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Anxiety disrupts the evaluative component of performance monitoring: An ERP study

Kristien Aarts and Gilles Pourtois

Department of Experimental Clinical and Health Psychology, Ghent University, Belgium

Correspondence:

Gilles Pourtois

Department of Experimental Clinical and Health Psychology

Ghent University

Henri Dunantlaan 2

9000 Gent

Belgium

Phone: +32 9 264 9144

Email: gilles.pourtois@ugent.be

Abstract

Thirty low and 30 high anxious participants performed a speeded Go/noGo task during which they had to rely on evaluative feedback to infer whether their actions were timely (correct) or not. We focused on FRN, an ERP component that is sensitive to the valence of feedback. Depending on the context, neutral faces served either as positive or negative feedback. Whereas the FRN of low anxious individuals did discriminate between neutral faces when used either as positive or negative feedback, the FRN of high anxious individuals did not. However, before the FRN, we also found evidence for a differential perceptual effect at the level of the N170 face-specific component between the two feedback conditions, equally so in low and high anxious individuals. These results suggest that anxiety disrupts selectively the evaluative component of performance monitoring, which presumably allows to ascribe a given value (either positive or negative) to actions.

Keywords: Anxiety, ERP, FRN, N170, attribution

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Depending on the situation and circumstances, the control of behavior is based on the monitoring of either internal or external signals, or sometimes a combination of both. For example, the adequacy of a given action in response to a familiar stimulus may be determined based on an internal representation allowing to compare the discrepancy between the actual and expected or desired action, with a swift detection of any divergence between the two (Gehring et al., 1993). However, in many situations, performance monitoring cannot be achieved solely based on the processing of internal signals, but the processing of new external feedback information in the environment is required to establish whether the current action is appropriate (e.g., timely, correct) or not. Hence, the processing of feedback information available in the environment often indicates the appropriateness of certain actions and in turn allows to correct or adjust behavior if required, eventually leading to learning and preventing errors from recurring in the future (Holroyd & Coles, 2002; Rabbitt, 1966).

Several ERP studies looking at outcome evaluation processes based on external feedback have described an ERP component, the feedback-related negativity (FRN) that is selectively associated with the processing of the valence or motivational significance of the feedback (Gehring & Willoughby, 2002; Holroyd & Coles, 2002; Miltner et al., 1997). The FRN is a negative component peaking at fronto-central electrodes roughly 250-300 ms after presentation of relevant feedback information. Usually, the FRN was found to be larger after negative feedback on task performance, e.g., the presentation of an evaluation signal indicating error commission or monetary loss, compared to positive feedback, e.g., the presentation of an evaluation signal indicating correct performance or monetary reward (Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003). These findings point to the involvement of the FRN in the processing of the valence or reward value of the feedback. Interestingly, the FRN component shares many electrophysiological properties with another ERP component, the error-related negativity (ERN; Falkenstein et al., 2000; Gehring et al., 1993), which is also involved in performance monitoring, though based on the processing of internal error signals. The ERN is a negative component generated roughly 50-100 ms following error commission over fronto-central scalp electrodes. In both cases, this negative ERP component would reflect the activation of a reinforcement learning system within the dorsal Anterior Cingulate Cortex (dACC) that enables a rapid evaluation of outcomes or actions (Frank et al., 2005; Holroyd & Coles, 2002).

Noteworthy, although the FRN primarily reflects an evaluative component, this ERP component is also permeable to individual differences in affect. Because the hypersensitivity to negative events and the tendency to worry about negative outcomes are hallmarks of several affective personality traits or disorders like anxiety and depression (Maner & Schmidt, 2006; Mineka et al., 2003; Wray & Stone, 2005), one may assume that performance monitoring may vary with these affective personality traits. Consistent with this hypothesis, several studies have reported an effect of anxiety or depression on the ERN (e.g., Aarts & Pourtois; 2010; Holmes & Pizzagalli, 2008; Olvet & Hajcak, 2008). By contrast, the evidence supporting a systematic modulation of the FRN (and hence the processing of external evaluative feedback) as a function of negative affect is mixed. In a recent study, De Pascalis et al. (2010) found that individuals who were more sensitive to punishment (as measured using the BIS/BAS; see Carver & White, 1994) had a larger FRN to monetary loss following incorrect noGo trials during a Go/noGo task. In an earlier ERP study, Tucker et al. (2003) found that (clinically) depressed patients had increased FRN following all feedback, i.e., feedback following fast, medium as well as slow responses. Surprisingly, moderately depressed individuals showed larger FRN following feedback evaluating slow responses compared to the FRN amplitude in severely depressed patients. In contrast to these results, Foti and Hajcak (2009) reported a blunted difference in FRN amplitude between negative (non-reward) and positive (reward) feedback in depressed individuals. When turning to anxiety, which is usually related to depression (Beck et al. 1988; Mendels et al., 1972) and punishment sensitivity (Bijttebier et al., 2009), but which is also mainly characterized by an extreme worry about the expectancy of possible failures in the future (Eisenberg et al., 1998; Mitte, 2007; Shepperd et al., 2005), the results of two studies converged and showed a larger FRN amplitude for low, compared to high anxious individuals (Gu et al., 2010; Simons, 2010). According to Yeung et al. (2005), the FRN also reflects an evaluation process that is influenced by the motivational significance of ongoing actions. These authors reported a correlation between the amplitude of the FRN and the subjective involvement in the task. Consistent with this notion, two recent ERP studies confirmed that evaluative feedback processing (and hence the FRN component) is also influenced by higher-level cognitive or motivational factors (i.e., responsibility, see Li et al., 2010; empathy, see (Fukushima & Hiraki, 2009), which may, depending on the context or situation, make the evaluative feedback stimulus more or less salient. Hence, depending on the specific goals and needs, the FRN may vary in magnitude in response to evaluative performance feedback. These studies therefore confirm that motivational significance (besides valence) may be an important determinant of the amplitude modulations of the FRN found during standard performance monitoring tasks. More generally, these results suggest that the FRN component is not encapsulated or immune to higher-level motivational or emotional factors, such that the affective predispositions of the participant may in principle modulate the size and expression of this performance monitoring ERP component. In this study, we tested this prediction and compared the FRN of low vs. high trait anxious individuals during a standard speeded Go/noGo task.

The goal of our study was to investigate effects of sub clinical trait anxiety on performance monitoring, when this process primarily relies on the processing of external evaluative feedback (with a focus on the FRN component therefore). Notably, these external feedback consisted of neutral and emotional faces in our study, because these visual stimuli usually provide important social and ecologically-valid signals used to gauge the actions and intentions of our conspecifics in daily life situations. Moreover, because emotional faces are complex stimuli that carry an intrinsic emotional value (when compared to abstract symbolic cues) and because negative emotional faces might be perceived or attended differentially in high compared to low anxious individuals (Fox et al., 2002; Knyazev et al., 2008), we used an experimental procedure enabling to explore performance monitoring brain effects when the intrinsic valence/pleasantness of the feedback stimulus was controlled for and eventually neutralized. More specifically, we compared performance monitoring (i.e., FRN) of low vs. high trait anxious participants when the feedback information used was kept constant (i.e., same neutral visual stimuli serving as performance feedback), but the perceived experimental situation could be either “positive” or “negative”. This manipulation allowed us to compare the exact same physical stimuli (i.e., neutral faces) used as performance feedback for positive outcomes in one context and for negative outcomes in the other, and test if performance monitoring brain processes (with a focus on the FRN component) differed between low vs. high trait anxious individuals.

We tested the hypothesis that performance monitoring processes of high anxious participants based on the processing of external evaluative feedback may be impaired, reflected by a blunted FRN to negative feedback in these participants. More specifically, we surmised that the impairment in high anxious individuals does not translate a relative insensitivity to outcome evaluation in general, but reflects instead a failure to readily compare the perceived valence of the feedback with the inferred (internalized) value of the action (just performed). In this framework, a blunted FRN component may reflect an inability to relate the valence of the feedback (either positive or negative) to the internalized value of the action (that has been made prior to feedback delivery and therefore awaits evaluation; see Holroyd & Coles, 2002). To indirectly validate this assumption, we also explored the possible relationship between "locus of control" (LOC; Rotter, 1966) and the FRN component. The LOC provides an estimate of attribution style, defined as the disposition to ascribe the cause of actions or events to either internal or external drives or forces. We reasoned that participants with an internal (as opposed to external) LOC may probably more easily relate or integrate the value of the (external) evaluative feedback with the (internally-generated) action (i.e. cause) they have just made and which is evaluated by the feedback. Accordingly, if the FRN reflects the integration process linking the perceived valence of the feedback with the internalized value of the action (just performed) during performance monitoring, we may thus predict a larger FRN for individuals characterized by a more internal (as opposed to external) LOC. Moreover, because earlier studies found a relationship between LOC and trait anxiety (i.e. high anxious individuals have a more external LOC, see Archer, 1979), we sought to assess whether higher levels of trait anxiety may somehow downplay the possible link between LOC and the FRN (see also Gu et al., 2010; Hajcak et al., 2003).

Although we mainly focused on the FRN component in this study, given the strong link between this specific ERP deflection and performance monitoring processes (Holroyd & Coles, 2002), we could also explore whether trait anxiety and/or the perceived valence of the feedback not only influenced the FRN component, but also an earlier structural encoding stage during evaluative feedback processing. Faces elicit a well-described category-selective ERP component i.e., the N170, which reflects structural encoding (Bentin, Allison, Puce, Perez, & McCarthy, 1996; George et al., 1996). This component peaks 150-170 ms after face stimulus onset with a maximum amplitude over right lateral occipital-temporal and hence it can easily be dissociated in time and space from the FRN deflection. Although some previous ERP studies have failed to reveal any change of the N170 amplitude with the emotional facial expression content of the faces (Eimer & Holmes, 2002), other studies have reported systematic modulations of this category-selective ERP component with emotional facial expressions, especially so for negative expressions such as fear and anger for which the amplitude of the N170 was augmented, compared to a neutral facial expression (Batty & Taylor, 2003; Campanella et al., 2002; Righart & de Gelder, 2006; Vuilleumier & Pourtois, 2007). Based on these previous ERP results (Vuilleumier & Pourtois, 2007), we surmised that the N170 would be larger for neutral faces used as negative feedback, compared to positive feedback. By contrast, since previous ERP studies mainly failed to provide evidence for a clear effect of anxiety at this early stage of face processing (Kolassa et al., 2007; Kolassa & Miltner, 2006; Muhlberger et al., 2009; Rossignol et al., 2005), we did not predict any strong effect of trait anxiety on the amplitude of the N170.

Methods

Participants

A total of 73 undergraduate students participated in this experiment in exchange of 20 Euro payment. Ten individuals had later to be excluded from the analysis due to an obvious discrepancy between the level of trait anxiety measured by the STAI-T during the pre-screening phase (at the beginning of the academic year) and their actual level of trait anxiety measured a second time at the day of testing (2–6 months later). Moreover, the data of 3 other participants had to be disregarded due to excessive noise and artifacts during the EEG recording. Hence, the final sample consisted of 60 participants. Using a standard median-split (*Me* = 37), we created a group of sub clinical high trait anxious participants and a group of low trait anxious participants. These two groups did not differ with respect to age and gender (see Table 1). They were all right handed, had no history of psychiatry or neurological disease, were free of any psychoactive medication and had normal or corrected-to-normal vision. They gave written informed consent prior to the experiment, and the study was approved by the local ethical committee (Faculty of Psychology & Educational Sciences, Ghent University).

Speeded Go/noGo task

We used a modified version of a speeded Go/noGo task previously used and validated in a group of low and high (sub clinical) anxious participants (Figure 1; Vocat et al., 2008; Aarts & Pourtois, 2010). Visual stimuli were shown on a 19-inch LCD screen. They consisted of an arrow (11.4° x 0.05° of visual angle at a 60 cm viewing distance) that was presented in the center of the screen on a white background. Each trial started with a black fixation cross that lasted for 1000 ms. Then, a black arrow (i.e., cue), either oriented up or down, was presented. After a variable interval ranging from 1000 ms up to 2000 ms, the black arrow became either green or turquoise while its orientation could either remain identical or shift in the opposite direction. When the black arrow turned green and the orientation remained unchanged, participants were instructed to press a predefined key on the response box as fast as possible with the index finger of their right hand (Go trials). However, participants had to withhold responding when either the arrow became green but changed orientation, or when the arrow became turquoise and kept its initial orientation. For noGo trials, this color arrow remained on the screen for a maximum duration of 1000 ms. Instructions emphasized both speed and accuracy. After the response, feedback was presented for 1000 ms (a 1000 ms blank screen preceded this feedback).

We used an online adaptive algorithm to set up a limit for “correct”/fast reaction times (RTs), i.e., deadline procedure. The rationale of this procedure was to facilitate the occurrence of fast decisions and in turn increase uncertainty regarding the actual speed. At the beginning of the experiment, the RT limit was set to 300 ms (this cutoff was determined based on previous pilot testing; Vocat et al., 2008). This limit was adjusted online as a function of the immediately preceding trial history, more specifically as the mean of current and previous RT. If the current RT was slower than this limit (arbitrarily classified as “slow hit”), the participant received negative feedback. If the RT was faster than the limit, positive feedback was presented (arbitrarily classified as “fast hit”). Hence, feedback was used to stress both speed and accuracy. When the response was incorrect, i.e., either a false alarm (response on noGo trial) or an omission (absence of response on Go trial), negative feedback was presented alike. By contrast, participants received positive feedback when they correctly withheld responding on noGo trials. The added value of this adaptive algorithm is that uncertainty about speed RT is actually high throughout the task, which motivates participants to actively attend to the feedback information displayed systematically after each response in such a way to infer whether their actions are timely (fast hits/positive feedback) or not (slow hits/negative feedback). By contrast, feedback following actions on noGo trials, either correct inhibitions or false alarms, was not informative as participants could readily evaluate the accuracy of their actions on noGo trials using internal monitoring systems. Therefore, we primarily focused on the ERP responses to evaluative feedback following correct Go trials, corresponding either to fast hits (positive feedback) or slow hits (negative feedback).

Feedback on task performance consisted of emotional or neutral faces. However, in order to control for the intrinsic emotional value of these faces (and focus on performance monitoring processes), we created two different emotional contexts such that we could compare the exact same neutral face stimuli used in two opposite situations (either a positive outcome/fast hit or a negative outcome/slow hit). More specifically, in the positive context, neutral faces served as negative feedback (slow hits) and were presented together with happy faces that served as positive feedback (fast hits, see Figure 1A). By contrast, in the negative context, neutral faces served as positive feedback (fast hits), and were presented together with angry faces that were used as negative feedback (slow hits, see Figure 1B). Each participant (*n* = 60; 30 low and 30 high anxious) was randomly assigned to one of these two emotional contexts (hence this variable was a between-subject factor). As a result, 4 experimental groups of equal sizes (*n* = 15) were created by crossing trait anxiety level (low vs. high) and emotional context (negative vs. positive).

The experiment consisted of 60 practice trials and 360 test trials. The test trials were divided into 6 blocks of 60 trials each (40 Go and 20 noGo trials, 10 of each type). Trial presentation was randomized within blocks. After the first block, the experimenter emphasized again the importance of speed as well as accuracy in this task. Between blocks, a brief self-paced pause (always shorter than 5 min) was implemented. Stimulus presentation and response recording were controlled using E-prime software (V2.0., http://www.pstnet.com/products/e-prime/).

Face stimuli

Ten different face identities (5 per gender) displaying a neutral, happy or angry emotional expression were selected from the Karolinska Directed Emotional Faces database (KDEF; Lundqvist et al., 1998). Within each emotional expression category (i.e., angry, happy and neutral), faces were selected randomly in order to control for differences in identity and gender between negative and positive feedback. Based on independent ratings obtained for these 10 faces (Goeleven et al., 2008), we could establish that the arousal and intensity level of these faces did not differ significantly between angry and happy faces, $t < 1$. The neutral faces were rated as less arousing and intense compared either to the angry faces (intensity: $t(18) = 3.70$, $p < .005$; arousal: $t(18) = 6.90$, $p < .001$) or the happy faces (intensity: $t(18) = 6.15$, $p < .001$; arousal: $t(18) = 11.30$, $p < .001$). After completing the task, every face used during the experiment was presented again one by one to each participant and he/she was asked to rate the valence of the face using a visual analog scale ranging from -50 (very negative) to +50 (very positive). The face remained on the screen until response. These subjective ratings of the faces allowed us (i) to check that the emotion (or lack of) displayed by the face was properly recognized as such by participants, and (ii) more importantly, to assess whether the valence of neutral faces would reliably vary across the two emotional contexts, in a predictive way (i.e., neutral faces in the positive context would be judged as relatively more negative, whereas neutral faces in the negative context would be judged as relatively more positive). Hence, these subjective ratings of the faces also provided an indirect check of the manipulation of the emotional context performed in our study.

Questionnaires

We measured levels of state anxiety both before and after the Go/noGo task, using the state version of the STAI. Importantly, we also measured the attribution style and more specifically the LOC of each participant, using a standard questionnaire (Rotter, 1966). This questionnaire may be useful, as it provides an estimate of the inclination of participants to attribute outcomes in daily life situations to either internal as opposed to more external causes. Higher LOC scores correspond to a tendency to attribute the cause of events or situations to external drives or forces. Previous studies generally showed a positive relationship between externality and trait anxiety (Archer, 1979) and such positive correlation was also confirmed in our study in the low (r = .50, p < .005) but not in the high anxious group (r = .11, p >.10).

EEG acquisition

Continuous EEG was acquired at 512 Hz using a 128-channel (pin-type) Biosemi Active Two system (http://www.biosemi.com) referenced to the Common Mode Sense (CMS)-Driven Right Leg (DRL) ground. ERPs of interest were computed offline following a standard sequence of data transformations (Picton, et al., 2000): (1) Re-referencing of the EEG signal using a common average reference; (2) -500/+1000 ms segmentation around the onset of the feedback stimulus; (3) pre-stimulus interval baseline correction (from -500 ms to feedback onset); (4) vertical ocular correction for blinks (Gratton et al., 1983) using the difference amplitude of two electrodes attached approximately 1 cm above and below the left eye; (5) a second pre-stimulus interval baseline correction (from -500 ms to feedback onset); (6) semi-automatic artifact rejection [electrodes with 20% or more noise at an amplitude level of 100 µV were excluded, $M = 6$ electrodes, $SEM = 1$; no significant difference between groups (low vs. high anxiety) and contexts (negative vs. positive), $F(1, 56) = 1.61$, $p > .10$; amplitude (µ) scale across participants, $M = -85/+85$, $SEM = 2$; no significant difference between groups and contexts, $F(1, 56) = .12$, $p > .10$; % of rejected artifacts: $M = 14$, $SEM = 1$; no significant difference between groups and contexts, $F(1, 56) = .97$, $p > .10$]; (7) averaging of the stimulus-locked ERPs for each type of feedback separately (i.e., negative feedback following a slow hit and positive feedback following a fast hit) and (8) low pass digital filtering of the individual average data (30 Hz).

We primarily focused on two well-documented ERP components, the FRN and the N170. Because peak or area measures of the FRN may confound variation in the FRN with differences in other adjacent ERP components, such as the P300, the FRN was measured base-to-peak over a fronto-central electrode along the midline (i.e., electrode FCz where the FRN reaches its maximum amplitude, see Holroyd et al., 2004) 150-350 ms after feedback onset. More specifically and following standard practice (see Holroyd et al., 2003), the FRN amplitude was quantified as the difference between (i) the maximum amplitude value between 150 ms and 250 ms following feedback onset at electrode FCz and (ii) the most negative amplitude value occurring between this first maximum and up to 350 ms after feedback onset at the same electrode location. The N170 amplitude was measured at occipito-temporal sites (left electrodes: D30, D31, D32, A9, A10 and A11; right: B6, B7, B8, B10, B11 and B12) as the maximal negative peak amplitude occurring during a restricted timewindow spanning from 150 to 200 ms post-face stimulus (feedback) onset (see Bentin et al., 1996).

Data analyses

RTs faster than 150 ms and slower than 500 ms were removed from the analyses (see also Aarts & Pourtois, 2010). Using these criteria, 0.42 % (*SEM* = 0.13) of the RT data were found to be faster than 150 ms while 2.69 % (*SEM* = 0.40) were slower than 500 ms. In total, 3.11 % of the RT data were eventually removed. The percentage of outliers was similar between groups (RTs faster than 150 ms: $F(1, 56) = .61$, $p > .10$; RTs slower than 500 ms: $F(1,56) = .06$, $p > .10$) and contexts (RTs faster than 150 ms: $F(1, 56) = .34$, $p > .10$; RTs slower than 500 ms: $F(1,56) = 1.63$, $p > .10$), and no significant interaction was found between those two factors (RTs faster than 150 ms: $F(1, 56) = 1.64$, $p > .10$; RTs slower than 500 ms: $F(1,56) = 1.87$, $p > .10$).

Because the presentation of feedback information following correct inhibitions (on noGo trials) or response errors (i.e., false alarms on noGo trials) was not informative, only ERP components in response to feedback following fast (positive feedback) and slow hits (negative feedback) were included in the analyses. Unlike response errors or correct inhibitions, in these two conditions, participants had actually to rely on external feedback information to determine, given the speed pressure imposed, whether their responses were “correct” (fast) or not (slow), relative to the arbitrary limit updated on a trial-by-trial basis. We first performed statistical analyses in which we directly compared the exact same feedback stimuli (neutral faces) used either as positive (fast hits) or negative (slow hits) outcome. These analyses enabled to exclude low-level differences (as well as intrinsic pleasantness) between these two opposite evaluative outcomes.

N170 peak amplitudes were analyzed using a mixed model ANOVA including the between-subject factors group (low vs. high anxiety) and context (negative vs. positive), and the within-subject factor electrode position (6), as well as hemisphere (right vs. left). The last within-subject factor was included in the analysis to verify if the N170 component recorded in this study was larger in the right compared to the left hemisphere (Bentin, et al., 1996; Itier & Taylor, 2004). We also ran an auxiliary analysis in which we examined amplitude modulations of the N170 for emotional as well as neutral faces. In this more complex model, N170 peak amplitudes were analyzed using a mixed model ANOVA including the between-subject factors group (low vs. high anxiety) and context (negative vs. positive), and the within-subject factor electrode position (6), valence of feedback (negative vs. positive) and hemisphere (right vs. left).

FRN base-to-peak amplitudes were first analyzed for neutral faces only using a mixed model ANOVA including the between-subject factors group (low vs. high anxiety) and context (negative vs. positive). Next, FRN base-to-peak amplitudes were analyzed for emotional and neutral faces using an ANOVA including the factors group (low vs. high anxiety) and context (negative vs. positive) and the within-subject factor valence of feedback (negative vs. positive).

Results

Trait anxiety

Participants of each group (low vs. high anxiety) were randomly assigned to one of the two contexts (negative vs. positive). As expected, trait anxiety differed significantly between groups, $F(1, 56) = 118.49$, $p < .001$, while no main effect of context, $F(1, 56) = .02$, $p > .10$, and no interaction between group and context was observed, $F(1, 56) = .10$, $p > .10$.

Subjective ratings of the faces

At the end of the experimental session, participants were asked to rate the valence of every face used as performance feedback using a visual analog scale ranging from negative (-50) to positive (+50) values. Due to technical problems, the rating data of two low anxious individuals who were assigned to the positive context could not be saved properly and were lost. Critically, neutral faces in the positive context were evaluated as more negative (*M* = -18.30, *SEM* = 1.53) compared to the same neutral faces presented in the negative context (*M* = 12.00, *SEM* = 1.92), *F*(1, 54) = 151.28, *p* < .001, confirming that these neutral faces used as feedback had acquired a differential valence depending on the emotional context. This effect was not different for low vs. high anxious participants, F(1, 54) = .77, p > .10. No significant main effect of trait anxiety was evidenced on these ratings, *F*(1, 54) = 2.14, *p* > .10. Happy and angry faces were, as expected, clearly rated as positive (*M* = 33.85, *SEM* = 1.37) and negative (*M* = -33.83; *SEM* = 1.12), respectively, but these ratings did not differ between low and high anxious participants, *F*(1, 54) = .004, *p* > .10.

State anxiety

As expected, the level of state anxiety before the task differed significantly between the two groups, *F*(1, 56) = 19.73, *p* < .001 (see Table 1). After the Go/noGo task, this level of state anxiety reliably increased (see also Aarts & Pourtois, 2010, for similar finding), *F*(1, 56) = 23.88, *p* < .001, but low trait anxious individuals still had a lower level of state anxiety than high trait anxious individuals, *F*(1, 56) = 10.00, *p* < .005. This increase in state anxiety level was not influenced by context, *F*(1, 56) = .51, *p* > .10, neither did context interact significantly with group, *F*(1, 56) = .23, *p* > .10. These results confirmed that the Go/noGo task was demanding, and that the constant and updated speed pressure imposed likely led to an increased experience of negative affect (equally so in both groups and contexts), given the intrinsic difficulty to keep producing fast correct responses throughout the experimental session in these conditions (see Aarts & Pourtois, 2010).

Behavioral results

After each trial, feedback on task performance was presented. Negative feedback (either a neutral face in the positive context or an angry face in the negative context) was presented following response errors (i.e., false alarms) or slow hits, while positive feedback (either a neutral face in the negative context or a happy face in the positive context) was presented following correct inhibitions (on noGo trials) or fast hits. Performance during the Go/noGo task was comparable between groups (low vs. high anxiety) and contexts and no significant interaction between group and context was evidenced (see Table 2a and 2b). Participants committed on average 24% or 29 errors in the speeded Go/noGo task and this percentage/number did not differ between groups, $F(1, 56) = 2.12$, $p > .10$, and contexts, $F(1, 56) = 1,30$, $p > .10$. Similarly, no significant differences in the number of fast or slow hits were observed between groups (fast hits: $F(1, 56) = .44$, $p > .10$; slow hits: $F(1, 56) = .74$, $p > .10$) and contexts (fast hits: $F(1, 56) = 2.63$, $p > .10$; slow hits: $F(1, 56) = 1.80$, $p > .10$), and the interaction between group and context did not reach significance (fast hits: $F(1, 56) = .00$, $p > .10$; slow hits: $F(1, 56) = .70$, $p > .10$) (see Table 2a). As expected (see Aarts & Pourtois, 2010), participants reacted faster on incorrect noGo trials ($M = 248.67$, $SEM = 3.57$) than on slow hits ($M = 310.47$, $SEM = 2.96$), $F(1, 56) = 677.00$, $p < .001$, but faster on fast hits ($M = 233.14$, $SEM = 2.31$), $F(1, 56) = 7235.83$, $p < .001$. These RTs were comparable for both groups and contexts (all *p*’s > .10). Moreover, a typical post-error slowing effect was observed indicated by slower decisions to hits following an error compared to hits following another hit, $F(1, 56) = 50.03$, $p < .001$. This effect was not different between contexts, $F(1, 56) = .01$, $p > .10$, and groups, $F(1, 56) = 2.62$, $p > .10$, nor did the interaction between group and context reach significance, $F(1, 56) = .53$, $p > .10$ (see Table 2b), suggesting preserved behavioral performance and cognitive control abilities in the two groups and two contexts. Altogether, these behavioral results showed comparable performance (accuracy and speed) for low and high anxious participants, and for the two emotional contexts. This allowed us to compare the feedback-related ERP effects between groups and contexts, while the number of positive and negative feedback was balanced across groups and conditions.

ERP results

N170 component

Visual ERPs time-locked to the onset of the face feedback clearly showed a conspicuous negative deflection around 178 ms following stimulus onset (see Figure 2AB), with a maximum amplitude over lateral occipito-temporal electrodes on both sides, with a clear right hemispheric dominance (see Figure 2CD). These properties were compatible with the face-specific N170 component (Bentin et al., 1996). We first carried out a statistical analysis in which we compared the amplitude of the N170 generated in response to the exact same physical stimuli (i.e., neutral faces), but in two different contexts (negative context where neutral faces were used as positive feedback; and positive context where neutral faces were used as negative feedback).Results of this analysis showed that the N170 was significantly larger in the right (M = -7.78) compared to the left hemisphere (M = -6.15), $F(1, 56) = 8.20$, $p = .006$, but more importantly, that this face-specific component was larger in the positive context (M = -8.18), compared to the negative context (M = -5.74), $F(1, 56) = 5.54$, $p < .05$. This result indicated a larger N170 component for neutral faces when used as negative feedback (i.e., positive context), relative to the same neutral faces when used as positive feedback (i.e., negative context). This effect did not differ between low and high anxious participants, $F(1, 56) = .64$, $p > .10$, nor was there a main effect of group, $F(1, 56) = .03$, $p > .10$. (see Figure 2EF). This result was important as it suggested that when carefully controlling for low-level differences (and intrinsic pleasantness), the valence of the feedback was processed differentially as a function of the emotional context, as early as 170-180 ms post-stimulus onset, equally so for low and high anxious participants.

Next, we performed a more complex data analysis where we included emotional faces as well. This analysis showed that the amplitude of the N170 was concurrently influenced by the valence of the feedback and the context, $F(1, 56) = 33.72$, $p < .001$. While in the negative context, the N170 was slightly larger for negative feedback (i.e., angry face; *M* = -6.13) than positive feedback (i.e., neutral face; *M* = -5.74), *F*(1, 56) = 3.07, *p* < .10, in the positive context, the N170 was clearly larger for positive feedback (i.e., happy face; *M* = -9.46) compared to negative feedback (i.e., neutral face; *M* = - 8.18), *F*(1, 56) = 48.00, *p* < .001. This effect was not modulated by the level of trait anxiety, *F*(1, 56) = 1.45, *p* = .23 (Figure 2AB). These results suggest that probably not the valence of the feedback per se, but instead the perceived emotionality (e.g., arousal) of the faces increased the amplitude of the N170 (Batty & Taylor, 2003; Vuilleumier & Pourtois, 2007).

FRN component

Following the N170, another negative deflection was observed ~250 ms over fronto-central electrodes (e.g., FCz), consistent with the electrophysiological properties of the FRN (Holroyd & Coles, 2002). As expected, when computing the difference wave (negative feedback - positive feedback), the obtained negative activity reached its maximum amplitude at electrode FCz ~250 ms post-feedback onset. Results of the univariate ANOVA performed on the amplitude of the FRN in response to neutral faces, with context and group as between-subject factors revealed a significant effect of context, *F*(1, 56) = 9.51, *p* = .003, indicating that neutral faces in the positive context (which corresponded to negative feedback) elicited a larger FRN (*M* = 8.18, *SEM* = 0.54) than the exact same neutral faces in the negative context (which corresponded to positive feedback) (*M* = 6.13, *SEM* = 0.41). However, this differential effect of context (i.e., valence of feedback) was different for low vs. high anxious individuals, *F*(1, 56) = 3.04, *p* = .09. Planned comparisons revealed that neutral faces presented in the positive context led to a significantly larger FRN than the same neutral faces used in the negative context, but only for low anxious participants, *F*(1, 28) = 12.06, *p* < .005 (see Figure 3ABC). No such differential effect of context was observed for the amplitude of the FRN for high anxious individuals, *F*(1, 28) = .87, *p* > .10 (see Figure 3DEF). This result suggests that, unlike low anxious participants, high anxious participants failed to differentiate the acquired valence of the feedback on task performance conveyed by these neutral faces. This finding corroborated the assumption of a selective performance monitoring deficit, as evidenced here for the FRN amplitude, in high anxious participants.

Next, FRN amplitudes were analyzed for neutral and emotional faces concurrently in an auxiliary analysis. This ANOVA revealed a significant three way interaction between valence, context and anxiety, $F(1, 56) = 4.75$, $p < .05$. While both low and high anxious individuals did not differentiate positive from negative feedback in the negative context, $F(1, 28) = 0.22$, $p = .64$ (Figure 3GH), a clear effect of feedback valence was observed in the positive context, $F(1, 28) = 32.49$, $p < .001$. This effect was larger in low anxious ($M = 1.83$, $SEM = 0.33$), $t(14) = 5.47$, $p < .001$, compared to high anxious individuals, ($M = 0.60$, $SEM = 0.26$), $t(14) = 2.27$, $p < .05$ (Figure 3IJ). Hence, this result confirmed that the amplitude of the FRN component varied with the valence of the feedback, depending on levels of trait anxiety[1].

Interestingly, additional correlation analyses confirmed that low vs. high anxious individuals reliably differed at the level of the FRN, and hence during the rapid monitoring of performance feedback. We found a significant negative correlation between the LOC and the amplitude of the FRN to neutral faces in low anxious individuals irrespective of the emotional context ($r = -.49$, $p < .01$; see Figure 4A), while no such association was evidenced

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[1] Similar results were obtained when the STAI-T scores (after log transformation because they were not normally distributed) were included in the analyses as a covariate, i.e., significant three way interaction (valence x anxiety x context): $F(1, 56) = 4.10$, $p < .05$; positive context: significant main effect of valence: $F(1, 28) = 5.20$, $p < .05$, interaction between anxiety and valence: $F(1, 28) = 3.59$, $p = .07$; negative context: no significant main effect of valence: $F(1, 28) = 1.16$, $p = .29$, no significant interaction between anxiety and valence: $F(1, 28) = 1.07$, $p = .30$.

in high anxious individuals (*r* = -.03, *p* > .10; see Figure 4B). This significant correlation found in low anxious participants indicated that the larger the FRN component, the more the behavior was (usually) attributed to internal causes in these individuals[2].

Finally, we performed additional control analyses to ascertain that these FRN results were not confounded by an overlapping P300 or Late Positive Potential (LPP) effect, given that previous ERP studies showed a blunted LPP in high compared to low anxious individuals (Foti et al., 2010; Weinberg & Hajcak, 2010). At posterior parietal leads along the midline (electrode Pz), we isolated a positive component time-locked to the onset of the feedback, sharing similarities with the LPP. This component peaked 350 ms post-feedback onset and lasted ~650 ms, hence showing a sustained activity. Results showed that the mean amplitude of this LPP component (as computed during this time interval at electrode Pz) was larger for positive compared to negative feedback, *F*(1, 56) = 19.29, *p* < .001, but this valence effect was not modulated by anxiety, *F*(1, 56) = .00, *p* > .10, or context, *F*(1, 56) = 1.33, *p* = .25. The interaction between context and anxiety did not reach significance either, *F*(1, 56) = .12, *p* > .10. This analysis also disclosed that the LPP was smaller in high compared to low anxious individuals, *F*(1, 56) = 4.71, *p* < .05, in agreement with these previous studies (Foti,

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[2] We also computed and analyzed response-locked ERPs, with a focus on the ERN component that was previously shown to vary with trait anxiety (e.g., Aarts & Pourtois, 2010), especially in situations where action monitoring did not rely exclusively on the processing of external feedbacks on task performance, but internal action monitoring (i.e., no feedback) was required (Olvet & Hajcak, 2009). Response-locked ERPs revealed a clear negative component peaking ~30 ms post response onset, with a maximum amplitude at fronto-central electrodes along the midline (including FCz), and which was substantially larger for response errors relative to correct hits, *F*(1, 55) = 23.14, *p* < .001. These electrophysiological properties were compatible with the ERN/Ne (Falkenstein et al., 2000; Gehring et al., 1993). However, the ERN amplitude did not vary between low vs. high anxious participants, *F* < 1, nor between the negative vs. positive context, *F* < 1, consistent with previous findings (Olvet & Hajcak, 2009).

et al., 2010; Weinberg & Hajcak, 2010). These control analyses confirmed that the reported FRN effect (and its modulation by levels of trait anxiety and emotional context) did not overlap (in time and electrode locations) with a later LPP effect taking place during feedback processing.

Discussion

The goal of this study was to test the assumption that high anxious participants may exhibit action monitoring deficits, as reflected by an invariance of the FRN to opposite performance feedback. Given that low and high anxious individuals might already differ in the way they actually perceive the intrinsic pleasantness of the feedback (regardless of any influence of higher-order performance monitoring brain mechanisms), we also looked at an earlier perceptual ERP component, namely the face-specific N170 (Bentin et al., 1996), and verify whether this earlier brain response could vary with the valence of the feedback (as implemented with a contextual modulation, see also Righart & de Gelder, 2006). A number of new results emerge from this ERP study.

First, we found a comparable behavioral performance (i.e., accuracy and speed) between low and high anxious individuals during the speeded Go/noGo task, and between the positive and negative emotional context. This result confirmed that trait anxiety did not simply alter behavioral performance during our speeded Go/noGo task (Aarts & Pourtois, 2010; Hajcak et al., 2003) and that the ERP difference found at the level of the FRN between high vs. low anxious participants could not be related to obvious changes in the behavior across these two groups. Moreover, we did find evidence for an increase in levels of state anxiety induced by the Go/noGo task (pre-post comparison; see also Aarts & Pourtois, 2010), but this change was actually the same in both groups and contexts. Importantly, emotional ratings of the faces also confirmed that neutral faces acquired a different valence depending on the emotional context they were embedded in (i.e., they were perceived as relatively more negative when used as negative, compared to positive feedback), but this contextual modulation effect was similar in both groups, confirming preserved perceptual functions in high anxious participants.

Secondly, our new ERP results show that, when controlling for the intrinsic pleasantness of the feedback stimuli, the face specific N170 component (Bentin, et al., 1996) was reliably increased for neutral faces used as negative feedback, relative to the same neutral faces used a positive feedback (see also Vuilleumier & Pourtois, 2007). Importantly, this differential structural encoding of the face as a function of the acquired valence of the evaluative feedback was similar for low vs. high anxious participants. Moreover, following the N170, a larger FRN component was found for neutral faces serving as negative feedback compared to the same neutral faces serving as positive feedback, but only in low anxious participants. These new electrophysiological findings therefore confirm that performance monitoring was modulated by levels of trait anxiety, as only low, but not high anxious individuals, showed a systematic variation of the FRN amplitude as a function of the valence of the feedback. However, our ERP results also showed that this effect of anxiety on feedback processing was component specific and concerned mainly the FRN component. The dissociation found between the N170 and FRN component during feedback processing in high anxious individuals suggests that trait anxiety does not simply alter evaluative feedback processing in general. Instead, it specifically influences a stage of performance monitoring (reflected by the FRN component) during which the perceived valence of the feedback is presumably compared to the internalized value of the action (Holroyd & Coles, 2002). However, our additional results obtained for the N170 component also show that the positive vs. negative valence of the feedback is correctly perceived as such by these high anxious participants, ruling out the possibility of a low-level perceptual deficit accounting for our FRN findings. Interestingly, we also found that across low anxious participants, the amplitude of the FRN was related to the attribution style (as measured using a standard questionnaire, see Rotter, 1966), whereas no such relationship could be evidenced in high anxious participants. The amplitude of the FRN was larger for low anxious individuals who were more inclined to attribute the cause or origin of their actions or behavior to internal (as opposed to external) drives or forces. Altogether, these new ERP results inform about the stage of processing following evaluative feedback onset during which trait anxiety may reliably influence performance monitoring. We discuss the implication of these new results in more detail here below.

Spared encoding of the emotional value of the feedback in anxiety

Our ERP results for the N170 component showed that high anxious individuals could actually reliably and correctly decode the intrinsic emotional value of the feedback information, despite an apparent deficit in linking this emotional value to a correct error prediction signal (as shown by the FRN). Hence, effects of trait anxiety on performance monitoring appear to be rather selective, since they mainly concern a specific stage of processing (the mid-latency FRN component), while leaving unaffected earlier perceptual stages (N170 component) during evaluative feedback processing. Previous ERP studies already showed that context influences the early structural encoding of faces, as shown by enhanced N170 components for faces embedded in negative context/background information (Righart & de Gelder, 2006, 2008). Here, we found an enhanced N170 component for neutral faces associated with a negative outcome, relative to the exact same faces used as positive feedback. However, because we found that the N170 amplitude was in both contexts increased for emotional compared to neutral faces, it appears that the emotional significance or level of arousal (instead of the valence per se) of the face may be the critical dimension influencing this early visual component (see also Batty & Taylor, 2003). Importantly, when neutral faces were used as negative feedback and directly compared to the exact same neutral faces used as positive feedback, a larger N170 was observed for negative compared to positive feedback. This might indicate an augmented emotional significance of neutral faces in the positive emotional context. Crucially, our results for the N170 showed that this effect of emotional significance was similar in low and high anxious individuals, suggesting preserved perceptual emotional processes (i.e., structural encoding of the face) in high anxious participants during evaluative feedback processing. Behavioral results obtained for the ratings of the faces also corroborated this conclusion.

Selective alteration of performance monitoring in anxiety

By contrast, a modulatory effect of trait anxiety during evaluative feedback processing was evidenced when looking at the fronto-central FRN component. While this performance monitoring component reliably discriminated between negative and positive feedback in low anxious participants, it did not in high anxious participants. Strikingly, the amplitude of the FRN for positive and negative feedback in high anxious individuals was similar (i.e. no larger FRN for negative compared to positive feedback), and comparable in both cases to the FRN following positive feedback in low anxious individuals. This suggests impaired performance monitoring functions in anxiety. Although the morphology of the FRN component found in this study was slightly different compared to previous studies (Hajcak et al., 2004; Holroyd et al., 2004), this difference may be due to the use of complex facial stimuli as performance feedback, relative to simple symbolic cues in these earlier studies. Likewise, here outcome evaluation at the level of the FRN was actually based on speed (fast vs. slow hits), but not accuracy, a factor that might potentially account for changes in the morphology of this performance monitoring ERP component across studies. At any rate, future studies are needed to corroborate this statement. Importantly, control analyses showed that the reported FRN results did not overlap with a later LPP effect (Foti et al., 2009; Schupp et al., 2004), the latter being indicated by a blunted LPP component for high compared to low anxious participants, consistent with previous ERP studies (Foti, et al., 2010; Weinberg & Hajcak, 2010). Our ERP results further show that the effect of feedback valence was only observed in the positive context, where happy faces and “neutral” faces were presented, and that this difference was larger for low, compared to high anxious participants. In the negative context, the amplitude of the FRN did not differentiate between angry and “neutral” faces. These FRN results are in line with previous studies that did already report a comparable asymmetry, with a larger differentiation at the level of the FRN between neutral and positive feedback than between negative and neutral feedback (Hajcak, Holroyd, Moser, & Simons, 2004; Holroyd & Coles, 2002).

The main ERP result showing a modulatory effect of trait anxiety on the FRN component is in accordance with previous studies (Gu, et al., 2010; Simons, 2010) and more generally, the reinforcement learning theory (Holroyd & Coles, 2002). This model proposes that that the FRN component reflects the perceived discrepancy between the expected and the actual outcome (i.e., prediction error), here based on the processing of an external evaluative feedback (as opposed to an internal motor representation for the ERN component). A larger FRN in low compared to high anxious individuals suggests that trait anxiety likely influences the encoding of the prediction error signal during the processing of simple action-outcome sequences. Presumably, high anxious individuals might show a tendency to expect more negative external feedback/evaluations compared to low anxious individuals, and as a result these former participants would show blunted reactions to negative feedback, because the discrepancy between the actual and expected outcome is, by definition, smaller. Consistent with this notion, Maner and Schmidt (2006) showed a link between anxiety and pessimistic outcome expectancy. By contrast, here we did not find any modulation of the ERN component (and hence internal monitoring processes) as a function of trait anxiety, unlike previous ERP studies (Aarts & Pourtois, 2010; Hajcak, et al., 2003). This discrepancy could be explained by the use of salient evaluative feedback in this study (i.e., emotional faces), which may have introduced a strong bias towards the monitoring of these external evaluative feedback at the cost of more internally-oriented monitoring processes. Interestingly, in this condition, effects of trait anxiety on internal monitoring brain processes (i.e., ERN component) seem to disappear, in line with previous ERP results (Olvet & Hajcak, 2009).

The assumption that trait anxiety may selectively influence a performance monitoring process through which the perceived valence of the feedback is readily integrated with the internalized value of the action is indirectly supported by our additional correlation analysis between LOC and the amplitude of the FRN. Our results show that low anxious individuals characterized by an internal LOC had a larger FRN, relative to low anxious individuals with a more external LOC. This result indirectly confirms that the FRN is not only sensitive to the valence of the feedback per se, but also to higher-level motivational or emotional factors, including the motivational significance of our actions (Gehring and Willoughby, 2002; Yeung et al., 2005). Noteworthy was the absence of this relationship in high trait anxious participants, confirming that this psychopathological condition (here at the subclinical level) may reliably alter performance monitoring brain systems. Hence, this anxiety-related deficit during performance monitoring may concern a specific generative process enabling to readily bind the (internalized) value of the action with the perceived valence of the feedback. However, we have to acknowledge that because our trait anxiety estimate (based on a standard questionnaire in the literature) likely measures negative affect (or even depression) (e.g., Nitschke et al., 2001; Rossi & Pourtois, in press), enhanced levels of negative affect or internalized personality traits in general, rather than trait anxiety per se (see also Olvet & Hajcak, 2008), may account for the amplitude variations observed at the level of the FRN component in our study.

Conclusion

Results of this ERP study reveal a specific performance monitoring deficit associated with subclinical trait anxiety, although low and high anxious participants showed comparable behavioral performance during this speeded Go/noGo task. Our FRN results suggest that high anxious individuals have a selective impairment in integrating the emotional value or motivational significance of the feedback with the internalized value of the action executed 1000 ms prior to feedback delivery. This effect might be imputed to a selective change produced by trait anxiety in the normal reinforcement learning signal generated during action monitoring. However, our ERP results also show that the rapid decoding of the emotional significance of the facial feedback information (as reflected by the N170 component) is not altered in high compared to low anxious individuals, suggesting a component specific effect of anxiety during evaluative feedback processing. As such, our new ERP findings help better characterize the precise temporal locus during which trait anxiety reliably changes and influences performance monitoring brain functions.

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Table 1.

Descriptive statistics for the low and high anxious group

	Low anxiety				High anxiety			
	Negative context		Positive context		Negative context		Positive context	
	M	*SEM*	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
SEX	3M		2M		2M		2M	
Age	20.00	0.54	20.40	0.72	19.60	0.24	19.40	0.50
STAI-T	28.73	0.93	28.47	0.82	44.40	1.93	45.07	1.88
STAI-S1	29.67	1.51	31.13	1.37	36.40	1.67	38.53	1.78
STAI-S2	33.47	2.07	37.27	2.19	40.73	1.58	43.33	2.49
LOC	12.53	0.87	11.13	0.92	12.60	0.99	12.93	0.95

Table 2a.

Accuracy results in the speeded Go/noGo task

		Accuracy (Number)					
		Fast Hits		Slow Hits		Errors	
Anxiety	Context	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
Low	Negative	73	7	158	6	28	5
	Positive	82	5	147	5	36	5
High	Negative	69	5	158	5	24	4
	Positive	79	6	156	5	26	4

Note: None of the group differences were significant (*p* > .05)

Table 2b.

RT results in the speeded Go/noGo task

		Speed (ms)									
		Fast Hits		Slow Hits		Errors		Post-error Hit		Post-hit Hit	
Anxiety	Context	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
Low	Negative	237.86	4.56	314.68	6.15	256.81	7.22	302.91	8.89	287.10	7.76
	Positive	226.58	5.69	304.45	5.55	242.14	8.92	285.30	7.76	273.62	7.41
High	Negative	234.61	4.82	233.50	6.47	247.21	5.96	306.78	9.29	286.49	6.66
	Positive	233.50	2.97	308.77	5.72	248.51	6.26	303.89	10.07	280.40	6.17

Note: None of the group differences were significant (*p* > .05).

Figure caption

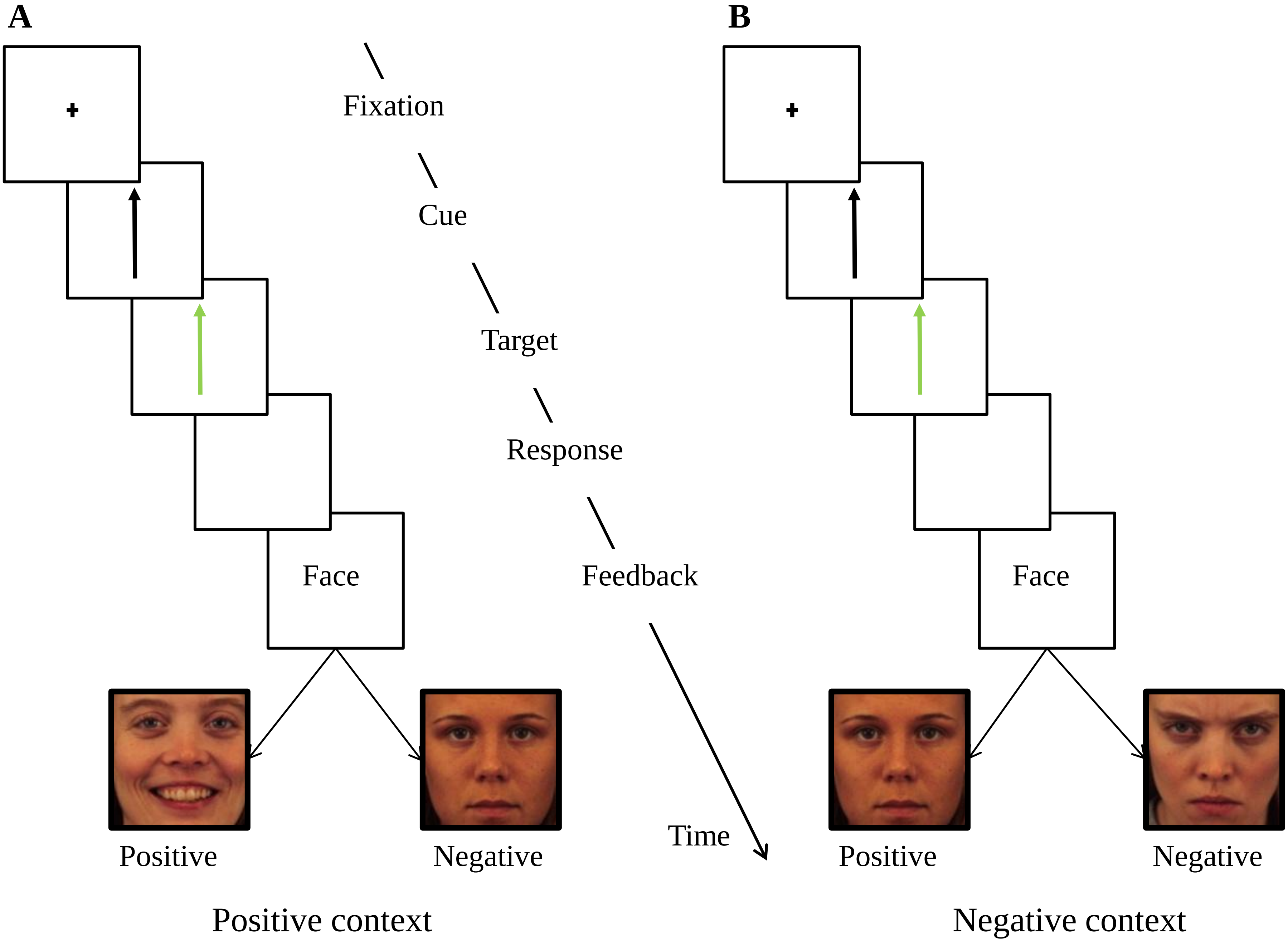
Figure 1. Stimuli and task. On each trial, a black arrow was first presented. After a variable interval (1000-2000 ms), the black arrow usually (2/3 trials) became green. Sometimes (1/3 trials) it became either turquoise and/or green but with a change in orientation (noGo trials). When it turned green and kept its initial orientation, participants were instructed to respond by pressing a predefined key of the response box as fast as possible (Go trials). Immediately after this response, a blank screen was shown for 1000 ms, before feedback on task performance was presented (1000 ms). Feedback on task performance was given by either neutral or emotional faces. For each and every trial, the actual RT speed was compared against an arbitrary limit (calculated and adjusted online) in such a way to determine whether the hit (correct response on Go trial) was either fast or slow, and hence whether a positive or negative feedback had to be shown (see Methods). Positive feedback was presented when the participant was fast (relative to this arbitrary limit), whereas he/she received a negative feedback when he/she was slow (relative to this arbitrary limit). (A) In the positive context, neutral faces were used as negative feedback and happy faces as positive feedback. (B) By contrast, in the negative context, angry faces were used as negative feedback whereas the exact same neutral faces were used as positive feedback.

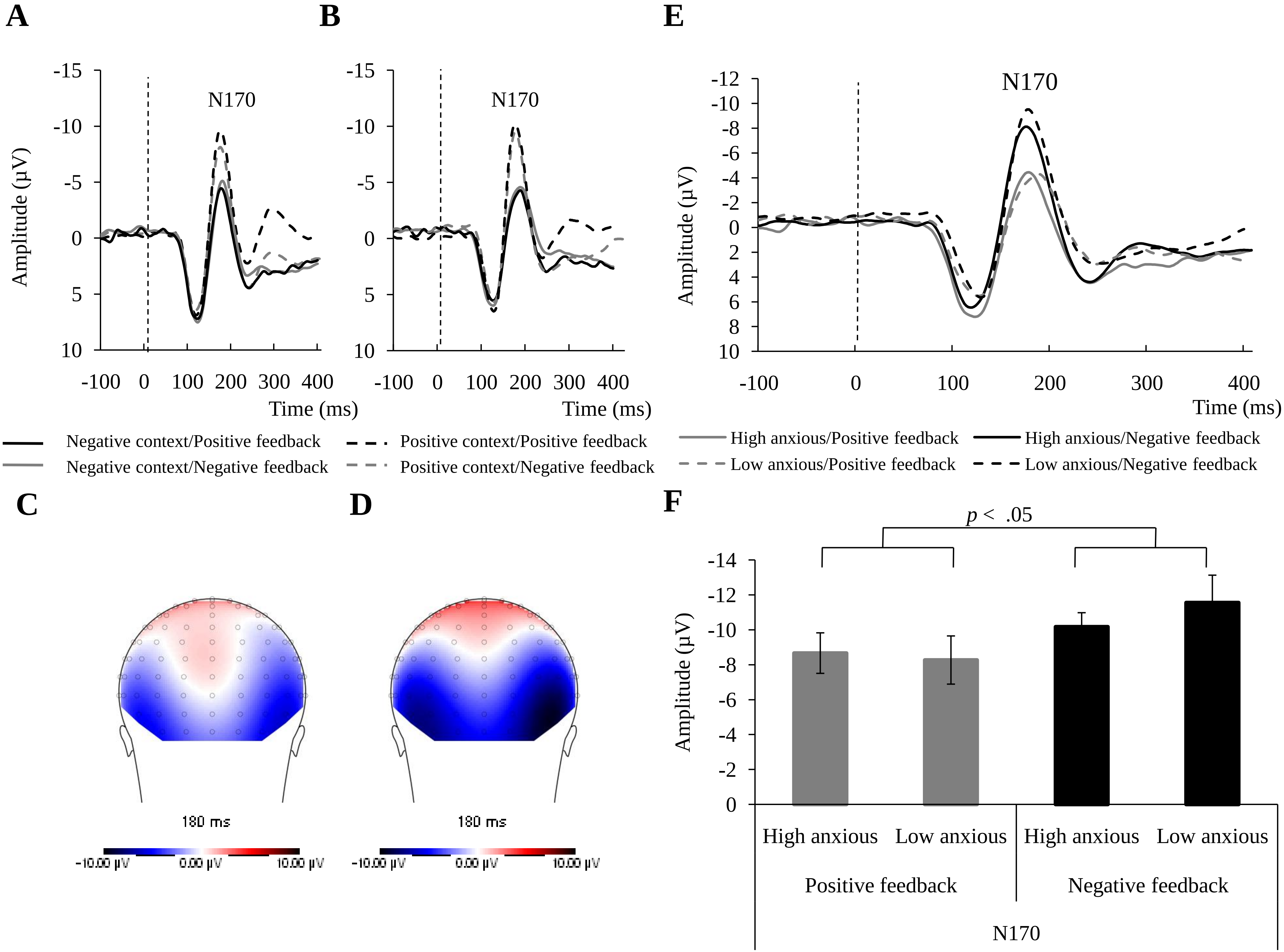
Figure 2. N170 results for emotional and neutral face feedback, separately. Grand average ERP waveforms (at occipito-temporal electrode B7, right hemisphere) for high (A) and low (B) anxious participants in the negative (neutral and angry faces) and the positive context (neutral and happy faces). (C) N170 occipital scalp map for neutral faces in the negative context (i.e., positive feedback). (D) N170 occipital scalp map for neutral faces in the positive context (i.e., negative feedback). (E) Grand average ERP waveforms (occipito-temporal electrode B7, right hemisphere) for low and high anxious participants for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive context). (F) Mean amplitude (μV; electrode B7) ± 1 standard error of the mean of the N170 for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive emotional context) in low and high anxious participants. N170 amplitude for neutral faces was larger in the positive context (i.e., negative feedback) compared to the negative context (i.e., positive feedback), $F(1, 56) = 5.54$, $p < .05$, but this effect was the same for low vs. high anxious participants, $F < 1$.

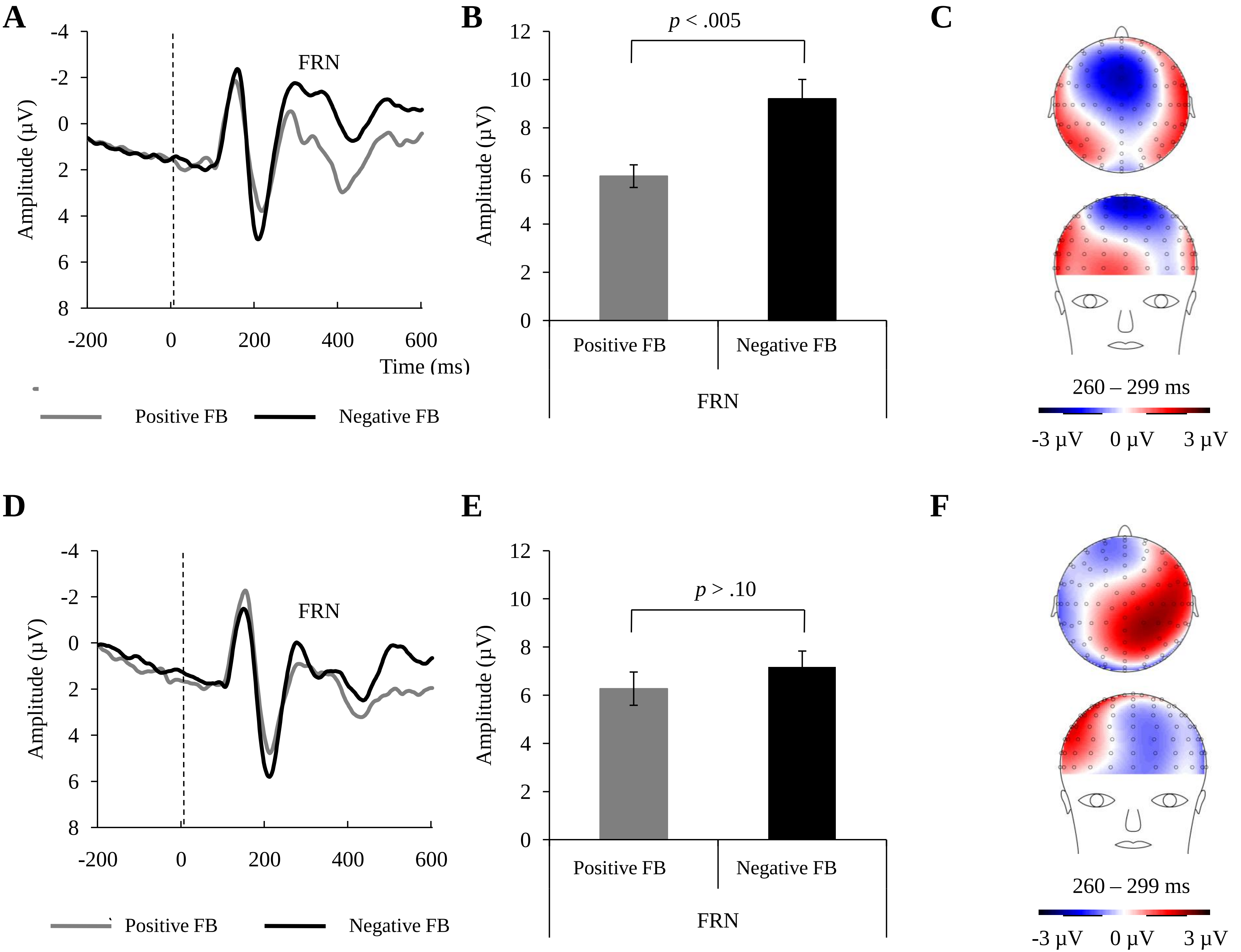
Figure 3. FRN results for emotional and neutral faces, separately. (A) Grand average ERP waveforms (electrode FCz) for low anxious participants for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive emotional context). (B) Mean amplitude (μV) ± 1 standard error of the mean of the FRN (base-to-peak measure) for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive emotional context) in low anxious participants. (C) Horizontal and frontal scalp topography of the FRN (260-300 ms post-stimulus onset) for low anxious individuals, obtained after subtracting the negative feedback (neutral face in positive context) from positive feedback (neutral face in negative context), showing a typical FRN voltage map distribution (i.e., circumscribed negative activity around FCz electrode position) in this group, relative to high anxious participants (compare with B). (D) Grand average ERP waveforms (electrode FCz) for high anxious participants for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive emotional context). (E) Mean amplitude (μV) ± 1 standard error of the mean of the FRN (base-to-peak measure) for neutral faces serving as positive feedback (in the negative context) and negative feedback (in the positive emotional context) in high anxious participants. (F) Horizontal and frontal scalp topography of the FRN (260-300 ms post-stimulus onset) for high anxious individuals, obtained after subtracting the positive context from the negative context condition. While the FRN of low anxious individuals differentiated between a neutral face presented in a negative context (“positive feedback”) vs. a neutral face presented in a positive context (“negative feedback”), the FRN amplitude of high anxious individuals was similar in both contexts in high anxious individuals. Grand average ERP waveforms (electrode FCz) for high (G) and low (H) anxious participants when neutral faces were used as positive feedback and angry faces as negative feedback (negative context). Grand average ERP waveforms (electrode

FCz) for high (I) and low (L) anxious participants when neutral faces were used as negative feedback and happy faces as positive feedback (positive context).

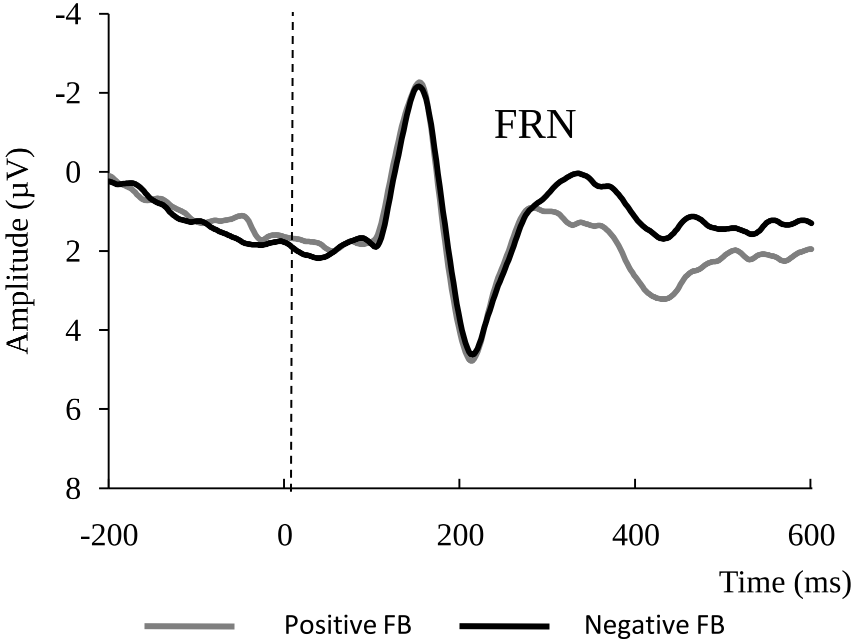
Figure 4. Correlation between FRN amplitude and subjective estimate of LOC for low vs. high anxious individuals. (A) A significant negative correlation was observed between FRN amplitudes and LOC scores in low anxious participants (r = -.49, p < .01). (B) No significant correlation was observed in high anxious participants (r = -.03, p > .10). This negative correlation in low anxious individuals indicated that the larger the FRN (and hence the sensibility to the valence of the feedback), the more towards internal (as opposed to external) sources/causes behaviors are usually attributed to.


A
B
Fixation
Cue
Target
Response
Feedback
Time
Face
Face
Positive
Negative
Positive
Negative
Positive context
Negative context


A
B
E
N170
-15
-10
-5
0
5
10
-100
0
100
200
300
400
Amplitude (µV)
Time (ms)
-12
-8
-6
-4
-2
2
4
6
8
Negative context/Positive feedback
Negative context/Negative feedback
Positive context/Positive feedback
Positive context/Negative feedback
High anxious/Positive feedback
Low anxious/Positive feedback
High anxious/Negative feedback
Low anxious/Negative feedback
C
D
F
180 ms
-10.00 µV
0.00 µV
10.00 µV
p < .05
-14
High anxious
Low anxious
Positive feedback
Negative feedback


A
-4
-2
0
2
4
6
8
Amplitude (μV)
FRN
-200
0
200
400
600
Time (ms)
Positive FB
Negative FB
B
12
10
8
6
4
2
0
Amplitude (μV)
p < .005
Positive FB
Negative FB
FRN
C
260 – 299 ms
-3 μV
0 μV
3 μV
D
-4
-2
0
2
4
6
8
Amplitude (μV)
FRN
-200
0
200
400
600
Positive FB
Negative FB
E
12
10
8
6
4
2
0
Amplitude (μV)
p > .10
Positive FB
Negative FB
FRN
F
260 – 299 ms
-3 μV
0 μV
3 μV

G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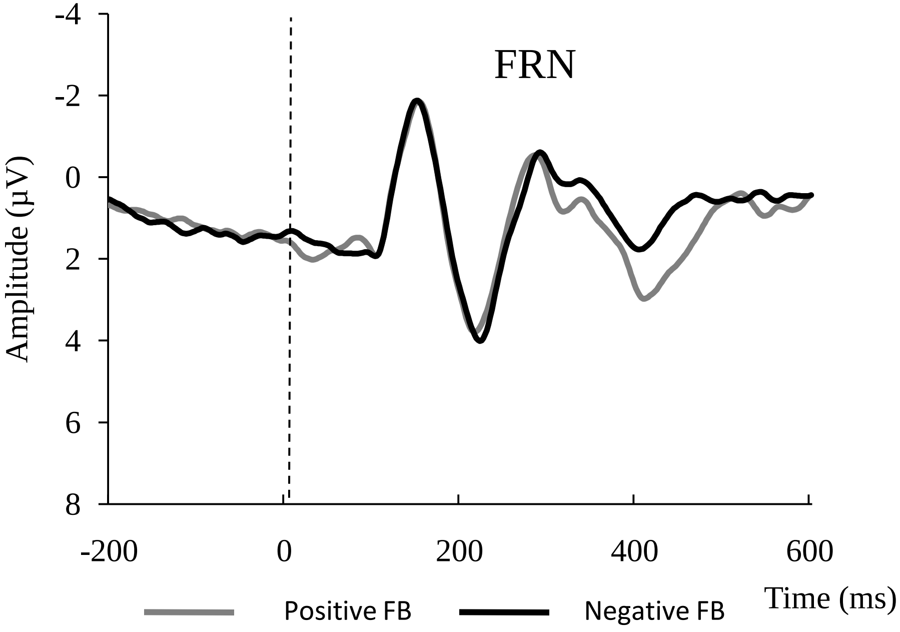
2
4
6
8
Amplitude (µV)
FRN
-200
0
200
400
600
Time (ms)
Positive FB
Negative FB

H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4
6
8
Amplitude (µV)
FRN
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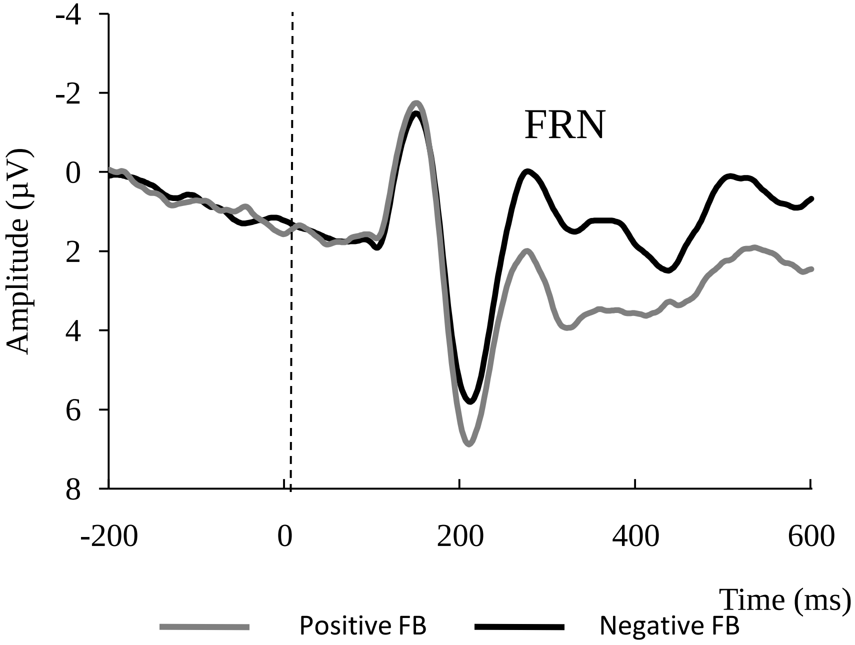
0
200
400
600
Time (ms)
Positive FB
Negative FB

I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6
8
Amplitude (µV)
FRN
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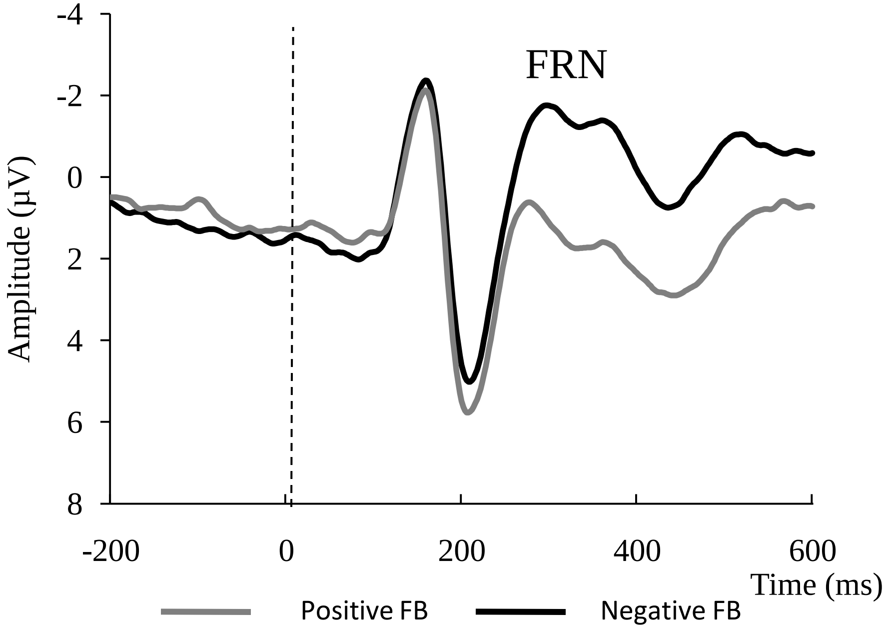
0
200
400
600
Time (ms)
Positive FB
Negative FB

J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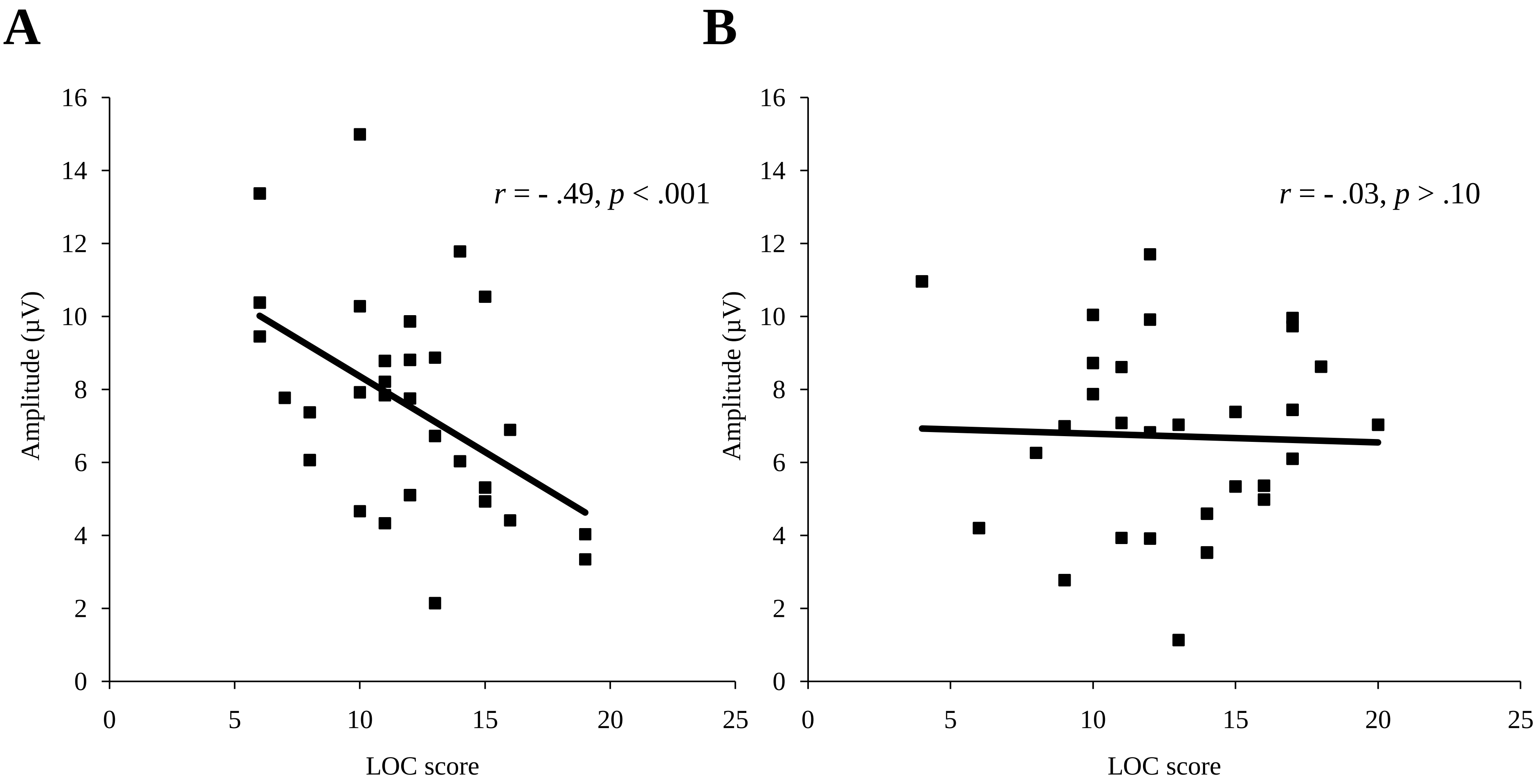
2
4
6
8
Amplitude (µV)
FRN
-200
0
200
400
600
Time (ms)
Positive FB
Negative FB


A
B
r = - .49, p < .001
r = - .03, p > .10
Amplitude (µV)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
LOC score