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Feedback-related negativity in perfectionists: An index of performance outcome evaluation

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Abstract

It has been suggested that maladaptive perfectionists are more prone to concern over their performance outcomes than adaptive perfectionists. Performance outcome evaluation is reflected in the amplitude of feedback-related negativity (FRN) in brain electroencephalography (EEG). Hence, the amplitude of the FRN after receiving unfavorable feedback indicating a negative performance outcome may reflect personality characteristics. In other words, EEG could be a better marker of personality characteristics than self-report measures. However, the FRN component has not yet been investigated between different types of perfectionists. In the present study, group differences in the FRN were examined between two groups of adaptive and maladaptive perfectionists and a group of non-perfectionists during a monetary gambling task. We observed a larger FRN amplitude for adaptive perfectionists than for maladaptive perfectionists. This finding is consistent with previous reports that reward prediction error is reflected in the amplitude of the FRN. This difference in FRN could be interpreted as the pessimistic outcome expectation biases in maladaptive perfectionists.

Keywords: Performance outcome evaluation, Feedback-related negativity; Event-related negativity; Perfectionism; Adaptive perfectionism; Maladaptive perfectionism.

1. Introduction

Evaluation and comparison of performance outcomes with internal standards are critical to optimizing future behaviors (Billeke et al., 2020; Ridderinkhof et al., 2004). Outcome evaluation facilitates reinforcement learning and is involved in performance monitoring (Hauser et al., 2014; Schmid et al., 2018). A growing corpus of studies has utilized event-related potentials (ERP) to examine the neural activities related to outcome evaluation. In particular, studies have identified feedback-related negativity (FRN) as the most relevant ERP component that reflects the external evaluation of negative performance outcomes (i.e., neural activity elicited by feedback indicating an unfavorable outcome; Foti & Weinberg, 2018). Individual differences and personality traits have been found to modulate the magnitude of FRN amplitude (Mothes et al., 2016; Takács et al., 2015). Previous studies have demonstrated that perfectionism as a personality disposition has an impact on the neural correlates of negative performance processing (Perrone-McGovern et al., 2017). However, FRN particularly has not been investigated among perfectionists. Studying the impact of personality traits such as perfectionism on FRN will add to the body of knowledge in the area of negative performance outcome evaluation and might open the doors to identifying personality characteristics using EEG markers of individuals rather than their self-reports.

1.1. Perfectionism

Definitions of perfectionism as a personality trait center on striving for flawlessness, setting excessively high performance standards, and overly self-criticism over not meeting standards (Stoeber, 2018). However, it has been shown that perfectionism is best conceptualized as a multidimensional and multifaceted construct (Gotwals et al., 2012). Cumulative evidence indicates that two major dimensions of perfectionism should be differentiated; an adaptive dimension, which has been described as normal (Hamachek, 1978), healthy (Stumpf & Parker, 2000), and positive (Terry-Short et al., 1995) perfectionism, and a maladaptive dimension that has been described as neurotic (Hamachek, 1978), unhealthy (Stumpf & Parker, 2000), and negative (Terry-Short et al., 1995) perfectionism.

Adaptive perfectionists refer to those who set high personal standards for their performance. However, maladaptive perfectionists are excessively concerned about making mistakes. They may evaluate their performance critically, negatively react to making mistakes, and fear negative evaluations more frequently (Stoeber & Otto, 2006). Positive affect (Mallinson-Howard et al., 2019), happiness, life satisfaction (Suh et al., 2017), and self-esteem (Chen et al., 2017) are among the positive psychological outcomes predicted by adaptive perfectionism. In contrast, Maladaptive perfectionism may be followed by depression (Cooks & Ciesla, 2019), anxiety (Tyler et al., 2019), and low self-esteem (Taylor et al. s, 2016).

Perfectionistic striving seems to be a common characteristic of adaptive and maladaptive perfectionists. However, evaluative concern about performance outcomes has been suggested to be the main factor in distinguishing between adaptive and maladaptive perfectionists (Stoeber, 2018).

There is a third group of individuals that show no evidence of perfectionism (Lundh and Saboonchi, 2003). This large group of people who can be labeled as non-perfectionists, also experience low levels of depression and anxiety, like adaptive perfectionists. This group of non-perfectionists has possibly lower self-actualization, creativity, and positive quality of life than adaptive perfectionists (Lars-Gunnar, 2004).

1.2. Feedback-related negativity

FRN as a negative-going potential is generated in the anterior cingulate cortex (ACC) and peaks at 200-300 ms following an evaluative performance feedback presentation (Gehring & Willoughby, 2002). The FRN has been suggested to be larger for unexpected negative compared to expected positive feedback (Burnside et al., 2019; Soder & Potts, 2017; Weismuller & Bellebaum, 2016). Therefore, the difference between expected and real outcomes can modulate the amplitude of the FRN (Hauser et al., 2014; Weismuller & Bellebaum, 2016).

Moreover, FRN is a neural correlate of prediction error (PE) which refers to the differences between outcome and expectancy. Seemingly, larger FRN magnitudes will be observed when the outcome is worse than expected in comparison to when the outcome is better than expected (Gu et al., 2021). As a result, FRN may be responsive to pessimistic outcome expectation biases (Takács et al., 2015). In this regard, Gu et al., (2010) have reported more negative amplitudes of FRN for low-anxious participants relative to their highly anxious peers. The authors have explained this difference in terms of outcome prediction error. High anxious individuals are said to pessimistically predict their performance outcome, which makes them expect negative feedback in a cognitive task. So, getting negative feedback is not unexpected and surprising for them, which leads to a lower amplitude of FRN. In the case of low anxious individuals, however, the negative feedback was an unexpected outcome, resulting in larger FRN amplitudes. Nevertheless, there is still much to be understood about the specific cognitive and affective processes that elicit FRN.

1.3. Perfectionism and error processing

Perfectionism has been shown that significantly impact the ERP correlates of negative performance (error) processing. One of the well-known ERP components related to negative performance processing is error-related negativity (ERN). ERN is known to reflect internal error processing (i.e., neural activity elicited by error commission; Foti & Weinberg, 2018; Gehring et al., 2018). It has been suggested that maladaptive perfectionists have a greater amplitude of ERN than adaptive perfectionists (Perrone-McGovern et al., 2017). The larger ERN could indicate hypervigilance in evaluative concerns in maladaptive perfectionists (Shafran et al., 2002). Besides, perfectionists with high personal standards and high evaluative concerns (maladaptive perfectionists) have a larger amplitude of ERN than those with pure high personal standards (adaptive perfectionists; Stahl et al., 2015).

Both ERN and FRN have been suggested to generate in the ACC and play an essential role in performance monitoring (Gehring et al., 2018; Gehring & Willoughby, 2002). Despite the similarities between the two components, ERN reflects the use of self-generated information in processing an error, while FRN has been suggested to reflect the externally provided information in detecting a negative performance outcome. In other words, while ERN is elicited by error commission, FRN is generated by negative feedback indicating unfavorable performance outcomes (Foti & Weinberg, 2018). However, the studies mentioned above have investigated group differences between adaptive and maladaptive perfectionists in the ERN, and none of them has studied the FRN. Studying FRN between perfectionists will add to our understanding of the electrophysiological correlates of evaluative concerns in perfectionists, particularly when they receive negative feedback from an external source.

1.4. Aim & Hypothesis

This study aimed to investigate whether the type of perfectionism influences the features of FRN. Following previous research that suggested a higher evaluative tendency and larger ERN amplitudes in maladaptive than adaptive perfectionists, we hypothesized a larger (or more negative) amplitude of the FRN for maladaptive than adaptive perfectionists following the negative feedback presentation. We used the monetary gambling task to measure FRN which provide the participant with four sorts of positive and negative feedback including loss-error, gain-correct, less-correct, and gain-error (see procedure section for more details). Loss and gain refer to the monetary punishment or reward respectively. The error shows that the other choice would have yielded a higher reward or a lower punishment than the selected response. Correct reveals that the alternative choice would have yielded a higher penalty or a lower reward relative to the chosen choice (Nieuwenhuis et al., 2004). We hypothesized different between-group differences in those conditions, which will be the largest difference in the loss-error condition, and the smallest in the gain-correct condition. We expected the highest difference in the loss-error condition because it was the most negative feedback .We additionally included a non-perfectionist group that allows us to investigate the typical FRN that is not modulated by any kind of perfectionism.

However, anxiety as one of the major factors related to perfectionism has not been focused on as a control variable in studying perfectionism and error processing. A vast body of studies showed that maladaptive perfectionism positively correlated with anxiety (Tyler et al., 2019; Karababa, 2020; Eley et al., 2020; Lamarre and Marcotte, 2021; Butković et al., 2021) but adaptive perfectionism negatively related to anxiety (Gnilka et al., 2012; Vastone and Hicks, 2019). Moreover, recent studies showed that anxiety had a significant effect on FRN amplitude (Jones et al., 2020; Tobias and Ito, 2021). Considering these two lines of study, it is plausible that anxiety interferes with the potential impact of perfectionism on FRN amplitude. Thus, the effect of anxiety is better to be concerned in the research aimed to study perfectionism and error processing. To control the effect of anxiety, we excluded the participants who got high scores on the anxiety scale.

2. Method

2.1. Participants

A sample of 400 university students completed the perfectionism (Almost Perfect Scale-Revised or APS-R) and anxiety (Beck Anxiety Inventory or BAI) questionnaires (see the instruments section for details of the tests). First, a total of 19 participants (13 women and 6 men) who had reported a history of neurological or psychiatric disease were removed. Second, 23 participants [16 women (M = 34.81, SD = 10.16) and 7 men (M = 30.00, SD = 9.83)] who got scores above 21 in BAI were excluded. We divided the remaining 358 participants based on their scores in the APS-R subscales into three groups of adaptive perfectionists, maladaptive perfectionists, and non-perfectionists (see below for details). Then, we invited 72 participants who got the highest scores in the APS-R in each group (see below for details). While 11 participants declined further participation (3 adaptive, 5 maladaptive, and 3 non-perfectionist), 61 participants were recruited for the EEG experiment. Additional three participants were excluded because of noisy EEG data.

The data of a final sample of 58 participants (19 adaptive perfectionists, 21 maladaptive perfectionists, and 18 non-perfectionists; 40 women and 18 men) were analyzed. There was no significant age difference between the groups [F (2,35.2) = 1.81, p = .179; adaptive: M = 22.26, SD = 3.12, range = 18-29; maladaptive: M = 21.95, SD = 2.48, range = 18-27; non-perfectionist: M = 20.94, SD = 1.73, range = 19-26]. There was also no significant gender difference between the groups [X^2 (2, N = 58) = 2.92, p = .232; adaptive: 13 women and 6 men; maladaptive: 17 women and 4 men; non-perfectionist: 10 women and 8 men]. All participants were right-handed, had a normal or corrected-to-normal vision, with no reported history of neurological or psychiatric disorders. There was also no significant difference in anxiety scores between the groups [F (2, 36.6) = 0.57, p = 0.56]. Also, the correlation between the anxiety scores and each APS-R subscale of high standards [r (58) = .14, p = .290], discrepancy [r (58) = .16, p = .223] and order [r (58) = .06, p = .646] were not significant. Therefore, we assume that anxiety may not confound any possible findings of the study.

2.2. Instruments

2.2.1. Almost Perfect Scale-Revised

Almost Perfect Scale-Revised (APS-R; Slaney et al., 2001) contains 23 items and three subscales: The high standards subscale (7 items) measures high personal standards and performance expectations. The order subscale (4 items) measures preferences for order and organization. The discrepancy subscale (12 items) measures the most clearly negative characteristic of perfectionism in tapping "the perception that one consistently fails to meet the high standards that one has set for oneself" (Slaney et al., 2002). Responses are rated on a 7-point Likert scale from 1 (strongly disagree) to 7 (strongly agree). According to Rice and Ashby (2007), scores greater than or equal to 42 in the high standards subscale with scores lower than 42 in the discrepancy subscale could demonstrate adaptive perfectionism, while scores greater than or equal to 42 in both high standards and discrepancy subscales show maladaptive perfectionism. Individuals who get low scores in the high standards subscale (lower than 42) are classified as non-perfectionists. Rice and Ashby (2007) found Cronbach's alpha coefficients of 0.86 for high standards, 0.87 for order, and 0.93 for the discrepancy indicating adequate reliabilities, which were 0.72, 0.75, and 0.84 respectively.

2.2.2. Beck Anxiety Inventory (BAI)

We used the Beck Anxiety Inventory (BAI; Beck et al., 1988) which is one of the most studied and a standardized anxiety questionnaires for the society to which our sample is belonged (Kaviani and Mousavi, 2008: Khesht-Masjedi and Omar, 2015). The BAI consists of 21 items. Each item is on a 4-point scale ranging from 0 (not at all) to 3 (severely, I could barely stand it). Thirteen items describe physical or physiological symptoms (e.g., heart pounding), 5 items represent cognitive aspects of anxiety (fear of the worst), and 3 items have a physical and cognitive connotation (e.g., terrified). It has an excellent internal consistency (coefficient alpha = 0.91) and a test-retest reliability coefficient of 0.65 (Bardhoshi et al., 2016). In the present study, Cronbach's alpha of 0.81 was obtained for the BAI. The sum scores higher than 21 in this questionnaire reveal moderate to potentially concerning levels of anxiety (Beck et al., 1988), therefore, as we outlined above, 23 participants who had a sum score higher than 21 were discarded.

2.3. Monetary gambling task

We used a modified version of the monetary gambling task (Gehring & Willoughby, 2002). In this task, each trial began with the presentation of a 500 ms fixation point, followed by two cards with numerals 5 and 25 as alternatives. The alternatives were shown for 2000 ms, and participants had to choose between them by pressing the left or right arrow keys, respectively, for the cards on the left and right sides of the screen with the right indexes and middle fingers of their right hand. After a 500 ms inter-stimulus interval, the chosen alternative with a bold black border around it and the other alternative choice were shown together with the + or - sign indicating the valence of the outcome of each numeral. This served as the feedback that remained on the screen for 1000 ms, followed by the next trial after a 1000 ms blank screen. The task was composed of 16 blocks of 24 trials, containing a total of 384 trials (see Fig.1).

The 12 potential combinations of numerals 5 and 25 with - and + signs were repeated twice per block randomly and with an equal chance (see Table 1). These combinations led to four conditions: gain-correct, gain-error, loss-correct, and loss-error. While loss and gain demonstrate the monetary penalty and reward (achievement) respectively, error and correct reveal accuracy. The error shows that the other possible choice would result in a bigger reward or a minor penalty than the chosen option. Correct reveals that the alternative choice would be followed by a larger penalty or a lesser reward relative to the chosen choice (Nieuwenhuis et al., 2004). Three conditions of task consisting of loss-error, loss-correct, and gain-error can represent the difference between perfectionists in reaction to negative feedback. The loss-correct condition can indicate the reaction to loss even though the picked answer is correct. Nevertheless, the gain-error condition can be a marker of the error response regardless of whether the preferred response follows by gain. Although the mentioned two conditions represent poor performance, the loss-error condition could be the best representative of negative feedback, which implies losing money and making a wrong response simultaneously. The loss-error and gain-correct conditions make up 320 trials, while the loss-correct and gain-error conditions make up 64 trials of the whole task. One of the possible outcomes per each condition was analyzed (Table 1). Thus, we concluded 32 trials for each condition to analyze.

2.4. Procedure

Participants were asked not to drink coffee or consume energy drinks on the day of the experimental session. They were also asked to maintain their usual daily activity and sleep rhythms before the experiment. All participants signed a consent form before their participation. The participant sat comfortably in an electrically shielded room, approximately 80 cm in front of a computer screen. After a brief description of the experiment, the EEG cap was attached and each participant was given the relevant task instructions. Then, the subjects performed a practice block of the task to ensure they understand the instructions. In the next step, Participants completed a revised version of the monetary gambling task (Gehring & Willoughby, 2002), executed and provided employing the eevoke™ (ANT Neuro, Enschede, Netherland) software, while their brain responses were reordered. Finally, all the participants were paid for their participation.

2.5. EEG data recording and preprocessing

Continuous electroencephalogram (EEG) signals were recorded on 64-channel with waveguard™ cap (ANT Neuro, Enschede, Netherland), configured to 10-10 systems. All data were referenced to the mean activity of two mastoids. All signals were filtered with a band-pass of 0.3-100 Hz and digitized at a rate of 250 Hz. Electrode impedance was kept below 10 KΩ.

The data was processed in MATLAB (version R2014a) using the EEGLAB toolbox (version 14.1.2.). Data were filtered offline using a band-pass filter between 0.3 and 30 Hz. Three participants were excluded due to noisy data, which was caused by sweating. For each feedback stimulus, a 1000 ms (from 200 before the feedback presentation to 800 ms after that) epoch of data was extracted from the continuous data for the analysis. A pre-stimulus period of 200 ms was subtracted as a baseline. According to the literature (Gehring and Willoughby, 2002; Nieuwenhuis et al., 2004; Hajcak et al., 2006), the FRN amplitude was expected at FCz, Cz, and Fz. The amplitude of FRN was defined as the mean value of the signal at electrodes FCz, Cz, and Fz in a window from 250 to 350 ms (based on previous relevant studies e.g., Liu et al., 2014; Bress et al., 2012) after feedback presentation.

2.6. Data analysis

After excluding the missing trials (10%), the response time and FRN amplitude of the remaining trials were analyzed. We conducted 3 (group: adaptive, maladaptive, non-perfectionist) by 2 (gaining: loss, gain) by 2 (correctness: error, correct) repeated measure ANOVAs for response times. A similar repeated measure ANOVA by including electrodes (FCz, Cz, Fz) was conducted for the FRN amplitude. Note that since our model has only two levels, the assumption of sphericity is always met. We further explored significant main or interaction effects using posthoc comparisons that were corrected by the Tukey method for multiple testing. A similar repeated measure ANOVA was conducted on the number of included trials for each condition that showed no significant main or interaction effect [F < 1.64, p > .205, η_p^2 < .057] (see Table 2) that suggested a comparable signal-to-noise ratio for further comparisons. Also, we conducted an odd-even split-half reliability test on the FRN data across all participants and separately for each of the four conditions and the three electrodes. The Spearman-Brown correlations were > .97 for the four conditions and the three electrodes.

To directly test our priori hypotheses, we compared the performance of the two perfectionist groups in the four conditions using independent-sample t-tests. The dependent variable was response times, and the FRN amplitude in three electrode sites. The alpha level was not corrected for testing the priori hypotheses. The analysis was conducted using jamovi (Version 2.2).

3. Results

3.1. Response time

The repeated measure ANOVA revealed a significant main effect of the group [F (2, 55) = 8.53, $p < .001$, $\eta_p^2 = .237$], suggesting between-group differences in response time (Table 3). Posthoc analysis showed slower responses in the adaptive group as compared to the maladaptive group [t (55) = 4.11, $p < .001$], and the non-perfectionist group [t (55) = 2.41, p = .050]. No significant difference was observed between the maladaptive and non-perfectionist groups [t (220) = 1.59, p = .260].

The main effect of gaining was also significant [F (1, 55) = 4.66, p = .035, $\eta_p^2 = .078$] which shows slower responses in gain than in loss conditions. The interaction of the group by gaining by correctness showed a trend [F (2, 55) = 3.02, p = .057, $\eta_p^2 = .099$]. We explored this interaction by comparing the response times in the four conditions between the three groups. The posthoc comparisons revealed significantly slower responses in the adaptive group than the maladaptive group in the loss-error condition [t (55) = 4.41, p = .003] and the gain-correct condition [t (55) = 3.99, p = .010]. No other significant between-group difference was observed after correction for multiple testing [t (55) < 2.94, p > .156].

3.2. ERP data

The repeated measure ANOVA revealed a significant effect of gaining [F(1, 55) = 7.50, p = .008, $\eta_p^2 = .120$], a significant effect of the electrode [F(2, 110) = 26.51, $p < .001$, $\eta_p^2 = .325$], a trend of gaining by correctness by group interaction [F(2, 55) = 2.62, p = .082, $\eta_p^2 = .087$], a significant interaction of gaining by electrode by group [F(4,110) = 2.91, p = .025, $\eta_p^2 = .096$], a trend of correctness by electrode interaction [F(2,110) = 3.00, p = .054, $\eta_p^2 = .052$], and a significant interaction of correctness by electrode by group [$F(4,110) = 3.77$, $p = .007$, $\eta_p^2 = .120$]. As the electrode derived most of the observed effects, we conducted the following analyses separately for each electrode (Table 4).

FCz

The repeated measure ANOVA revealed a significant effect of gaining [F (1, 55) = 5.92, $p = .018$, $\eta_p^2 = .097$] showing a larger FRN amplitude in loss than gain conditions. The interaction of group by gaining by correctness showed a trend [F (2, 55) = 2.67, $p = .078$, $\eta_p^2 = .088$]. However, posthoc comparisons revealed no significant difference between conditions in any of the groups after correction for multiple testing [t (55) < 3.23, $p > .077$]. The other effects were not significant.

Cz

The repeated measure ANOVA revealed a significant effect of gaining [F (1, 55) = 8.36, $p = .005$, $\eta_p^2 = .132$] showing a larger FRN amplitude in loss than gain conditions. The other effects were not significant. Topographical distribution maps were taken from 250-350 ms post feedback window in all conditions for each group are presented in Fig. 5.

Fz

The repeated measure ANOVA revealed a trend of gaining [F (1, 55) = 3.07, $p = .085$, $\eta_p^2 = .053$] and a significant interaction of group by gaining [F (2, 55) = 3.32, $p = .043$, $\eta_p^2 = .108$]. Posthoc comparisons showed that this effect is derived only by the maladaptive group [t (55) = 3.12, $p = .033$] which shows a larger FRN amplitude in loss than in gain conditions in this group.

The interaction of group by correctness was also significant [F (2, 55) = 4.43, $p = .016$, $\eta_p^2 = .139$]. However, posthoc comparisons revealed no significant difference between correct and error conditions in any of the groups [*t* (55) < 2.13, *p* > .291]. The other effects were not significant (Table 5, Fig.3 and Fig.4).

3.3. The comparisons between perfectionist groups

Response time

Direct comparison of the two perfectionist groups revealed a significant difference in the loss-error condition [$t(38) = 4.80$, $p < .001$, Cohen's $d = 1.52$], in the gain-error condition [$t(38) = 2.75$, $p = .009$, Cohen's $d = 0.87$], in the gain-correct condition [$t(38) = 4.76$, $p < .001$, Cohen's $d = 1.51$], and a trend in the loss-correct condition [$t(38) = 1.93$, $p = .062$, Cohen's $d = 0.61$] suggesting longer response times in adaptive than the maladaptive group in all conditions (see Fig.2).

FCz

Direct comparison of the two perfectionist groups revealed a significant difference in the loss-error condition [t (38) = 2.89, $p = .006$, Cohen's $d = 0.91$], suggesting a larger FRN amplitude in the adaptive than maladaptive group. No significant difference was observed in other conditions [t (38) < 0.95, $p > .350$, Cohen's $d < 0.30$].

Cz

Direct comparison of the two perfectionist groups revealed a significant difference in the loss-error condition [t (38) = 2.52, $p = .016$, Cohen's $d = 0.80$], suggesting a larger FRN amplitude in the adaptive than maladaptive group. No significant difference was observed in other conditions [t (38) < 1.15, $p > .259$, Cohen's $d < 0.36$].

Fz

Direct comparison of the two perfectionist groups revealed a trend in the loss-error condition [t (38) = 1.91, $p = .064$, Cohen's $d = 0.65$] suggesting a larger FRN amplitude in the adaptive than maladaptive group. No significant difference was observed in other conditions [t (38) < 1.33, p > .192, Cohen's d < 0.42].

4. Discussion

This study aimed to investigate whether the type of perfectionism influences performance feedback processing. For this purpose, we compared response time and FRN features elicited by negative and positive feedback between two groups of adaptive and maladaptive perfectionists and a group of non-perfectionists. Our results showed longer response times for adaptive perfectionists compared to the other two groups in all conditions, and larger FRN amplitude in the loss-error condition for adaptive perfectionists relative to the maladaptive group.

The FRN is elicited in the ACC and is an electrophysiological equivalent of brain dopaminergic activities (Gehring & Willoughby, 2002). It has been suggested that this component is associated with performance monitoring and outcome evaluation (Gehring & Willoughby, 2002; Miltner et al., 1997). Previous studies have reported group differences between perfectionist subgroups in other ERP correlates of performance monitoring involved in the internal error processing like ERN (Perrone-McGovern et al., 2017; Stahl et al., 2015). However, we know next to nothing about possible brain response differences between perfectionism subgroups to external error processing (or negative feedback) and negative outcome evaluation. Thus, the present study extends the existing literature on this topic and contributes to a more nuanced understanding of the relationship between perfectionism and performance monitoring. We investigated the FRN component as an EEG marker of perfectionists' evaluation of their performance and their reaction to feedback in two groups of adaptive and non-adaptive perfectionists.

The behavioral findings of the present study suggest that adaptive perfectionists invest more time in the decision-making between two choices compared to maladaptive perfectionists and non-perfectionists. Kobori and Tanno (2012) demonstrated a slowed reaction in individuals with high perfectionism than in individuals with low perfectionism in a failure condition, which may be a marker for attentional bias in perfectionists. Moreover, accuracy is more important than speed for adaptive perfectionists with a stronger tendency to perfectionistic striving; hence, they spend more time choosing accurate answers. Thus, invested time in a task could be a possible mediator between perfectionistic striving and high performance (Stoeber et al., 2010). Previous research also found that adaptive perfectionists indicated higher performance than maladaptive ones in real life and experimental tasks (Lizmore et al., 2019; Madigan et al., 2020). Therefore, longer reaction times for adaptive perfectionists than the maladaptive group in our study probably show the adaptive group's tendency to have accurate choices. In fact, accuracy is more important than speed for this group.

Moreover, our ERP findings revealed a significant effect of the type of perfectionism on the FRN amplitude, indicating a significantly larger FRN amplitude in adaptive than maladaptive perfectionists. This finding is consistent with previous research stating that individual differences and personality traits make differences in the features of FRN (Mothes et al., 2016; Takács et al., 2015). This is the first neurophysiological report of the group differences in negative performance outcome evaluation and external error processing based on perfectionism.

We hypothesized that the FRN amplitude after negative feedback would be higher for maladaptive than adaptive perfectionists and non-perfectionists because they are more concerned about making mistakes and receiving negative feedback. However, the findings contradict our prediction and rather support the reward prediction error as a cognitive process eliciting the FRN. Previous research has demonstrated that the FRN amplitude reflects the reward prediction error as well (Burnside et al., 2019). It has been found that the FRN amplitude is greater for unexpected negative than expected outcomes (Weismuller & Bellebaum, 2016). However, maladaptive perfectionists with numerous experiences of the discrepancy between expected and received outcomes (Flett et al., 2016) probably have a pessimistic bias in outcome prediction. Negative outcomes are expected for this group with pessimistic outcome prediction bias and more evaluative concerns than adaptive perfectionists and non-perfectionists. As a result, the FRN amplitude in response to negative feedback presentation for this group would be smaller than the adaptive group and non-perfectionists. It should be noted that FRN is typically measured as a difference between a negative and positive feedback condition and a better analysis followed by an obvious FRN in topography for this study will be a comparison between the most negative (loss-error) and the most positive (gain-correct) condition. However, the results in the other two conditions should be interpreted with caution and considering the participants' attitude to the different aspects of feedback i.e., the achievement (gain/loss) and accuracy (correct/error). Perfectionists' extreme attitude and their point-of-view (pessimistic or optimistic) might cause a different categorization of the feedback. Consequently, the loss-correct condition as a semi-positive for optimists (emphasizing accuracy) might be evaluated as semi-negative feedback for pessimists (emphasizing achievement). In a similar way, the gain-error condition might be understood as semi-negative feedback for optimists and pessimists respectively. Accordingly, a typical topography for FRN can be seen for adaptive perfectionists (Fig5. a, right panel). The resulting negativity in this condition is mainly due to differences in evaluating the achievement. In addition, another highlighted negativity is present (Fig 5, A, left panel) that might reflect the difference in evaluating the achievement. For the maladaptive group, the FRN reflects differences in the achievement conditions (Fig 5, B, left panel).

The study on obsessive-compulsive disorder (OCD) patients has also revealed a reduction in FRN amplitude for exploration of negative feedback, which is supposed to be a result of altered punishment processing associated with OCD patients' deficits in behavioral adaptation (Endrass et al., 2013). Keren et al. (2018) in their meta-analytical review have shown blunted striatal fMRI and FRN signals for depressed patients, during reward feedback. It shows a decreased brain sensitivity to anticipating and consuming rewards in depression. Although several studies have revealed an elevated amplitude of FRN in the case of depression, high levels of anhedonia may attenuate this effect (Mueller et al., 2015).

In agreement with our results, previous studies suggested that the outcome prediction bias could be the explanation for group differences in the FRN (Gu et al., 2010). As mentioned above, maladaptive perfectionists have been proposed to experience high levels of preoccupation with negative performance outcomes. Probably, these constant concerns followed by pessimistic outcome expectancies and the pessimistic bias, in turn, lead to smaller FRN amplitude than those of adaptive perfectionists and non-perfectionists.

However, it is suggested that caution in the interpretation of FRN as an index of negative prediction error should be applied (Huang and Yu, 2014). A recent body of studies revealed that FRN is larger for motivational salient outcomes in both appetitive and aversive conditions (Hird et al. 2018; Soder and Potts 2018; Soder et al. 2020; Talmi et al. 2013). It is demonstrated that the no loss feedback elicited more negative FRN than loss, although no loss is clearly better than loss. Also, no win feedback elicited more negative FRN than win feedback (Huang and Yu, 2014). Although monetary loss serves to represent RPEs, and negative feedback generally, it is a problematic choice for specifically eliciting a motivational salience component. Money can only be an appetitive stimulus for humans, not an aversive stimulus (Stewardson and Sambrook, 2021). It is a potential limitation of the present study that used a monetary task, and future studies are suggested to apply a task that provides motivational salience in order to measure the FRN amplitude more precisely.

Also, we should mention that though the loss-error and gain-correct conditions made up 320 trials and the loss-correct and gain-error conditions made up 64 trials of the whole task, no oddball effect was observed due to the low frequencies of two later conditions. Our main analysis was based on comparing the reaction time and FRN amplitudes of the two perfectionist groups, separately within each condition. In other words, the two independent-sample t-tests that were conducted between the groups can't be confounded by the oddball effect. One might argue that this oddball-like effect might affect participant performance as a part of the design, which could be true; however, we might expect that possible confounding effect to be canceled out for the analysis as both groups have done the same number of trials. Moreover, looking at the behavioral data (figure 2) and ERP data (figure 4) doesn't show any possible classification of the conditions (i.e., loss-error & gain-correct vs loss/correct & gain-error) that further approve the absence of this oddball-like effect in this dataset.

In the current study, we didn't have a priori sample size calculation, however, we tried to have a decent sample based on the previous relevant studies while considering our resources. After screening 400 students and excluding the noisy data, we included 58 students in our final sample, which is larger than most of the previous studies in the field (for example Gu et al., 2010 had a total sample of 33 divided into two groups of high and low trait-anxiety individuals, and Martínez-Velázquez et al., 2015 had 30 participants divided into two groups of adults and adolescents). This is approved by mostly large Cohen's d effect sizes (> 0.8) for the observed effect in the reaction time and FRN amplitudes. In addition, we did a posterior sample size calculation using G-power (Faul et al., 2007) with an effect size of 0.25 which suggested a total sample size of 45 which is smaller than our final sample size.

The current study indicated the relationship between perfectionism and the ERP correlates of performance evaluation, as well as performance monitoring. To obtain a more complete picture of this relationship, future studies need to additionally investigate the participants other than students, the other facets of perfectionism, underlying neurochemical activities of performance outcome evaluation, as well as on general performance monitoring.

5. Conclusion

The present study provides the first evidence for group differences in the FRN amplitude between adaptive and maladaptive perfectionists. The findings of the current study revealed that there is a difference between adaptive and maladaptive perfectionists in FRN amplitude, showing that these two groups are different in response to external feedback, especially error processing. FRN amplitude in the maladaptive group was smaller than the adaptive group when they are getting negative feedback, which is evidence to support reward prediction error. Expecting negative outcomes will generate smaller FRN amplitude when a maladaptive perfectionist is provided with an adverse performance. Conversely, an adaptive perfectionist who expects to get positive feedback about their performance would reveal a larger FRN amplitude when they get negative feedback since it is unexpected for them, and the FRN amplitude will arise in surprise conditions.

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7. Authors' contribution

Leyla Karami Isheqlou: Conceptualization, Data curation, Writing- Original draft preparation, Writing- Reviewing and Editing

Mojtaba Soltanlou: Data analysis, Reviewing, and Editing

Mostafa Zarean: Conceptualization, Visualization

Mohammad Taghi Saeedi: Methodology, Software

Soomaayeh Heysieattalab*:* Supervision, Validation, Writing - Original Draft, Writing - Reviewing and Editing, Investigation.

Ethical approval

Before the experiment, all the participants were provided with ethical research clearance and written informed consent, which was approved earlier by the ethics committee of Tabriz University of Medical Sciences (Research ethics code: IR.TBZMED.REC.237).

The disclosure of data collection and analysis

We declare that we reported all measures, conditions, and data exclusion in the paper. Data will be made available on request. In the current study, we didn't have a priori sample size calculation, however, we did a posterior sample size calculation using G-power with an effect size of 0.25 which suggested a total sample size of 45 which is smaller than our final sample size.

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Figure legends:

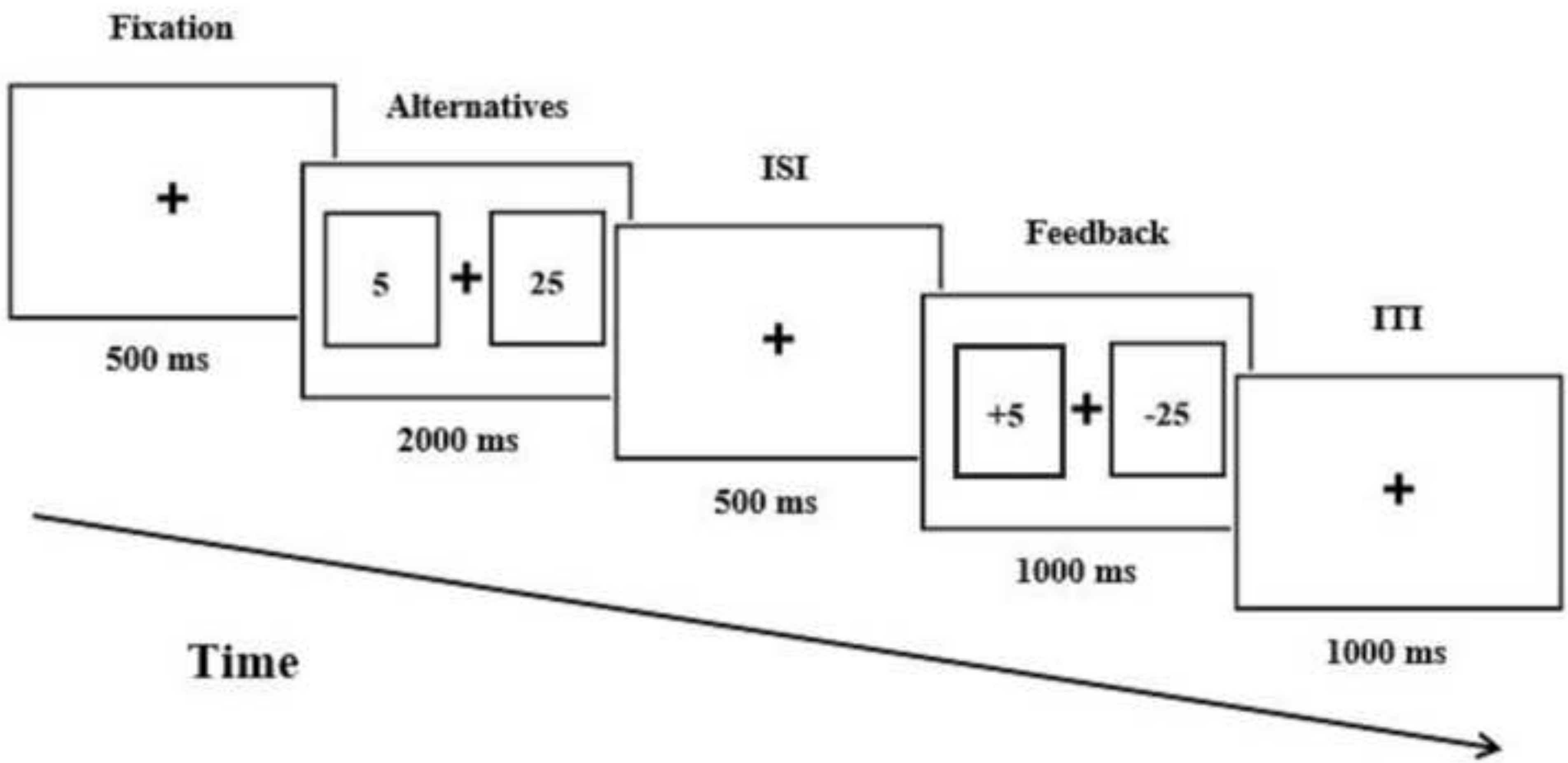
Figure 1. The sequence of events within a single trial of the monetary gambling task.

Figure 2. Reaction time for groups in different conditions of the study.

Figure 3. Grand mean ERP waves (FRN at FCz, Cz, and Fz) in the study conditions from 200 ms before to 800 ms after feedback.

Figure 4. Mean amplitude FRN at FCz, Cz, and Fz for groups in different conditions of the study.

Figure 5. Topographical distribution maps were taken from 250-350 ms post feedback window for the difference between loss and gain in both error and correct conditions.


Fixation
Alternatives
ISI
Feedback
ITI
+
5
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+5
-25
500 ms
2000 ms
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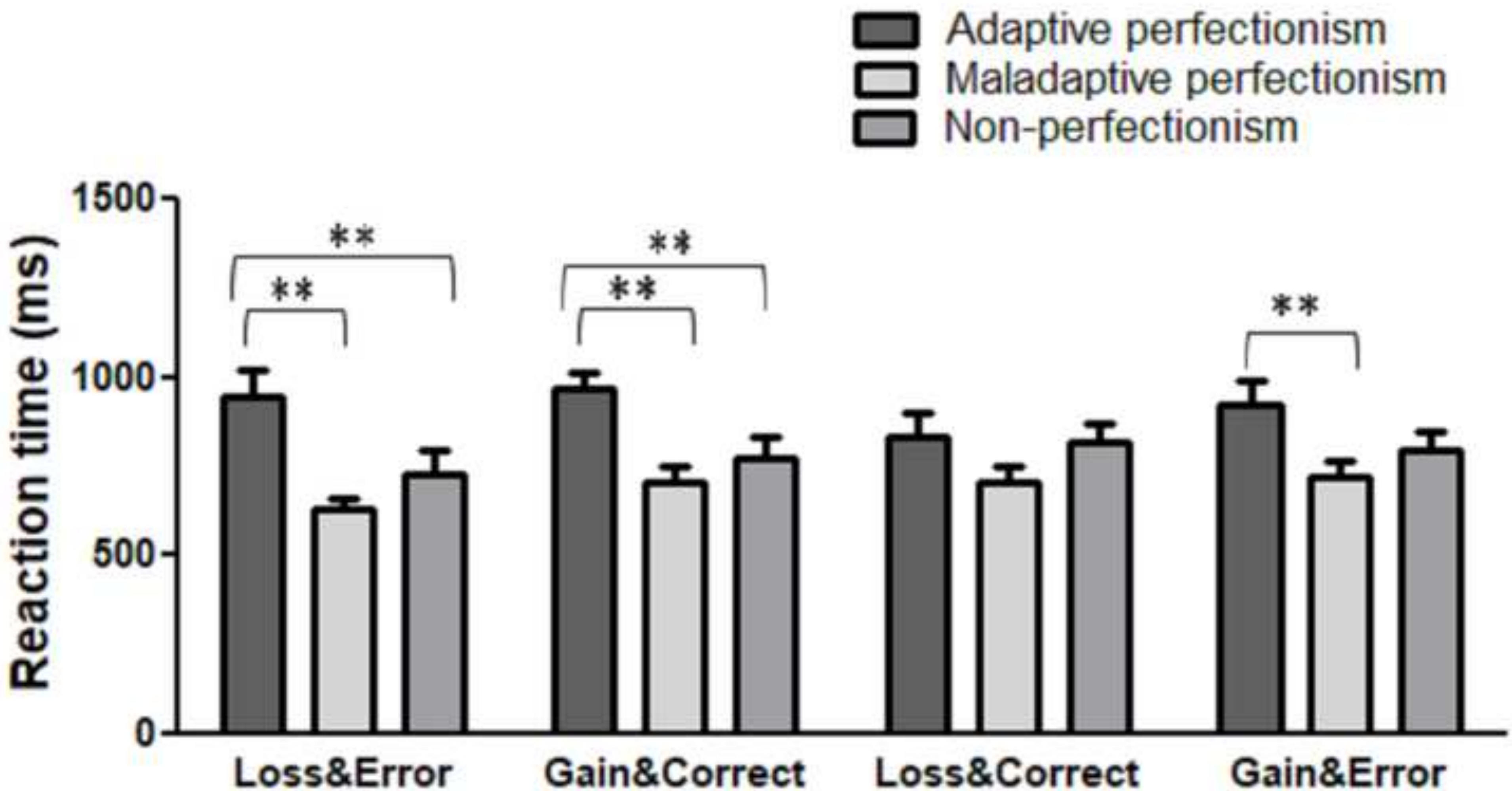
1000 ms
1000 ms
Time


Adaptive perfectionism
Maladaptive perfectionism
Non-perfectionism
Reaction time (ms)
1500
1000
500
0
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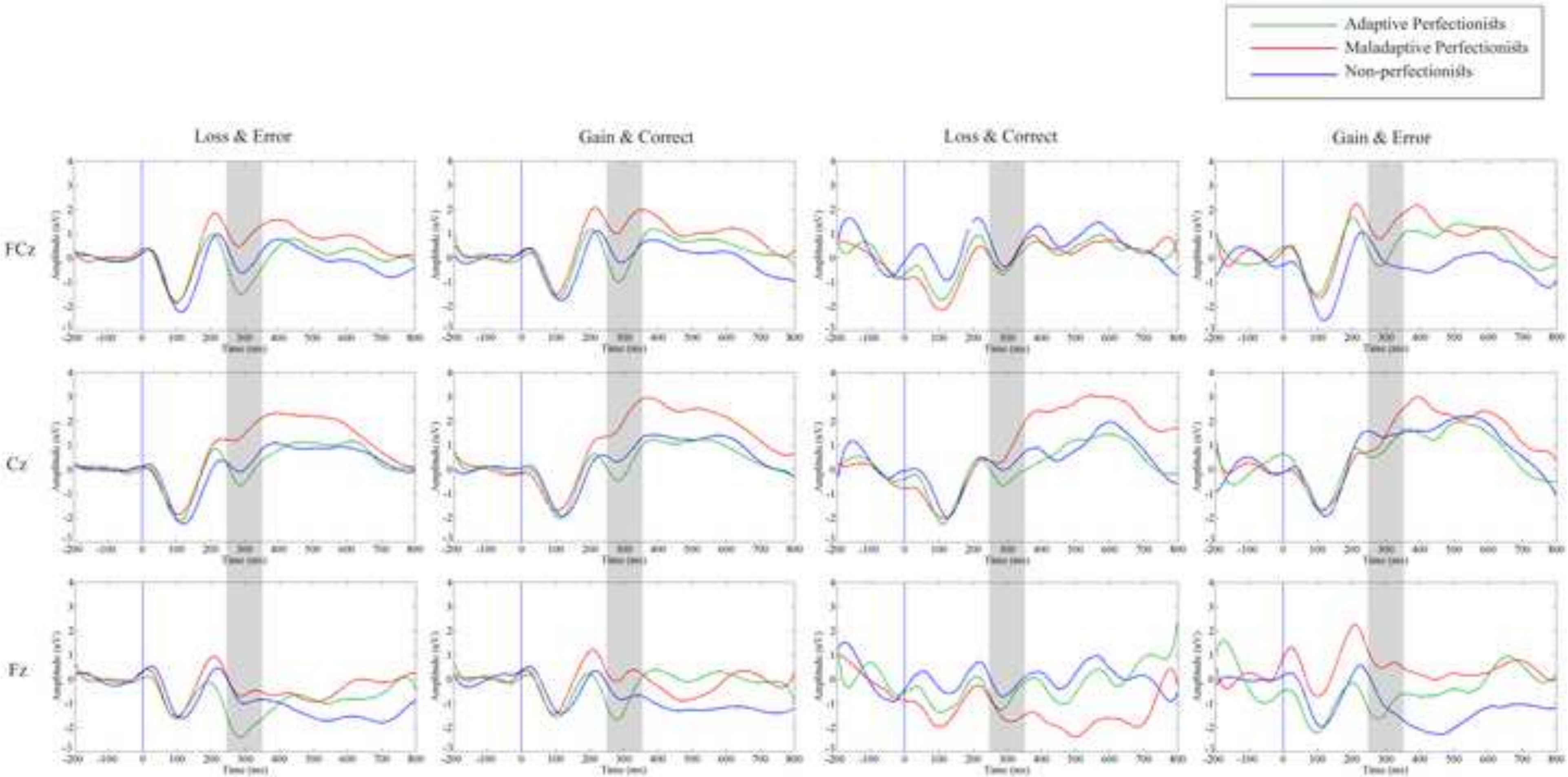
Loss&Error
Gain&Correct
Loss&Correct
Gain&Error


Adaptive Perfectionists
Maladaptive Perfectionists
Non-perfectionists
Loss & Error
Gain & Correct
Loss & Correct
Gain & Error
FCz
Cz
Fz

Figure

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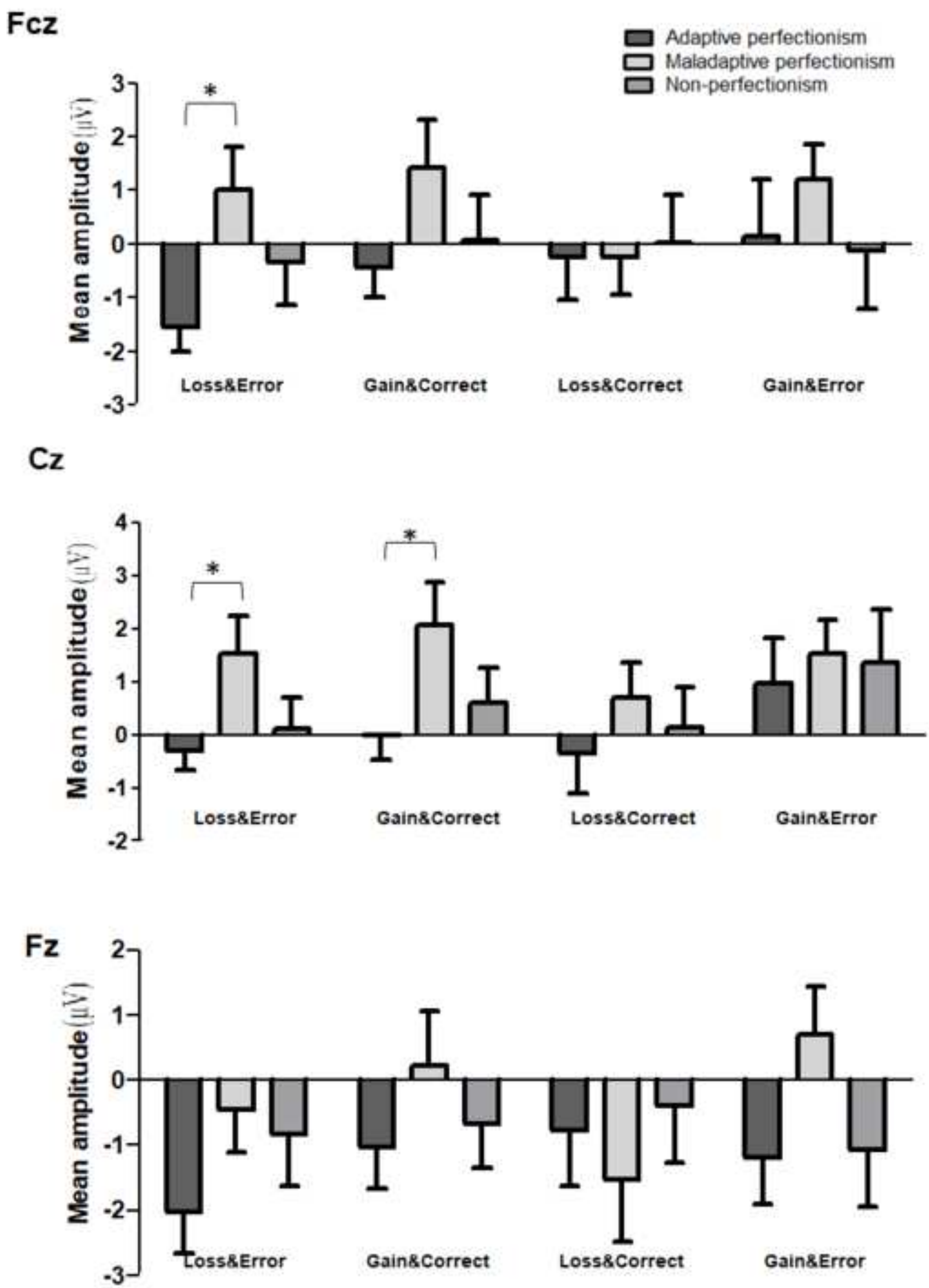

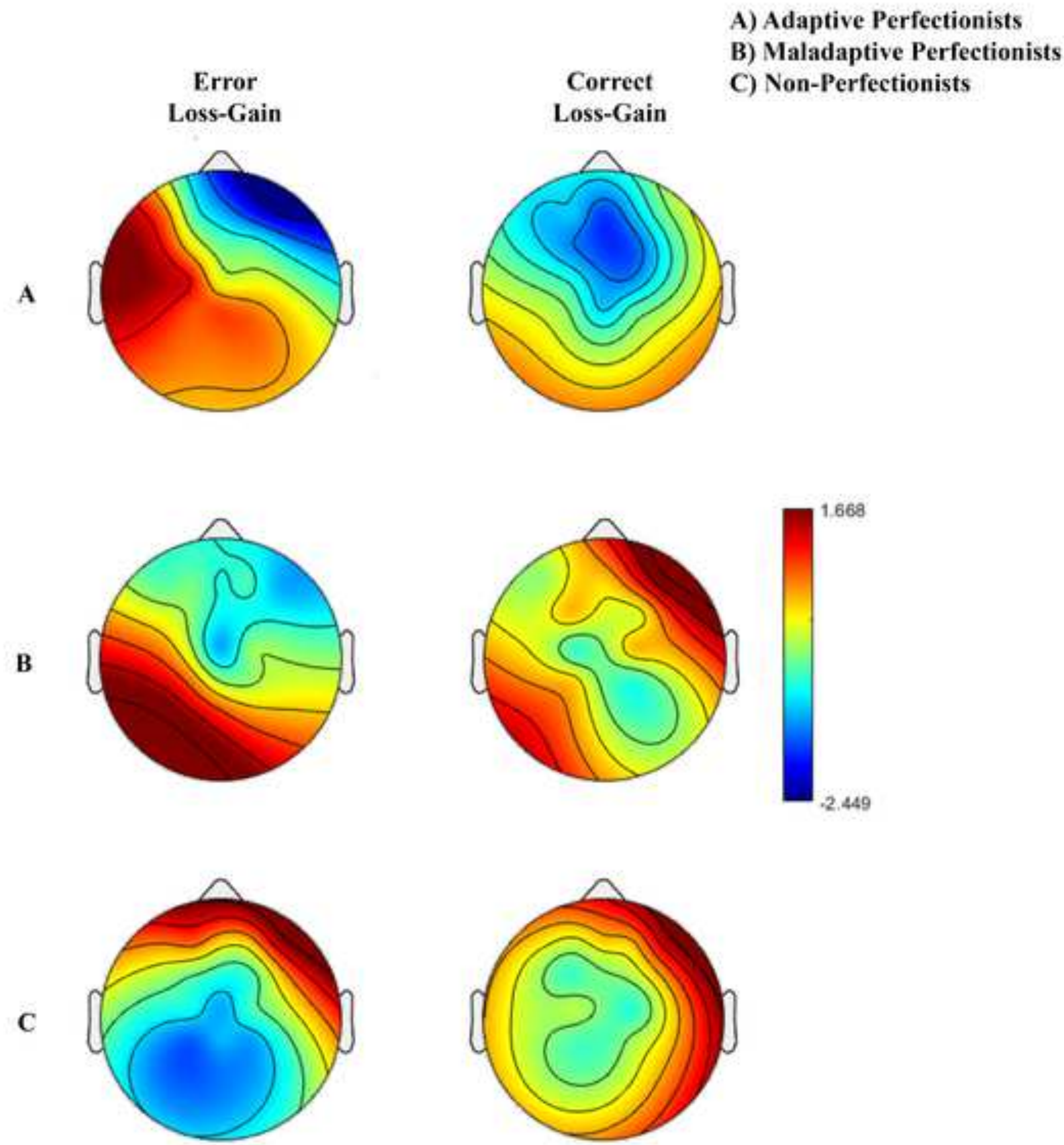
A) Adaptive Perfectionists
B) Maladaptive Perfectionists
C) Non-Perfectionists
Error
Loss-Gain
Correct
Loss-Gain
A
B
C
1.668
-2.449

Table 1: List of possible combinations of chosen outcomes and alternative outcomes. The blue conditions indicate the four conditions chosen here to analyze. Adopted from Nieuwenhuis et al, 2004.

condition	chosen outcome	alternative outcome
Loss and error	-5	+25
Gain and correct	+5	-25
Loss and correct	-5	-25
Gain and error	+5	+25
Loss and error	-25	+5
Gain and correct	+25	-5
Loss and error	-25	-5
Gain and correct	+25	+5
Loss and error	-5	+5
Gain and correct	+5	-5
Loss and error	-25	+25
Gain and correct	+25	-25

Table 2: Mean and standard deviation of trials used for analyses

Group	Condition			
	Loss and error	**Gain and correct**	**Loss and correct**	**Gain and error**
Adaptive Perfectionists	23.5±4.1	23.7±3.86	22.6±4.52	23.7±4.23
Maladaptive Perfectionists	22.5±4.48	23.3±4.53	24.5±4.17	22.9±3.74
Non-perfectionists	25.0±3.22	24.4±3.18	23.4±3.47	23.3±4.00

Table 3: ANOVA results for reaction time

	F	df	p	η^2p
Group	8.53	2,55	< .001	0.237
gaining	4.66	1,55	0.035	0.078
gaining x group	0.63	2,55	0.532	0.023
correctness	0.33	1,55	0.563	0.006
correctness x group	1.62	2,55	0.207	0.056
gaining x correctness	0.07	2,55	0.790	0.001
gaining x correctness x group	3.01	2,55	0.057	0.099

Table 4: ANOVA results for all factors and interactions

	F	df	p	η^2p
group	1.33	2,55	0.274	0.046
gaining	7.50	1,55	0.008	0.120
gaining x group	1.00	2,55	0.371	0.035
correctness	0.06	1,55	0.795	0.001
correctness x group	1.08	2,55	0.344	0.038
electrode	26.50	2,110	<.001	0.325
electrode x group	0.31	4,110	0.866	0.011
gaining x correctness	0.17	1,55	0.676	0.003
gaining x electrode	0.74	2,110	0.477	0.013
correctness x electrode	3.00	2,110	0.054	0.052
gaining x correctness x group	2.62	2,55	0.082	0.087
gaining x electrode x group	2.91	4,110	0.025	0.096
correctness x electrode x group	3.76	4,110	0.007	0.120

gaining x correctness x electrode	0.02	2,110	0.972	0.001
gaining x correctness x electrode x group	0.76	4,110	0.553	0.027

Table 5: ANOVA results for FRN mean amplitude at FCz, Cz, and Fz

Electrode		**F**	**df**	**p**	**η²p**
	Group	1.23	2,55	0.300	0.043
	gaining	5.91	1,55	0.018	0.097
	gaining x group	1.00	2,55	0.374	0.035
FCz	correctness	0.10	1,55	0.753	0.002
	correctness x group	1.17	2,55	0.318	0.041
	gaining x correctness	0.18	2,55	0.670	0.003
	gaining x correctness x group	2.66	2,55	0.078	0.088
	Group	1.88	2,55	0.163	0.064
	gaining	8.36	1,55	0.005	0.132
Cz	gaining x group	0.03	2,55	0.961	0.001
	correctness	2.15	1,55	0.148	0.038
	correctness x group	0.19	2,55	0.821	0.007
	gaining x correctness	0.05	2,55	0.810	0.001
	gaining x correctness x group	2.16	2,55	0.124	0.073
	Group	0.68	2,55	0.506	0.024
	gaining	3.06	1,55	0.085	0.053
	gaining x group	3.32	2,55	0.043	0.108
Fz	correctness	0.27	1,55	0.601	0.005
	correctness x group	4.43	2,55	0.016	0.139
	gaining x correctness	0.13	2,55	0.712	0.003
	gaining x correctness x group	1.04	2,55	0.358	0.037

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