Received: 16 January 2022 | Revised: 18 July 2022 | Accepted: 20 July 2022

DOI: 10.1111/psyp.14166

PSYCHOPHYSIOLOGY SPR WILEY

ORIGINAL ARTICLE

Reduction of anticipatory brain activity in anxious people and regulatory effect of response-related feedback

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Funding information
Foro Italico University of Rome, Grant/Award Number: CDR2. BANDO2020DRF

Abstract

Elevated anxiety levels degrade task performance, likely because of cognitive function reduction in the frontoparietal brain network. This study aimed to test whether anxiety could impact the frontal cortex anticipatory brain functions and to investigate the possible beneficial effect of response-related feedback on task performance. The electroencephalographic activity was recorded while participants performed two Go/No-go tasks: one with response-related feedback on errors (feedback task) and one task without feedback (standard task). We first tested whether anxiety levels could be associated with pre-stimulus ERP components such as the prefrontal negativity (pN), linked with top-down attentional control, and the Bereitschaftspotential (BP), related to motor preparation. Then, we assessed whether feedback could affect anxious people's brain preparation, reducing the state of uncertainty and improving performance. Results showed that the pN was almost absent and the BP was lower during a standard task in the high anxiety than in the low anxiety group. In the feedback task, these components increased in the high anxious, becoming comparable to the low anxious. Behavioral results showed that false alarms in the high anxiety group were larger than in the low anxiety group during the standard task but became comparable in the feedback task. Similarly, response time in the high anxiety group was slower in the standard task than in the feedback task, and high anxious people were faster in the feedback task than in the standard one. This study contributes to clarifying neural correlates of anxiety, showing brain activity reductions related to action preparation in frontal areas. In addition, response-related feedback tasks could be used to normalize task performance in high anxious people.

KEYWORDS
anxiety, BP, feedback, pN

1 | INTRODUCTION

Many situations with uncertain outcomes such as the first day of work, public speeches, exams, or athletic performances may cause diverse levels of unpleasant anticipatory emotions with psychological signs such as worried thoughts and feelings of tension, known as anxiety. Anxiety is a natural body anticipatory response to relevant future events that we experience with apprehension. In literature, this anticipatory feeling was divided into two main dimensions: a stable affective dimension, the trait anxiety (how we usually feel), and anxiety related to a specific event (e.g., task demands and environmental conditions), the state anxiety. Both these two dimensions of anxiety are associated with task performance. For example, elevated levels of trait anxiety have been shown to negatively affect task performance, causing stress (Broadbent & Broadbent, 1988; Coleman et al., 1980; Cratty & Hanin, 1980; Egloff & Hock, 2001; Eysenck & Calvo, 1992; Gaudry & Spielberger, 1971; Hogg, 1980; Kaplan, 1974). On the other hand, also state anxiety has been shown to affect task performance, for example, the "individual zones of optimal functioning" model (Hanin, 1989) predicts peak athletic performance at intermediate levels of state anxiety. In addition, it has also been shown that elevated levels of state anxiety may weaken proactive control, whereas it may enhance reactive control (e.g., Yang et al., 2018).

Evidence suggests that elevated levels of trait anxiety are associated with impaired performance in different laboratory cognitive tasks (Eysenck et al., 2007; Williams et al., 1997). Moreover, it has been shown that the performance of high anxious people can be improved by giving rewards for their performance, such as feedback (Cisler et al., 2010; Mahan & Ressler, 2012; Mandler & Sarason, 1952; Sarason, 1957, 1959). At the brain level, different research has shown the key role played by the frontoparietal network in anxious people (Delgado et al., 2008; Ochsner & Gross, 2005), which includes the prefrontal cortex, the inferior parietal lobule, a portion of the middle cingulate gyrus, and the precuneus (Dosenbach et al., 2008). Furthermore, this network seems to detect the need for strategy adjustment, which incorporates feedback for better processing in later trials (Dosenbach et al., 2008). Other functional magnetic resonance imaging (fMRI) studies, using tasks with non-emotional stimuli, showed a decreased functioning of this network in people with high trait anxiety (Bishop, 2009; Bishop et al., 2007; Hayes et al., 2009). This phenomenon is probably because high anxious people, or with anxiety disorders, have a deficit in the executive control of the frontoparietal network, not allowing them to manage their emotions properly, also in tasks that use neutral stimuli (Goldin et al., 2009). In addition, also the default mode network shows lower activity in people with high trait anxiety, general anxiety disorders, panic disorder, and social anxiety, and these kinds of people need external instructions to regulate their responses (Evans et al., 2009; Klumpp et al., 2011; Krug & Carter, 2010; McClure et al., 2007; Simmons et al., 2008; Tuescher et al., 2011).

There are several kinds of feedback, but those that are provided in terms of external instructions (extrinsic feedback), thus immediately after response emission (such as those usually provided by teachers or coaches), seem particularly effective in improving task performance (e.g., Coccia, 2019). This feedback type has been defined as "response-generated feedback" since they are inevitably generated by behavior (e.g., Wulf & Prinz, 2001). The effectiveness of response-generated feedback might be explained by the "constrained-action" hypothesis, where it has been shown that this kind of feedback enhances performance since it directs performers' attention to their own body movements, causing them to use a more conscious mode of control, which constrains the motor system and interferes with automatic control processes (McNevin et al., 2003).

To the best of our knowledge, no one has investigated the anxiety effect on preparatory pre-stimulus ERP components as the well-known Bereitschaftspotential (BP, also known as readiness potential or RP), a slow rising negativity over centroparietal areas originating in the supplementary motor cortex, and the more recently discovered prefrontal negativity (pN, Berchicci et al., 2012), a negativity activity originating from the pars opercularis of the inferior frontal gyrus. These two pre-stimulus components have been associated with motor and cognitive preparation, respectively (for a review, see Di Russo et al., 2017). The pN has been repeatedly observed in discriminatory response tasks and associated with top-down attentional and inhibitory control correlating with response accuracy rates (Bianco, Di Russo, et al., 2017; Di Russo et al., 2019; Perri et al., 2015).

We hypothesized that response-generated feedback could improve performance in anxious people because it facilitates cognitive processing, normalizing the frontoparietal brain network functions. Considering that anxiety is anticipatory processing, we hypothesize that this network could affect anxiety during the task preparation phase because several electrophysiological studies (e.g., Di Russo et al., 2019, Di Russo et al., 2021) found a strong involvement of the prefrontal cortex during the task preparation stage in discriminatory response tasks using event-related potentials (ERPs) measures.

We predicted that anticipatory brain activities (BP and pN) of high anxious people during a standard task should be lower than low anxious peers and, consequently, negatively impact performance. Additionally, we expected normalization of the BP and pN components and performance in the task with feedback. The main goal was to assess whether the feedback on one's own performance could affect anxious people's brain preparation, reducing the state of uncertainty and consequently improving performance. This is because anxious people exhibited a decline in frontal cortex activity (see Ansari & Derakshan, 2011a, 2011b; Bishop, 2009). Our hypothesis is also supported by the fact that damaging certain portions of the prefrontal cortex impairs the ability to anticipate future affective outcomes, which results in an inability to guide behavior adaptively (Klouda & Cooper, 1990). Anxious people tend to feel uncertain or unsure about their own motor and cognitive activities, and, consequently, they tend to be more anxious in performing a task. The introduction of feedback, with the aim of making participants more aware of their mistakes, could improve behavioral performance (by increasing the speed and accuracy of their responses) through the normalization of cognitive control generated by feedback.

2 | MATERIALS AND METHODS

2.1 | Participants

For the determination of the sample size, we used G*Power 3.1.9.7 Software (Faul et al., 2007). Inputs for this calculation were taken from a normative study on a large sample from the present laboratory using tasks and dependent measures similar to the current study (Di Russo et al., 2019). We calculated that in Di Russo et al. (2019), the correlations among repeated measures ranged from .61 to .85 for pre-stimulus ERP components (pN and BP) while ranging from .55 to .87 for behavioral measures (response time, omission, and commission errors). Considering the lowest found correlation (.55), and a 2×2 mixed analysis a variance design, to detect a medium effect size (f = 0.25), with power (1–β) set at .90 and α = .05, the recommended minimum sample size comprised 32 participants (16 per group). Accordingly, 32 (16 females; mean age 22.1 years, SD = 2.2) were recruited for the study. All volunteers were students at the "Foro Italico" University and received extra credits for their participation.

Participants were equally divided into two groups as a function of their trait anxiety scores, measured by the Italian version (Pedrabissi & Santinello, 1989) of the STAI-Y2 scale (State-Trait Anxiety Inventory). The STAI-Y2 is a 20-item questionnaire on a 1–4 Likert scale (score ranges from 20 to 80; Pedrabissi & Santinello, 1989). Participants were previously selected from a larger sample of 143 students, excluding those with normal anxiety levels (scores from 35/80 to 43/80), such as previously done by Ansari and Derakshan (2011a, 2011b). Those who scored 44/80 and above on the trait STAI scale was classified as high anxious and who scored 34/80 and below were classified as low anxious (see Ansari & Derakshan, 2011a, 2011b, and Buselli et al., 2020 for the relative classifications). None of the participants exceeded a score of 60, which is classifiable as pathological (Buselli et al., 2020). The two groups were also selected to be age- and sex-matched.

All participants had normal or corrected-to-normal vision (to avoid excessive eye blinking only glasses—and not contact lenses—were allowed), reported no past or present neurological or anxiety disorders, and were right-handed (Oldfield, 1971; Salmaso & Longoni, 1985). Before the experiment, all participants were informed about the procedure and provided written informed consent. The study was approved by the Institutional Review Board of the University of Rome "Foro Italico" (protocol code: CARD-74/2020; Date: 6 July 2020).

2.2 | Procedure and task

Participants performed a standard discriminatory response task (Go/No-Go task) and the same task version but with response-related feedback (knowledge of results feedback type, participants did not win a prize or receive a punishment). In both tasks, participants had to discriminate between Go and No-go stimuli. The standard and feedback sessions were counterbalanced among participants. Participants were seated in a quiet and dimly lit room in front of a computer monitor at a 114 cm distance. A response panel was fixed on the right armchair. A yellow circle (subtending 0.15×0.15° visual angle) served as a fixation point and was displayed on the screen for the whole duration of the experiment. Stimuli consisted of either six (three targets and three non-targets) squared configurations (subtending 4×4° and made of vertical, horizontal, or both vertical and horizontal segments) presented centrally on a dark gray background. Target and non-target stimuli were presented in random order for 250 ms with equal probability. During the feedback session, in the case of a lack of response to targets, a buzzing sound of 250 ms (binaural at 60 dB) was emitted 600 ms after the target onset (a time over the average response time), whereas in the case of an unwanted response to non-targets, the same sound was emitted concomitantly to the button press. No sounds followed correct responses. Sounds were emitted by two loudspeakers placed symmetrically on each side of the computer screen. The stimulus

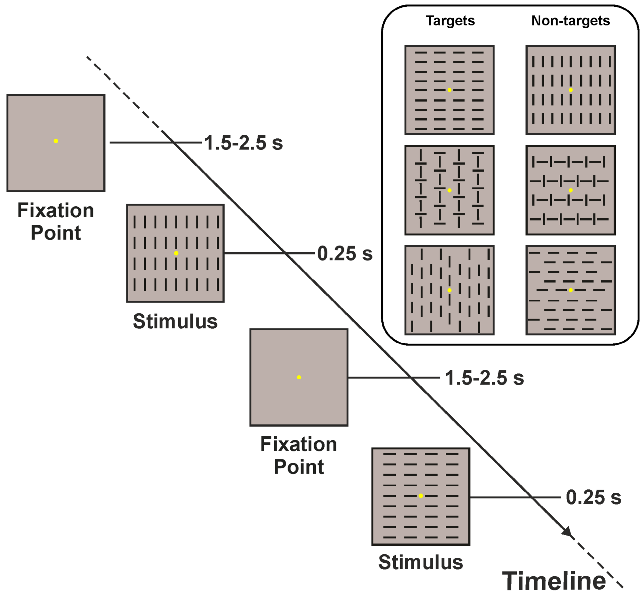

FIGURE 1 Schematic representation of the stimuli shapes and timing used in the experiment.

onset asynchrony ranged from 1.5 to 2.5 s in order to avoid time prediction effects on the response time and to reduce brain activity overlap. Figure 1 shows a representation of the stimuli. After receiving task instructions, participants were familiarized with the task by performing a block of 30 trials. The entire experiment consisted of two sessions (feedback and standard) of 10 runs, containing 84 trials each (participants performed a total of 840 trials: 420 target and 420 non-target stimuli per session). Each run lasted circa 3.5 min, and the participant was free to rest between blocks, so the total duration of the experiment depended on the participants' rest time and was about 40–50 min per session. The instruction was to fixate the central circle for all the run duration avoiding eye blinking and to press a button with the right index finger when target stimuli appeared, withholding the response if non-target stimuli appeared. Participants were required to be as accurate and fast as possible.

2.3 | Behavioral analyses

For both tasks, we calculated the following behavioral data: response times (RTs), commission errors (CE, response to non-targets), and omission errors (OE, omitted response to targets). The behavioral data obtained were analyzed using a 2×2 ANOVA analysis with task (standard and feedback) as within factor and Anxiety (high and low anxious) as between factors. Any value that exceeded two standard deviations above or below the mean was not considered.

2.4 | Electrophysiological recording and data analysis

The EEG signal was recorded using three BrainAmp™ amplifiers (Brain Products GmbH, Munich, Germany) with 64 scalp electrodes mounted following the 10–10 International system. All electrodes were initially referenced to the M1, and then re-referenced to the average of M1-M2. Horizontal and vertical electrooculograms (EOG) were recorded using additional bipolar montages with electrodes placed, respectively, at external canthi (HEOG) and below and above the left eye (VEOG). Electrode impedances were kept below 5 KΩ. The EEG was digitized at 250 Hz, amplified (bandpass of 0.01–80 Hz including a 50 Hz notch filter), and stored for offline averaging.

The EEG was processed using the software Analyzer 2.2 (Brain Products GmbH, Munich, Germany). The EEG was low-pass filtered (i.e., Butterworth) at 30 Hz (slope 24 dB/octave) and segmented using 1300 ms epochs lasting from 1100 ms before to 200 ms after the stimulus, with stimulus onset at 0 time. To study the pre-stimulus ERP, target and non-target trials were averaged together and the first 200 ms of the segment (−1100/−900 ms) was selected as baseline. The correction of eye movement artifacts was carried out using the ocular correction with the independent component analysis tool (ICA) available in the Analyzer software: this method, introduced by Jung et al. (2000), produced better results compared with other ocular correction methods (e.g., Hoffmann & Falkenstein, 2008). Then, epochs still contaminated by artifacts or other signals exceeding the amplitude threshold of ±60 μV were discarded. In the final average, about 7% of trials were rejected. On average, the trial left for each group and condition was the following: high anxious group 386 and 392 in the standard and feedback tasks, respectively. High anxious group 389 and 393 in the standard and feedback tasks, respectively. Differences in rejection rate between groups and conditions were not significant ($F < 1$).

To select the intervals and electrodes to be included in statistical analysis, the "collapsed localizer" method was used (e.g., Luck & Gaspelin, 2017), in which a localizer ERP is obtained by collapsing (averaging) all experimental conditions. To identify the interval of analysis, the global field power (GFP) was calculated. The GFP describes the ERP spatial variability at each time point considering all scalp electrodes simultaneously, resulting in a reference-independent descriptor of the potential field. The pre-stimulus interval in which the GFP was larger than 70% of its maximum value was used for further analysis. The GFP approach selected the pre-stimulus interval from −320 ms to 0 ms, in which the mean amplitude was calculated for statistical purposes. The electrodes with amplitude larger than 70% of the maximum value in the intervals selected by the collapsed localizer were jointed in spatial pools and considered for statistical analysis. Two foci of activity were clearly present, a bilateral prefrontal activity of the pN, and a medial centroparietal activity of the BP. The pN was then represented by a pool containing Fp1, Fpz, Fp2, AF7, AF3, AFz, AF4, and AF8 electrodes (prefrontal pool). The BP was represented by a pool containing Cz, CP1, CPz, CP2, P1, Pz, P2, and POz electrodes (centroparietal pool). Their amplitudes were submitted to a 2×2 ANOVA with task (standard vs. feedback) and Anxiety (high vs. low anxious) as factors.

To evaluate the statistical effect, the standardized effect size index, such as the partial eta squared (η_p^2), was also reported (Cohen, 1973). To reduce the likeli- hood of Type 1 errors in the ANOVAs, post hoc comparisons were performed using the Bonferroni correction to the *p*-value. The alpha level of .05 was used. All statistical analyses were performed using the SPSS version 13.0 for Windows (SPSS Inc., Chicago, IL, USA).

3 | RESULTS

3.1 | Behavioral data

Behavioral data are reported in Table 1. Regarding the response time (RT), the main effects of group or task were not significant ($F_{(1,30)} < 1$); however, the interaction between group and task was significant ($F_{(1,30)}$ = 6.75, $p = .014$; $\eta_p^2 = .184$). The post hoc comparison revealed that in the standard task, the high anxious group was slower (p = .041) than the low anxious group, whereas no differences were present in the feedback task. While no task differences were present in the low anxious group, the high anxious group showed faster RTs (p = .038) in the feedback than the standard task.

TABLE 1 Response time (RT) in milliseconds, percentage of commission, and omission errors (CE and OE) for the high and low anxious groups in the standard and feedback tasks. Standard deviation (SD) is reported in brackets

	Group	Standard task (SD)	Feedback task (SD)
RT	High anxious	487 (102)	444 (95)
	Low anxious	450 (98)	440 (89)
CE	High anxious	26.2% (5.2)	21.1% (4.8)
	Low anxious	20.5% (4.4)	18.7% (5.2)
OE	High anxious	10.3% (2.7)	4.5% (1.3)
	Low anxious	3.1% (.9)	1.1% (3.5)

Regarding the CE percentage, the main effect of group was not significant ($F_{(1,30)} < 1$), whereas the main effect of task was barely significant ($F_{(1,30)}$ = 4.21, $p = .049$; $\eta_p^2 = .123$), indicating that participants committed fewer CEs (19.8%) in the feedback than in the standard task (22.4%). The interaction between group and task was significant ($F_{(1,30)}$ = 7.84, p = .009; $\eta_p^2 = .207$). The post hoc comparison revealed that in the standard task, the high anxious group was less accurate ($p = .011$) than the low anxious group, whereas no differences were present in the feedback task. While no task differences were present in the low anxious group, the high anxious group showed less CE (p = .029) in the feedback than the standard task.

Regarding the OE percentage, the main effect of the group was significant ($F_{(1,30)}$ = 6.49, p = .016; $\eta_p^2 = .178$), indicating that the high anxious group (7.4%) committed more OEs than the low anxious group (2.1%). The task effect was close to significance ($F_{(1,30)}$ = 4.02, p = .052; $\eta_p^2 = .120$; standard: 6.7%; feedback: 2.8%). The interaction between group and task was not significant ($F_{(1,30)} < 1$). Despite an important reduction in OE in high anxious individuals relative to the low anxious group, the interaction was not significant, likely because of the large standard deviation of low anxious in the feedback task, which was 31.8% of the mean.

3.2 | ERP data

Figure 2 shows the pN and the BP waveforms at the prefrontal and centroparietal pools. Figure 3 shows the scalp topography for the two groups and tasks in the intervals from −320 to 0 ms. Both the pN and the BP initiated at about −800 ms and were maximal at the stimulus onset. Being this stimulus-locked ERP, the BP ends earlier than response-locked ERP because of the presence of positive stimulus-related activity (as the P2 and P3 components). The pN showed the typical bilateral prefrontal radial distribution, more prominent over the right hemisphere, whereas the BP showed a medial centroparietal radial distribution (For normative data on the pN and BP please see Di Russo et al., 2019).

ANOVA of the pN amplitude showed non-significant effects of group ($F_{(1,30)}$ = 1.87, p = .171) and task ($F_{(1,30)}$ = 2.33, p = .139). However, the interaction between group and task was significant ($F_{(1,30)}$ = 9.13, p = .005, η_p^2 = .217). Post hoc comparisons indicated that the pN of the high anxious group in the standard task was smaller ($p < .021$) than all other conditions, which did not differ from each other. The BP did not show any difference either between groups ($F_{(1,30)}$ = 1.57, p = .220)

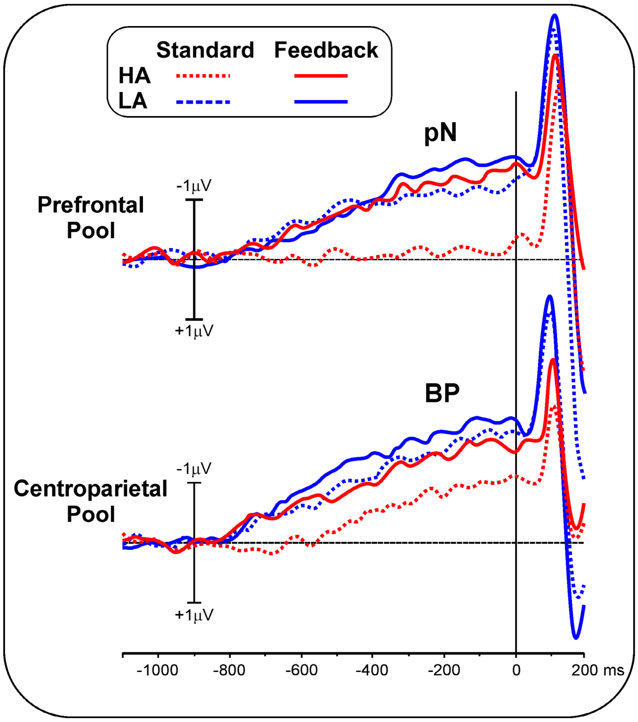

FIGURE 2 Pre-stimulus ERP waveform at the prefrontal and centroparietal pools representing the pN and BP, respectively, in both conditions (feedback and standard) in both groups. HA, high anxious; LA, low anxious.

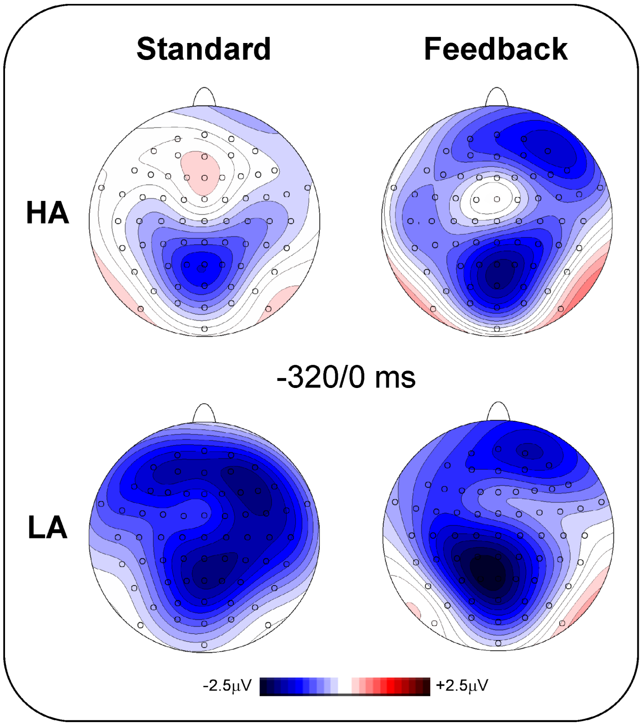

FIGURE 3 For both tasks and groups, the scalp topographies (top-flat view) of the pN and the BP components in the last 320 ms before the stimulus onset. HA, high anxious; LA, low anxious.

TABLE 2 Mean amplitude and standard deviation (SD) in μV of pN and BP components in the interval from −320 to 0 ms for the high and low anxiety groups in the standard and feedback tasks

Component	Group	Standard task (SD)	Feedback task (SD)
pN	High anxious	−.13 (.08)	−1.24 (.35)
	Low anxious	−1.14 (.28)	−1.46 (.43)
BP	High anxious	−.86 (.17)	−1.52 (.37)
	Low anxious	−1.62 (.45)	−1.88 (.52)

or between tasks ($F_{(1,30)} = 1.11$ $p = .300$). The interaction was significant ($F_{(1,30)} = 5.38$, $p = .027$, $\eta_p^2 = .152$). Post hoc comparisons indicated that the BP of the high anxious group in the standard task was smaller ($p < .036$) than all other conditions, which did not differ from each other. Table 2 reports the mean amplitude and standard deviation (SD) of pN and BP components for the two groups and tasks.

To test the relationship between ERP components and performance in people with different levels of anxiety traits, we correlated the amplitude of the pN and the BP with the CE percentage and the RT, respectively. As shown in Figure 4, results showed that the correlation was both significant and the high anxious group individuals filled the upper left part of the data cloud during the standard tasks and mixed up with the low anxious individuals during the feedback task.

4 | DISCUSSION

Previous research has shown that self-evaluation of motor/cognitive failures is positively correlated with the level of anxiety (Campeau, 1968; Mecacci et al., 2004; Matthews & Wells, 1988; Righi et al., 2009). Thus, anxious people tend to feel uncertain or unsure about their own motor and cognitive activities and, consequently, they tend to have worst performance than non-anxious people in many tasks. In support of this, in the present standard task, in which participants did not receive feedback on their wrong responses, the high anxious group was slower and less accurate than the low anxious group, whereas no differences were present in the task with feedback. Such as found in previous studies (Mussini et al., 2022), the presence of feedback in the present task helps people make fewer mistakes; indeed, participants committed fewer commission errors in the feedback than in the standard task.

Our results confirm that trait anxiety negatively influences performance in cognitive tasks. Moreover, we also extend current literature, interpreting this effect as due to a reduction of cognitive preparation within the

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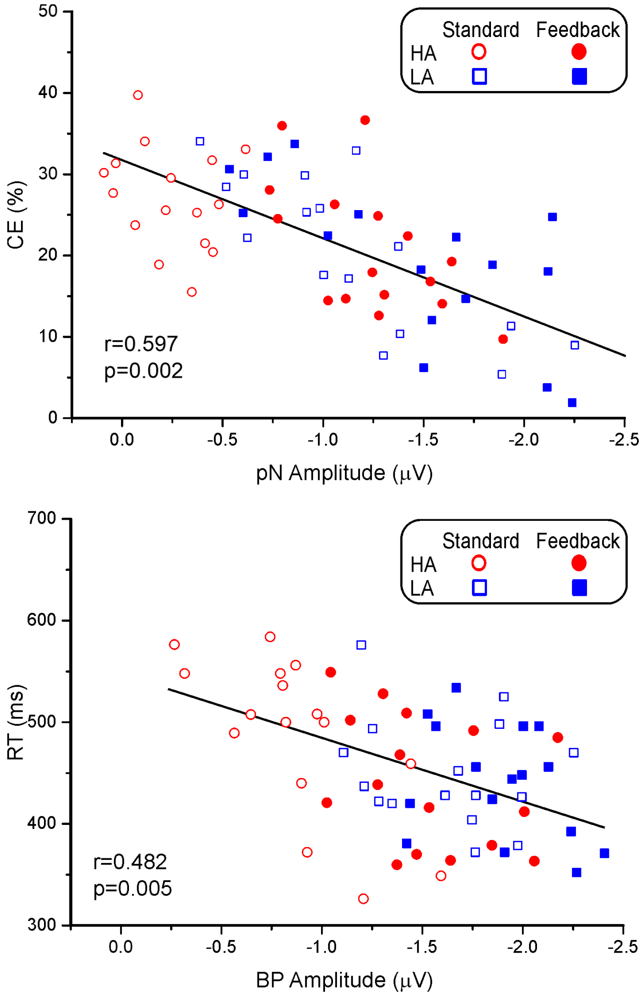

FIGURE 4 Above, is shown the correlation between the pN component and commission errors (CE). Below, is displayed the correlation between the BP and response time (RT). Different symbols and colors identified the two groups and tasks. HA, high anxious; LA, low anxious.

frontal cortex during the pre-stimulus phase. Our results fit with previous ERPs and fMRI research on anxiety (Ansari & Derakshan, 2011a, 2011b; Bishop, 2009), showing that high anxious people have lower activity in frontal areas. In addition, here, we specify that this activity reduction already occurs in the anticipatory phase of task performance before the stimulus appearance. This result seems to be also in line with the model of anxiety (Campeau, 1968) and with our predictions. The pN component, associated with cognitive preparation (specifically, top-down attention and inhibition; see Di Russo et al., 2016), appears to be highly reduced in the high anxious group during the standard task and became normal (as shown in low anxious group) in the feedback task. In contrast, the low anxious group showed the same activity during both tasks. The pN component is sensitive to several variables such as age, physical activity, and task complexity (Berchicci et al., 2012, 2015, 2016, 2019; Mussini et al., 2021; Perri et al., 2019); precisely, it has been shown that a large pN would mark a high top-down control. This negative activity has been repeatedly associated with proactive inhibitory control (Berchicci et al., 2012; Bianco, Berchicci, et al., 2017; Perri et al., 2014), with accuracy (such as here confirmed) in terms of commission errors (e.g., Bianco, Di Russo, et al., 2017) and omission errors (e.g., Perri et al., 2019). The fact that pN was reduced in the anxious group in the standard task suggests that the prefrontal cortex of anxious people has less inhibition, supported by attentional control theory (Eysenck et al., 2007; see also Berggren & Derakshan, 2013). Most studies that have provided support for this theory have used threat stimuli such as distractors (see Cisler & Koster, 2010, for review); however, other research has shown that anxiety was associated with impaired inhibition even in the absence of threats. Neural correlates of this effect are not yet clearly understood; for instance, different neuroimaging studies validate the assumption of impoverished recruitment of top-down resources in anxious people (Aarts & Pourtois, 2010; Ansari & Derakshan, 2011a, 2011b; Bishop, 2009; Botvinick et al., 2004). Moreover, research on anxiety showed that, even in the absence of threat stimuli, anxiety could influence inhibitory control, a process identifiable in our pN component (Bishop, 2009; Derakshan & Eysenck, 2009).

The introduction of response-related feedback in the present task normalizes not only the pN component but also the BP component in the high anxious group. This normalization affects response times, bringing them back to the level of the low anxious group. The BP amplitude, which originates in the premotor cortex, has been correlated (such as here confirmed) with response times (e.g., Di Russo et al., 2019) and associated with motor readiness (or readiness) for any self-piloted (e.g., Shibasaki & Hallett, 2006) or externally activated (e.g., Di Russo et al., 2017) voluntary movements. The presence of response-related feedback normalizes the performance in the high anxious group, likely because feedback increases stimulus and response awareness and, consequently, attention to the task, which lacks in high anxious people. These results are also in line with the attentional control theory (ACT), which assumes that anxiety impacts the ability to distribute attentional and cognitive resources to task performance in a fruitful way. This is because anxious people need a greater cognitive effort to achieve performance than people with low levels of anxiety. Moreover, this is also supported by the notion that the activity in the prefrontal cortex decreases in anxious people (Bishop, 2009). A hypothesis in this regard suggests that damaging certain portions of the prefrontal cortex impairs the ability to anticipate future affective outcomes, which results in an inability to guide behavior in an adaptive way (Klouda & Cooper, 1990). Such damage does not disrupt the individual's response to an immediate cue for reward and punishment, but it affects anticipation before an affective cue is shown. Furthermore, it has been demonstrated that the reduction of prefrontal cortex activity in stressful situations may reflect impaired cognitive control (Ossewaarde et al., 2011).

Therefore, anxiety appears to affect decision-making processes. In particular, this phenomenon causes abnormal reactivity of different brain areas: the insula (Ernst et al., 2002; Paulus et al., 2003), the amygdala (Etkin et al., 2004), and the prefrontal cortex (e.g., elevated anxiety is related to reduced recruitment of prefrontal control mechanisms in response to processing competition; Bishop, 2009). Therefore, these cognitive impairments, underlying high levels of anxiety, might be detrimental during decision-making processes.

Future studies with a large sample size could employ a mediation model between pre-stimulus ERPs, anxiety, and performance. To test if ERPs may mediate the impact of anxiety on behavioral performance.

In conclusion, the existence of a high level of anxiety is not necessarily a pathological disease, but it could cause dysregulation. This dysregulation could affect our lives, particularly our emotional processes, impacting daily life. In fact, anxiety regulation is central to almost all psychological treatments. The predominant perspective on emotion regulation and dysregulation is the appraisal theory; according to *Gross's process model*, any emotion can become dysregulated when the person lacks or fails to use an appropriate regulatory strategy (Grecucci et al., 2016). This theory appears in line with our results: people with high anxiety levels tend to prepare and react in an inappropriate way to environmental requests because they perceive the outcomes of their actions as uncertain. However, this can be mitigated when response feedback is provided. This conclusion is supported by the observation that the presence of trial-to-trial feedback moderates the relationship between error-related brain activity and anxiety (Olvet & Hajcak, 2009). The present findings may allow the development of new (drug-free) anxiety treatments based on response-related feedback.

AUTHOR CONTRIBUTIONS

Elena Mussini: Data curation; formal analysis; investigation; writing – original draft; writing – review and editing. **Francesco Di Russo:** Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; supervision; writing – review and editing.

ACKNOWLEDGMENTS

This study was supported by the University of Rome "Foro Italico" grant CDR2.BANDO2020DRF to FDR.

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How to cite this article: Mussini, E., & Di Russo, F. (2022). Reduction of anticipatory brain activity in anxious people and regulatory effect of response-related feedback. *Psychophysiology*, *00*, e14166. https://doi.org/10.1111/psyp.14166