipole	.13	-.01	.31[*]
Go RT, frontal no-go N2 dipole	.10	-.11	.30[*]
Aversive Verbal–Monetary			
EOC rate, frontal no-go N2 dipole	.33^{**}	.18	.36[*]
d' , frontal no-go N2 dipole	-.36^{**}	-.13	-.39[*]
No-go RT, frontal no-go N2 dipole	.18[†]	.17	.27[†]
Go RT, frontal no-go N2 dipole	.03	-.16	.23

d' , sensitivity. EOC rate, error-of-commission rate. No-go RT, response times to no-go stimuli. Go RT, response times to go stimuli. With the exception of a significant Pearson correlation in the total sample between no-go RTs for the aversive verbal–monetary reinforcement level and the posterior no-go N2 dipole ($r = .24^*$), no further correlations of the behavioral parameters with the posterior N2 dipole were significant. ^{*} $p < .05$ (two-tailed); ^{**} $p < .01$ (two-tailed); [†] $p \leq .10$ (two-tailed).

especially in the aversive verbal–monetary reinforcement condition. In general, the expected reinforcement-related variations of conflict monitoring intensity were observed, especially in the frontal no-go N2 dipole. However, we could not rule out the possibility that our aversiveness findings on frontal N2 amplitude and the frontal N2 dipole were at least in part an effect of the constant order of the reinforcement levels.

Study 2

To make sure that the aversiveness effects of Study 1 were not an effect of the constant order of the reinforcement levels (nonreinforcement, aversive verbal–nonmonetary, and aversive verbal–monetary), the reinforcement levels were counterbalanced in a second study. Therefore, Study 2 was conducted to validate the aversiveness of each reinforcement condition by means of affect ratings and behavioral data. With regard to state-affect ratings, we expected lower sum scores of self-reported pleasure (i.e., higher self-reported unhappiness) in the aversive reinforcement conditions than with nonreinforcement. If the behavioral results were similar to those in Study 1, we could conclude that the results of the frontal mean no-go N2 amplitude and the frontal no-go N2 dipole could indeed be traced back to the aversiveness of the reinforcement levels. More specifically, we proposed an increase of d' with more intense aversive

reinforcement and a decrease of go response times from nonreinforcement to the aversive reinforcement levels, similar to the findings observed in Study 1.

Method

Participants A total of 47 right-handed students at a German university (29 female, 18 male; age: $M = 24.93$ years, $SD = 7.18$, range 19–50 years). Again, all participants gave written informed consent and participated voluntarily in this study. The ages of the participants in Samples 1 and 2 did not differ substantially, $t(149) = 1.44$, $p = .15$, and all participants had normal or corrected-to-normal vision. As in Study 1, independent-samples t tests indicated that trait-BIS scores did not differ substantially between the cognitive-demand groups, $t(45) = 0.78$, n.s. Moreover, chi-square tests indicated that the numbers of men and women who were assigned to a low- or a high-cognitive-demand group did not differ substantially, either, $\chi^2 = 0.51$, n.s.

Measures As in Study 1, the German version of the BIS/BAS scales (Strobel et al., 2001) was applied, and the Cronbach's alphas for the BIS scale ($\alpha = .81$) and the total BAS scale ($\alpha = .75$) were moderate. In addition, the Self-Assessment Manikin inventory (SAM; Bradley & Lang, 1994) was applied only in Study 2. The SAM inventory is

a nonverbal pictorial assessment instrument that measures the dimensions of pleasure, arousal, and dominance. Each dimension is indicated by five manikins. The intensity on each dimension can be answered on a 9-point Likert scale. On each dimension, participants can make an “X” either on one of the manikin pictures or between two pictures. For pleasure, the SAM ranges from a smiling, happy figure (rating score = 1) to a frowning, unhappy figure (rating score = 9). For arousal, the SAM ranges from a sleepy figure with eyes closed (rating score = 1) to an excited figure with eyes widely open (rating score = 9). The dominance scale of the SAM includes a small figure, indicating that someone feels controlled and submissive (rating score = 1), whereas a large figure represents in-control and powerful feelings (rating score = 9).

Go/no-go task The go/no-go task was the same as in Study 1 (for examples of the trial sequence, see Fig. 1), with the one exception that the reinforcement levels were counterbalanced. Participants performed either a high- or a low-cognitive-demand go/no-go task with one of the three reinforcement-level sequences: (1) nonreinforcement → aversive verbal–nonmonetary reinforcement → aversive verbal–monetary reinforcement; (2) aversive verbal–nonmonetary reinforcement → aversive verbal–monetary reinforcement → nonreinforcement; (3) aversive verbal–monetary reinforcement → nonreinforcement → aversive verbal–nonmonetary reinforcement. As in Study 1, assignment to the cognitive demand groups was counterbalanced (every second participant performed the lower-cognitive-demand condition). As in Study 1, go and no-go letters were changed from task block to task block. In sum, the number of trials per block, trial sequence (Fig. 1), reinforcement levels, cognitive demand levels, and break length between the task blocks were the same as in Study 1.

Procedure About one week before the examination date, participants were instructed by telephone to omit alcohol use, to avoid unusual caffeine and nicotine consumption, and to avoid taking other stimulating substances the day before the examination. After arriving, participants gave written informed consent. Participants were seated in a comfortable chair approximately 95 cm from the 20-in. TFT computer screen. The room was sound-attenuating and well-lit. Presentation version 12.1 software was used to present the go/no-go task, and participants performed 10 practice trials. During task performance, the experimenter sat in an adjacent room, where the data were recorded. Each examination lasted approximately 1.5 h. After finishing the task, participants received credit points for participating. At the beginning of the aversive verbal–monetary task condition, participants received an additional starting bonus of €7. Each too-slow go response and each erroneous no-go response resulted in a loss of 3 cents. Participants were told that these losses would be subtracted from their bonus. If no errors or too-slow responses occurred

in the monetary loss condition, participants received the complete starting bonus of €7. They did not receive trial-by-trial monetary gains following correct go responses in this task condition. The positive and negative affect items of the PANAS were assessed prior to and after task performance in both studies.² The SAM inventory was applied in Study 2 prior to task performance and after each reinforcement condition of the go/no-go task, resulting in four measurement occasions. In Study 2, the procedure was the same as in Study 1, with the exceptions that the SAM inventory was applied, that EEGs were not recorded, and that the reinforcement conditions were randomized.

Statistical analysis Using SPSS 16.0 for the statistical analysis, we conducted a repeated measures ANCOVA with Reinforcement Level as a repeated factor (within subjects), Cognitive Demand and Gender as between-subjects factors, and trait-BIS and trait-BAS as covariates. The high-cognitive-demand level was assigned to $n = 23$ participants, and the low-cognitive-demand level to $n = 24$ participants. To investigate

² The state version (“moment” instruction) of the German translation of the Positive and Negative Affect Schedule (Krohne, Egloff, Kohlmann, & Tausch, 1996) was filled out both prior to (T_1) and immediately after (T_2) task completion, to investigate whether the go/no-go task had effects on state positive affect (PA) and state negative affect (NA). The PANAS consists of 10 PA and 10 NA items that are answered in a 5-point, Likert-type answer format. The Cronbach’s alpha coefficients for PA (premeasure, .81; postmeasure, .89) and NA (premeasure, .74; postmeasure, .65) were moderate in Study 1. Cronbach’s alpha for PA was comparable to values found in prior validation studies (Watson, Clark, & Tellegen, 1988) and to findings of a reliability generalization study on PA and NA (Leue & Lange, 2011), whereas Cronbach’s alpha for NA was somewhat smaller.

In Study 1, repeated measures ANOVAs including the PA and NA sum scores at T_1 and T_2 revealed a Time $\times$ Affect interaction, $F(1, 102) = 20.83, p < .01, \eta^2 = .17$. This interaction could be traced back to a PA main effect, $F(1, 102) = 65.69, p < .01, \eta^2 = .39$, and an NA main effect, $F(1, 102) = 18.49, p < .01, \eta^2 = .15$. Both main effects indicated a decrease in the sum scores from T_1 to T_2 , whereby the decrease of the PA sum scores was significantly more pronounced (difference score: $M = -4.25, SD = 1.71$) than the decrease of the NA sum scores (difference score: $M = -1.25, SD = 0.52$), $t(103) = -4.84, p < .01$. The means of the PA sum scores were $M = 31.71 (SD = 5.42)$ prior to task performance and $M = 27.46 (SD = 7.13)$ after finishing the task. The means of the NA sum scores were $M = 13.48 (SD = 2.98)$ prior to task performance and $M = 12.23 (SD = 2.46)$ after finishing the task.

In Study 2, the Cronbach’s alpha coefficients of PA (premeasure, .78; postmeasure, .88) and NA (premeasure, .73; postmeasure, .86) were moderate. Repeated measures ANOVAs including the PA and NA sum scores at T_1 and T_2 revealed a tendency toward a Time $\times$ Affect interaction, $F(1, 44) = 4.83, p = .05, \eta^2 = .10$. This interaction could be traced back to a time main effect for PA, $F(1, 44) = 20.19, p < .01, \eta^2 = .31$, indicating that PA decreased from $T_1 (M = 30.73, SD = 5.03)$ to $T_2 (M = 27.22, SD = 6.79)$. A time main effect for NA was not observed, $F(1, 44) = 1.06, p = .31, \eta^2 = .02$ [$M(T_1) = 13.13, SD = 3.22$; $M(T_2) = 12.53, SD = 3.94$]. The decrease in the PA sum scores was significantly more pronounced (difference score: $M = -3.51, SD = 4.79$) than the decrease in the NA sum scores (difference score: $M = -0.60, SD = 4.57$), $t(45) = -2.60, p < .05$.

the modulation of conflict monitoring intensity by means of trait-BIS and trait-BAS (Shapiro–Wilk test: $ps < .10$), normalized (Blom, 1958) trait-BIS and trait-BAS sum scores were applied as covariates in a repeated measures ANCOVA. The normalized sum scores were normally distributed (all $ps > .10$) and mean-centered. For the response times, a violation of the normal distribution was also observed (Shapiro–Wilk test: $ps < .10$). As in other studies, response times were therefore transformed using the natural logarithm (e.g., Wilkowski et al., 2010). Violations of sphericity were Greenhouse–Geisser corrected, and sensitivity (d') was computed according to Stanislav and Todorov (1999).

Results

Self-ratings With regard to the SAM inventory, a significant main effect of reinforcement level was observed for the pleasure scale (with high-sum scores representing unhappy mood), $F(1.94, 71.89) = 3.82, p < .05, \eta^2 = .09$. Simple contrasts indicated a substantial increase in unhappiness from nonreinforcement ($M = 3.66, SD = 1.46$) to aversive verbal–monetary reinforcement ($M = 4.13, SD = 1.85$), $F(1, 37) = 6.08, p < .05, \eta^2 = .14$, and from aversive verbal–nonmonetary reinforcement ($M = 3.77, SD = 1.66$) to aversive verbal–monetary reinforcement, $F(1, 37) = 4.29, p < .05, \eta^2 = .10$. The reinforcement level main effect for SAM-pleasure could be traced back to a linear trend, $F(1, 37) = 6.08, p < .05, \eta^2 = .14$. Although the simple contrast between nonreinforcement and aversive verbal–nonmonetary reinforcement was not significant for SAM-pleasure, the linear trend of the reinforcement level main effect for SAM-pleasure indicated an increase in unhappiness from nonreinforcement to both aversive verbal–nonmonetary reinforcement and aversive verbal–monetary reinforcement. The quadratic trend of the reinforcement level main effect for SAM-pleasure was not significant, $F < 1, n.s.$

Moreover, there was a Reinforcement Level $\times$ Trait-BIS interaction, $F(1.94, 71.89) = 3.57, p < .05, \eta^2 = .09$. Pearson correlations indicated that trait-BIS correlated substantially with SAM-pleasure following both aversive verbal–nonmonetary reinforcement, $r = .40, p < .01$, and aversive verbal–monetary reinforcement, $r = .38, p < .01$, but not following nonreinforcement, $r = .16, n.s.$ (all rs two-tailed). The results for state positive and negative affect are given in note 2.

Behavioral data As in Study 1, paired t tests revealed that the commission error rate ($M = .18, SD = .23$) was significantly higher than the omission error rate ($M = .01, SD = .02$) across all three task conditions, $t(46) = 5.13, p < .01$. Again as in Study 1, the analysis of sensitivity revealed a significant cognitive demand main effect, with higher sensitivity in the low-cognitive-demand (65:35) condition than in the high-

cognitive-demand (80:20) condition, $F(1, 45) = 9.97, p < .01, \eta^2 = .18$ (for descriptive statistics, see Table 2). The reinforcement level main effect was significant for sensitivity, as in Study 1, $F(1.57, 70.73) = 38.06, p < .01, \eta^2 = .46$, with a higher d' for aversive verbal–monetary reinforcement than for aversive verbal–nonmonetary reinforcement, $F(1, 45) = 154.47, p < .01, \eta^2 = .77$, and for nonreinforcement, $F(1, 45) = 22.57, p < .01, \eta^2 = .33$ (see Table 2). For sensitivity, the trait-BIS main effect was not significant, $F < 1, p = .36$.

The reinforcement level main effect was not significant for the mean go response times, $F(1.91, 63.07) = 2.07, p = .13, \eta^2 = .06$ (for descriptive statistics, see Table 2). As in Study 1, there was no cognitive demand main effect, $F(1, 33) = 1.82, p = .19, \eta^2 = .05$, and no Reinforcement Level $\times$ Cognitive Demand interaction for mean go response times, $F(1.91, 63.07) = 1.19, p = .31, \eta^2 = .04$. There was no significant reinforcement level main effect for the mean no-go response times and for cognitive demand, $Fs < 1, n.s.$ No personality main effects and no substantial interaction with reinforcement level or cognitive demand were observed for any performance parameter, $Fs < 1, n.s.$, in Study 2.

Discussion

The reinforcement level main effect for SAM-pleasure indicated a substantial increase of unhappiness from nonreinforcement to aversive verbal–monetary reinforcement and from aversive verbal–nonmonetary reinforcement to aversive verbal–monetary reinforcement. Although the simple contrast between nonreinforcement and aversive verbal–nonmonetary reinforcement was not significant for SAM-pleasure, the linear trend of the reinforcement level main effect for SAM-pleasure indicated increases in unhappiness from nonreinforcement to both aversive verbal–nonmonetary reinforcement and aversive verbal–monetary reinforcement. Moreover, individuals with higher trait-BIS scores reported more unhappiness with regard to the aversive reinforcement conditions than did lower-trait-BIS individuals. This is in line with rRST, which presumes that higher-trait-BIS individuals are more sensitive to conflict information and aversive reinforcement (Corr, 2008).

The results for the error-of-commission rate and the error-of-omission rate were the same as in Study 1. Moreover, the effects of cognitive demand were the same in both studies for both sensitivity and mean go response times. The main effect of reinforcement level for sensitivity could be traced back to the same simple contrast results as in Study 1 (i.e., higher sensitivity in the aversive verbal–monetary condition than in the aversive verbal–nonmonetary condition and the nonreinforcement condition). In contrast to Study 1, the reinforcement level main effect for mean go response times was not significant in Study 2. This might have been due to the smaller sample size in Study

2. As in Study 1, we did not observe main effects of reinforcement level and cognitive demand for mean no-go response times. Accordingly, we concluded that the results of the behavioral parameters in both studies were highly comparable. Because of the similarity of the behavioral findings in Studies 1 and 2, we presumed that the N2 results of Study 1 were not simply an effect of the constant task order, but that they indeed represent the effects of aversive reinforcement. Subsequently, we will discuss the N2 results in a broader conceptual framework.

General discussion

The present study investigated modulations of conflict monitoring intensity by means of mean no-go N2 amplitudes and by means of no-go N2 dipoles. We were specifically interested in the combined effects that aversive reinforcement and cognitive demand have on conflict monitoring intensity, in order to investigate whether the effects of trait-BIS in conflict tasks (see, e.g., Amodio et al., 2008) represent the effects of aversive reinforcement or are also related to the cognitive demands of conflict tasks. Therefore, we manipulated three levels of aversive reinforcement (within-subjects factor) and two levels of cognitive demand (between-subjects factor) in a go/no-go task. By independently manipulating aversive reinforcement levels and cognitive demand levels, we have extended previous studies of individual differences in conflict monitoring (Table 1) that applied a single cognitive demand level (i.e., one go:no-go ratio) and a single aversive reinforcement level (e.g., Amodio et al., 2008; Sehlmeier et al., 2010). We have also extended studies in which either different levels of aversive reinforcement (e.g., Leue et al., *in press*) or different levels of cognitive demand (Bruin & Wijers, 2002; Nieuwenhuis et al., 2003) have been manipulated.

The results for the behavioral data of Study 1 (noncounterbalanced order of reinforcement task blocks) and Study 2 (counterbalanced order of reinforcement task blocks) were very similar. Therefore, we concluded that counterbalancing the order of the reinforcement conditions did not substantially alter the results. Accordingly, the reinforcement-related results for frontal mean no-go N2 amplitude and the frontal no-go N2 dipole can be interpreted as the effect of the aversive reinforcement levels and not simply a result of the constant order of the task blocks. Our results indicate that the effects of reinforcement level on conflict monitoring are reflected in frontal areas of the brain that have been associated with ACC functioning. More specifically, our N2 findings illustrate that aversive verbal–nonmonetary and aversive verbal–monetary reinforcement, relative to nonreinforcement, enhance the conflict monitoring intensity (cf. Leue et al., *in press*). With regard to the conjoint effects of cognitive demand and aversive reinforcement during conflict monitoring, it is noteworthy that the

frontal N2 dipole was more negative for lower cognitive demand than for higher cognitive demand when aversive verbal–nonmonetary reinforcement and aversive verbal–monetary reinforcement were provided. More concretely, the frontal N2 dipole was most negative in the low-cognitive-demand, high-aversive-reinforcement condition. This might indicate that in a low-cognitive-demand condition, individuals have more resources available to anticipate the aversive effects of erroneous responses. Consequently, higher cognitive demand might prevent participants from focusing on the anticipation of aversive consequences of erroneous responses (probably because fewer or no resources for the processing of aversive reinforcement are available). Altogether, our results for the frontal N2 support the prediction of the rRST that the anticipation of aversive reinforcement intensifies conflict processing (Corr, 2008). In contrast to prior studies on trait-BIS and conflict monitoring (e.g., Amodio et al., 2008), the present study illustrates for the first time that the effects of trait-BIS on conflict monitoring intensity are influenced by the effects of aversive reinforcement and by the effects of cognitive demand. This becomes apparent from the trait-BIS main effect that was observed for the frontal no-go N2 dipole. Thus, it is possible to conclude that the effects of trait-BIS in conflict tasks that have been reported in previous studies (see Table 1) represent the conjoint effects of a specific combination of aversive reinforcement and cognitive demand levels. Moreover, from a more general point of view, variations of conflict monitoring intensity are related to the conjoint effects of aversive reinforcement and cognitive demand, as has been demonstrated by the Reinforcement Level $\times$ Cognitive Demand interaction for the frontal no-go N2 dipole. Finally, although reinforcement-related variations were found for the mean frontal N2 amplitude, the conjoint effects of aversive reinforcement and cognitive demand were obtained especially for the frontal no-go N2 dipole. Consequently, summary ERP measures such as the no-go N2 amplitude might prevent researchers from disentangling the effects that influence variations of conflict monitoring intensity.

Additionally, the more pronounced frontal no-go N2 dipole in higher- relative to lower-trait-BIS individuals across task conditions suggests that the aversive natures of cognitive demand and aversive reinforcement serve to enhance the conflict monitoring intensity in higher-trait-BIS individuals, as predicted by rRST (Corr, 2008). This result might also be regarded as a conceptual replication of the results of Amodio et al. (2008), who demonstrated a more negative N2 amplitude in higher- than in lower-trait-BIS individuals in a go/no-go task (80:20 go:no-go ratio) in which aversive verbal–nonmonetary reinforcement was provided following too-slow or erroneous responses (but that featured no variations of reinforcement level and cognitive demand).

As becomes apparent from the posterior N2 findings, higher cognitive demand also tends to intensify attentional

aspects of conflict monitoring in centro-parietal brain regions. Because higher cognitive demand was induced by means of a lower no-go stimulus frequency, one might conclude that top-down attentional control becomes more important during conflict monitoring when no-go stimuli occur less frequently (Gibbons, 2006; Kehler et al., 2009). This conclusion corresponds to that of Liston, Matalon, Hare, Davidson, and Casey (2006), who demonstrated the involvement of more posterior brain regions when the requirement of stimulus discrimination becomes more intense. Moreover, the result that higher cognitive demand tended to evoke a more negative posterior N2 dipole than did lower cognitive demand suggests that the posterior N2 and the parietal P3 might represent similar processes (cf. Nieuwenhuis et al., 2003). Studies on mental effort have introduced the P3 amplitude as an indicator of conscious stimulus processing (Mulder, 1986; Polich, 1987), and the parietal P3 amplitude has been discussed as indicating the amount of mental effort invested (cf. Beauducel, Brocke, & Leue, 2006). Because conflict monitoring is regarded as a demanding process, further research should investigate the relationship between mental effort and reinforcement-related conflict monitoring (Botvinick, Huffstetler, & McGuire, 2009).

Limitations and future directions

Despite the substantial similarity of the behavioral data in Studies 1 and 2, the present N2 results need to be replicated, ideally in a study with counterbalanced reinforcement-related and demand-related task blocks (as demonstrated in Study 2 for the behavioral data) with a sufficiently large sample. In this respect, we could not rule out that the nonsignificant reinforcement level effect for the go response times was due to the smaller sample size in our Study 2. It should also be noted that our aversive verbal–nonmonetary reinforcement level was only slightly more aversive than the nonreinforcement condition. Future studies might apply auditory rather than written aversive verbal feedback in order to intensify the differentiation of the reinforcement levels. Moreover, the rather large number of correlations calculated between the frontal N2 dipole and the behavioral parameters (Table 4) may have resulted in an inflation of the statistical power for these correlations. However, these correlations were reported in order to give a complete description of these data. They are not related to the central aims of this report.

In several studies, researchers have pointed out that the N2 component and the ERN are related to similar processes (Amodio et al., 2008; Boksem et al., 2006; Gehring et al., 2000; Hajcak & Foti, 2008), because both ERP components have been located in the ACC and in similar time windows. Moreover, prior studies have demonstrated that both ERPs are related to motivational traits and to conflict monitoring (e.g., Amodio et al., 2008). However, Yeung and Cohen (2006)

pointed out that the ERN should primarily reflect whether participants attend to relevant stimulus information, and that the ERN is probably more related to error monitoring than to conflict monitoring. In contrast, the N2 amplitude should reflect whether participants process irrelevant stimulus information, and the N2 has primarily been related to conflict monitoring (Yeung & Cohen, 2006). Since the processing of irrelevant stimulus information and conflict monitoring are both indicated by the N2 component, there might be a link between conflict monitoring and the processing of irrelevant information. The anticipation of aversiveness might be a basis for this link.

To further elucidate this link, it would be interesting in future source localization studies to investigate the functional similarities of both ERP components from the perspectives of Botvinick's (2007) integrative account of conflict monitoring, of rRST (Corr, 2008), and of reinforcement learning theory (Holroyd & Coles, 2002). However, whereas the ERN is by definition related to processes that occur along with errors, the N2 captures processes that occur when conflict processing is necessary in order to avoid errors. Since the ERN primarily represents error processing, whereas the N2 represents conflict monitoring (Yeung & Cohen, 2006), it is possible that the effects of reinforcement found for the N2 will not be found for the ERN. If only information that is directly relevant for stimulus processing determines the ERN amplitude, one would not expect to find effects of reinforcement on the ERN. Whether reinforcement conditions could serve to induce dissociations between the ERN and the N2 should be explored in future research, because such a dissociation might allow for more precise descriptions of the processes that are related to conflict monitoring.

Conclusions

The present study supports the prediction, following from Botvinick (2007) and Corr (2008), that conflict processing is linked to aversiveness. Our data provide evidence that conflict monitoring might comprise different processes that can be decomposed into different N2 topographies by means of the source localization technique. The frontal N2 dipole represents processes that are related to the anticipation of the aversive nature of conflict. The conjoint effects of cognitive demand and aversive reinforcement on this dipole suggest that conflict monitoring is highest in a situation that requires low cognitive demand but provides intense aversive reinforcement following erroneous responses. Thus, cognitive demand seems to reduce the anticipation of aversive reinforcement in the case of erroneous responses. The finding that conflict monitoring is more pronounced in higher- than in lower-trait-BIS individuals is compatible with rRST and supports the idea that aversive reinforcement intensifies conflict monitoring. As an extension of prior studies on conflict monitoring, the present study

suggests that independent manipulations of aversive reinforcement and cognitive demand are required in order to understand the processes underlying variations in conflict monitoring intensity. The joint manipulation of aversive reinforcement and cognitive demand is important because cognitive demand, although expected to be aversive, might prevent individuals from focusing on the signals of aversive reinforcement. Thus, under some circumstances, cognitive demand might even reduce the aversiveness of a go/no-go task.

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