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ORIGINAL PAPER

Feedback Related Negativity Amplitude is Greatest Following Deceptive Feedback in Autistic Adolescents

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Abstract

The purpose of this study is to investigate if feedback related negativity (FRN) can capture instantaneous elevated emotional reactivity in autistic adolescents. A measurement of elevated reactivity could allow clinicians to better support autistic individuals without the need for self-reporting or verbal conveyance. The study investigated reactivity in 46 autistic adolescents (ages 12–21 years) completing the Affective Posner Task which utilizes deceptive feedback to elicit distress presented as frustration. The FRN event-related potential (ERP) served as an instantaneous quantitative neural measurement of emotional reactivity. We compared deceptive and distressing feedback to both truthful but distressing feedback and truthful and non-distressing feedback using the FRN, response times in the successive trial, and Emotion Dysregulation Inventory (EDI) reactivity scores. Results revealed that FRN values were most negative to deceptive feedback as compared to truthful non-distressing feedback. Furthermore, distressing feedback led to faster response times in the successive trial on average. Lastly, participants with higher EDI reactivity scores had more negative FRN values for non-distressing truthful feedback compared to participants with lower reactivity scores. The FRN amplitude showed changes based on both frustration and reactivity. The findings of this investigation support using the FRN to better understand emotion regulation processes for autistic adolescents in future work. Furthermore, the change in FRN based on reactivity suggests the possible need to subgroup autistic adolescents based on reactivity and adjust interventions accordingly.

Keywords Autistic adolescents · Emotional reactivity · Affective Posner task · Feedback related negativity

Introduction

Background

Autism Spectrum Disorder (ASD) is a developmental disorder marked by persistent deficits in social communication and social interaction as well as restricted, repetitive patterns of behavior, interests, or activities. Symptoms of ASD present themselves in the early developmental period (*Diagnostic and statistical manual of mental disorders: DSM-5*, 2013). Often, poor emotion regulation (ER) and heightened emotional responses to stimuli is observed in autistic individuals (Mazefsky et al., 2013). In fact, it has been found that autistic individuals experience significantly higher ER impairment compared to their typically developing peers (Conner et al., 2021). It is important to note that autistic individuals may show either heightened or attenuated emotional responses, but both are linked to ER deficits. In other words, an autistic individual may overact to some stimuli,

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but may underreact to others or be emotionally flat or dysthymic. ER involves the combination of volitional, or intentional, efforts and habitual, involuntary responses to monitor, evaluate, and adjust emotional arousal and behavioral responses in order to achieve one's goals (Thompson, 1994). It is believed that emotion dysregulation may be a main factor in problems with aggression, depression, self-injurious behavior, and anxiety in autistic individuals (Conner et al., 2019; Lecavalier, 2006; Samson et al., 2015). Additionally, poor ER is linked to high rates of co-occurring psychiatric disorders (Mazefsky et al., 2013). Furthermore, ER impairment results in lower socialization skills (Guy et al., 2014; Larson et al., 2011) which can lead to missed opportunities (Eldeeb et al., 2021). For all these reasons, the need to address ER in autistic individuals is critical.

Questionnaires have been reliably used to assess ER in autistic individuals (Berthoz & Hill, 2005). From questionnaire information, the Emotion Dysregulation Inventory (EDI) has been developed and used to quantify emotion dysregulation in autistic individuals with subdomains for reactivity and dysphoria. Here, we focus on reactivity, as it has been identified as a primary dimension of emotion dysregulation in autism. Reactivity captures a tendency for intense, rapidly escalating, and poorly regulated negative emotional reactions (Mazefsky et al., 2018). The EDI enables clinicians to identify individuals with clinically elevated reactivity due to the availability of general norms and a clinical cutoff, which may lead to more effective understanding of emotion dysregulation and treatments (Mazefsky et al., 2013, 2021a, 2021b).

In order to provide a better link between instantaneous experiences of emotional distress and biology, electroencephalography (EEG) has been used in several studies to find event-related potentials (ERPs) linked with symptoms of ASD (Bosl et al., 2018; Eldeeb et al., 2021; Larson et al., 2011; Stavropoulos & Carver, 2014). ERPs capture brain-based electrical changes in response to an event (Handy, 2005), reflective of discrete stages of cognitive processing (Hudac et al., 2021). The temporal resolution is a key advantage of ERPs measuring brain changes on the scale of milliseconds. The feedback-related negativity (FRN) is an ERP that shows negative deflection in frontal and central channels and peaks around 250 ms following the onset of feedback (Hajcak et al., 2006). The FRN has been shown in previous research to be larger (i.e., more negative amplitude) to negative feedback than positive feedback (Bellebaum et al., 2014; Cohen et al., 2007; Hajcak et al., 2006; Larson et al., 2011; McPartland et al., 2012). Some researchers have found that the FRN can only provide a binary separation between positive and negative feedback (Hajcak et al., 2006). However, other researchers have found that the FRN amplitude can vary based on the magnitude of the positive or negative feedback when considering deviation from reward expectations (Bellebaum et al., 2010). Some researchers have referred to this deviation from reward expectations as surprise (Hauser et al., 2014; Moser & Simons, 2009).

Considering reliability, the FRN has been linked to reactivity to feedback in neurotypical individuals and is sensitive to feelings such as anger, making it a better measurement to capture emotional reactivity in autistic individuals (Riepl et al., 2016; Threadgill & Gable, 2020). Feedback is likely to alter behavior. Specifically, when participants receive feedback that their performance is unsuccessful, they will likely seek to improve performance. On a reaction time task, this improvement in performance would likely result in faster responses.

Current Study

The current study was conducted to examine whether feedback monitoring would vary based on reactivity. The Affective Posner Task was used to create conditions of distress to elicit emotional reactions (Posner, 1980). In the Affective Posner Task, participants responded as quickly as possible to guess the location of a star hidden behind one of two cards. After responding, participants received three types of feedback: "Correct," "Wrong," and "Too Slow" that is deceptively presented on 60% of correct trials even with accurate, rapid responses. Importantly, other work has found that this task does indeed elicit frustration (Deveney, 2019). Within this task, the FRN was evoked at the onset of feedback and the amplitude varied based on the perception of the feedback. We predicted that reactivity would be graded based upon the condition, such that participants would be most distressed from frustration (and thus exhibit a robust FRN) when deceived ("Too Slow"), moderately distressed when ("Wrong"), and not distressed when correct, as demonstrated in previous work (Deveney, 2019; Eldeeb et al., 2021). In other words, the "Too Slow" feedback should be the most frustrating because it suggests that the participant could have responded faster to avoid this feedback. Both distress (Eldeeb et al., 2021) and frustration (Deveney, 2019) have been used to describe the emotional effects of the Affective Posner Task. We use both of these terms to describe the emotional state participants experienced in the task.

Another objective of this project was to understand how the FRN in the context of deception related to individual differences. Reactivity is highly variable across autistic individuals and the relationship between the FRN, reactivity score, and response times in the successive trial may help us better understand the factors that contribute to this variability. First, because we believe the FRN to be linked to the underlying biology supporting reactivity, we predicted that participants with higher emotional reactivity via classic parent-report would have greater amplitude FRN values to deceptive feedback, specifically. Second, there is evidence

that the negative feedback, "Wrong" and "Too Slow", will lead to faster response times in successive trials (Deveney, 2019); thus, we predicted our results would mirror this prior work, such that participants would respond faster on the subsequent trial (relative to the current trial) following negative feedback.

Methods

Participants

Data were collected for 52 autistic participants across two data collection sites at the University of Pittsburgh and the University of Alabama. The project was approved by both local ethical review boards (IRB #STUDY17070496). Guardians of each participant provided written informed consent and participants provided written informed assent. Participant ages ranged from 12 to 21 years, inclusive. The average age was 14.4 years. The distribution of sex was 44 male participants and 8 female participants. This research is part of a larger ongoing randomized clinical trial comparing an ER-focused psychotherapy to supportive therapy. Adolescents and emerging adults were targeted for this intervention due to increased prevalence of poor ER during these ages (Mazefsky & White, 2014; Picci & Scherf, 2015). All data for the current research was collected pre-treatment. Inclusion criteria were as follows (1) ages 12–21 years, inclusive; (2) either a prior community diagnosis of ASD, or diagnosis of ASD confirmed by research reliable administration of the Autism Diagnostic Observation, Second Edition (Lord, 2012) or a score of 12 or higher on the Lifetime version of the Social Communication Questionnaire (Rutter et al., 2003); (3) presence of elevated emotion dysregulation at an initial phone screen (Reactivity raw score ≥ 7).

The Affective Posner Task

The participants played a game based on the Affective Posner Task (Posner, 1980). In the game, participants were shown two side-by-side white squares for 200 ms on a computer screen with a star hidden behind one of the squares (See Fig. 1). A blue square appeared over one of the white squares for 200 ms and 75% of the time hinted at the correct location of the star. The screen then transitioned to black and gave the participant up to 3000 ms to decide, using the arrow keys, the location of the star. Following the decision screen, a 3000 ms feedback screen appeared with either "Correct", "Wrong", or "Too Slow" feedback. The "Correct" feedback was given when the location of the star was correctly guessed. The "Wrong" feedback was given when the location of the star was incorrectly guessed. In the practice round, the "Too Slow" condition was given when the star location was correctly guessed, but the response time was longer than 500 ms. In the actual game, the "Too Slow" condition was given deceptively so that 60% of correct guesses were labeled as "Too Slow" regardless of response time. Thus, "Correct" corresponded to a non-distressed state and "Wrong" and "Too Slow" both corresponded to a distressed state as demonstrated in previous work (Eldeeb et al., 2021).

Before the game was played with EEG data being collected, two practice rounds were played for the participant to become familiar with the game. The first practice round consisted of only the "Correct" and "Wrong" feedback conditions (50 trials). In the second practice round, the "Too Slow" feedback condition was introduced (50 trials). In the actual game, EEG data were collected, and deception was introduced so that 60% of correct guesses resulted in the "Too Slow" feedback condition regardless of the response times (100 trials). To elicit greater emotional reaction and to encourage better focus, a point system was introduced in the second practice round and kept in the actual game. Participants started with 150 points in each of the rounds and were awarded 10 points for every "Correct" feedback and lost 10 points for every "Too Slow" and "Wrong" feedback. Participants were told that if they ended with more than zero points after all rounds were played, they would win a $50 prize (plus $25 for participation). The game was set so that all participants would win the $50 prize.

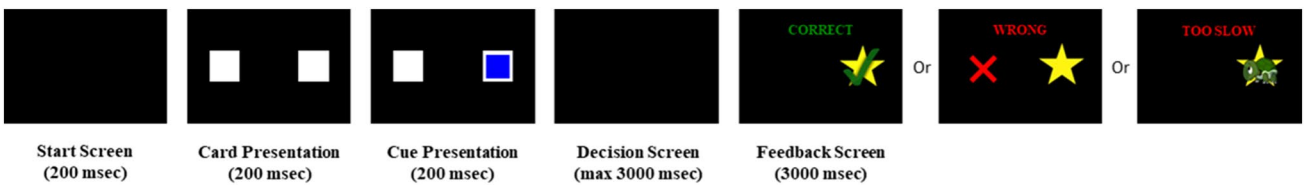

Fig. 1 Game Screen Order. The Affective Posner Task-based game screen order. The computer screen was blank for 200 ms followed by a 200-ms card presentation with a star hidden behind one of the cards. A blue cue was then added over one of the cards to give a hint as to the star location (this hint is correct 75% of the time). The participant then had up to 3 s during a blank decision screen to select the star location using the right and left arrow keys. Finally, a feedback screen was given for 3 s with "Correct" feedback for guessing the star location correctly, "Wrong" feedback for guessing the star location incorrectly, and a deceptive "Too Slow" feedback. "Too Slow" feedback was presented on 60% of trials with a correct guess

Reported Reactivity Measures

The EDI (Carla A. Mazefsky et al., 2018) was developed to assess emotion dysregulation in ASD using methods developed by the Patient-Reported Outcomes Measurement Information System (PROMIS®). Items are free of differential item functioning (DIF) based on age, gender, intellectual ability, or verbal ability (Carla A Mazefsky et al., 2018). The EDI's validity was supported by expected group differences (higher scores in a psychiatric inpatient sample versus an autism spectrum disorder community sample) and expected convergent and concurrent validity with related and other ER measures (Mazefsky et al., 2018). Reliability in the current sample was good ($\alpha = 0.88$). Items are rated on a 5-point scale based on severity of behavior during the previous seven days (severity; 0 = Not at all, 1 = Mild, 2 = Moderate, 3 = Severe, and 4 = Very Severe). The EDI yields two subscales; a reactivity score that captures quickly escalating, sustained, and poorly regulated negative emotional reactions (e.g., my child is "hard to calm him/her down when he/she is upset," "emotions go from 0 to 100 instantly"), and a dysphoria score that measures poorly upregulated positive affect, general unease, and low motivation (e.g., "very little makes him/her happy," "not responsive to praise or good things happening"). The reactivity score is higher for individuals with poor emotional reactions. In this study, the pre-treatment caregiver-report reactivity short form score (7 items; correlated at $r = 0.98$ with full reactivity scale) for each participant is used.

Clinical Assessments

All participants completed a series of clinical assessments as part of the larger randomized clinical trial. All clinical assessments considered in this study are parent-reported. Consistent with our hypotheses, our focus was on the EDI reactivity scores, because they reflect emotion-related reactivity. As part of the larger clinical trial, but not directly related to this study, additional clinical assessments included the EDI dysphoria, Social Responsiveness Scale (SRS), Patient-Reported Outcomes Measurement Information System (PROMIS), Child Behavior Checklist (CBCL for < 18 years old), and Adult Behavior Checklist (ABCL for ≥ 18 years old). T-score conversions were used on all clinical assessment scores to provide greater sensitivity. Table 1 provides the mean and standard deviation for each of the assessment t-scores for the 52 participants.

EEG Equipment

At the University of Pittsburgh, the games were played using a Lenovo ThinkPad P50 (16.5″ screen width) running the Psychophysics toolbox in MATLAB. EEG data were collected using the Wearable Sensing DSI-24 wireless dry electrode headset at a sampling rate of 300 Hz. The headset includes 21 Ag/AgCl electrodes at locations corresponding to the 10–20 International System. Ground was placed at the earlobes and all EEG data was referenced to channel Pz. At the University of Alabama, the games were played using a Dell monitor. EEG data were collected using a BrainVision actiCAP snap system at a sampling rate of 500 Hz. This system includes 32 Ag/AgCl electrodes at locations corresponding to the 10–20 International System. Ground was placed at channel FPz, and all EEG data were referenced to the left earlobe (channel A1). The data from the two different sites were unified by resampling all University of Alabama data to 300 Hz. Wilcoxon rank sum tests were used to confirm that the FRN amplitudes, reactivity scores, and response times across sites came from the same distribution ($p > 0.099$).

Table 1 Parent-report clinical assessment T-scores

Assessment	Mean (± std dev)
EDI reactivity	49.66 (± 6.97)
EDI dysphoria	51.55 (± 8.62)
SRS total score	74.75 (± 9.44)
PROMIS anxiety score	55.5 (± 9.54)
PROMIS depression score	54.36 (± 11.24)
CBCL/ABCL aggression score	63.85 (± 8.06)

Preprocessing

MATLAB R2019b was used with the EEGLAB v2021.0 toolbox to preprocess the raw EEG data (Delorme & Makeig, 2004). The raw EEG data were filtered using a Kaiser-windowed bandpass filter with cutoff frequencies of 1 and 30 Hz.

Next, artifact removal was performed. Artifacts can be created by blinking, muscle movement, or poor electrode connection. Using EEGLAB, EEG channels that contained bad data were removed. The criteria for a bad channel included no signal for at least 5 s or if the channel line noise relative to the signal was greater than 4 standard deviations from the channel signal mean.

After removing bad channels, portions of the remaining data were removed. Bad burst rejection was implemented via Artifact Subspace Reconstruction (ASR) (Chang et al., 2020). Bad burst rejection compares clean portions of the EEG data to the rest of the EEG data and removes windows of the rest of the data that highly differ from the clean portions.

Data portions that exceeded the mean power by more than 20 standard deviations within at least a quarter of the channels simultaneously were removed.

An additional artifact removal process, independent component analysis (ICA), was also performed. ICA was performed using the logistic infomax ICA algorithm (Bell & Sejnowski, 1995) and natural gradient (Amari et al., 1995).

Once the data were separated into individual components, each component was labeled as brain, line noise, channel noise, eye, muscle, or other using the ICLabel classifier (Pion-Tonachini et al., 2019). All components with at least 70% probability of being brain activity were kept, and all other components were removed from the signal.

The EEG data were re-referenced to the mean of channels A1 and A2 so that the data from both collection sites had a common reference. The original reference channel was added back into the dataset through spherical spline interpolation.

The data of interest is the EEG signal immediately after the onset of a visual feedback. Therefore, for each epoch, data was kept from 200 ms before the onset of the feedback up until 800 ms after the onset of the feedback. Each epoch was baseline corrected by subtracting the mean of the 200 ms of data before the onset of the feedback from the rest of the data.

Following preprocessing, the average number of trials kept for all conditions, for the "Correct" condition, for the "Wrong" condition, and for the "Too Slow" condition were 72.67($\pm$21.33), 24.87 ($\pm$7.20), 27.65 ($\pm$10.38), and 20.15 ($\pm$7.52) respectively.

Feature Calculation

The average EEG signal at channel Cz was calculated and plotted across all trials and participants in order to determine the appropriate time window to calculate the FRN. Based on previous work (Deveney, 2019) and verified upon visual inspection of the full sample grand-average waveform at Cz, the FRN was calculated by taking the mean value of the EEG signal, measured at the Cz electrode, between 230 to 300 ms post-feedback onset. More specifically, the FRN for each condition was calculated for each participant separately (e.g., averaged across all trials with "Correct" feedback, "Wrong" feedback, and "Too Slow" feedback).

In addition, response times were computed as the time taken by a participant to click the right or left arrow key in the next trial following the visual "Correct," "Wrong," or "Too Slow" feedback. The response times were averaged per individual per feedback condition.

After collecting average FRN, average response times in the successive trial, and reactivity scores, outlier removal was performed. To remove outliers, the z-score of the average FRN, average response times in the successive trial, and reactivity scores were taken. Any participant with any z-scored data greater than 3 or less than -3 was removed from the analysis. This left the final analysis with 46 participants. Three participants were excluded due to channel Cz being removed during EEGLAB preprocessing. Two participants were removed for response time outliers and one participant was removed for FRN outliers.

Analyses

The first step of the analysis was to determine if there were differences in the average FRN between the "Correct" (e.g., non-distress), "Wrong" (e.g., distress), and "Too Slow" (e.g., distress with deception) conditions. Difference in average FRN was tested using a repeated measures ANOVA test to compare means across repeated observations (i.e., across three different feedback conditions, $\alpha = 0.05$). In addition, an a priori Fisher's least significant difference (LSD) tested for pairwise differences in the average FRN for any two of the three feedback conditions using a pooled standard deviation from all three conditions ($\alpha = 0.05$). A Shapiro–Wilk test was performed and confirmed the normality of the average FRN data. To test overall group patterns, a similar repeated measures ANOVA test was performed with participants' average response times in the successive trial as the outcome between the three feedback conditions.

Next, a series of simple linear regression models were used to examine relationships between key outcomes. All regression models were fit separately for each of the three feedback conditions with a t-test to determine significance of β_1 ($\alpha = 0.05$). Three sets of models were generated to test relationships between: (1) average FRN and average response times in the successive trial; (2) average FRN and reactivity scores; and (3) for the sake of completeness, average response times in the successive trial and reactivity scores (See Appendix Table 2).

Additionally, to better understand the relationship between FRN and reactivity, a subgroup analysis was performed. The participants were split into two groups: elevated reactivity (≥ 46.9) and non-elevated reactivity (< 46.9). The threshold for splitting the two groups was determined based on a score greater than one standard deviation above norms from a general population sample of 1000 youth (Mazefsky et al., 2021a, 2021b). The same repeated measures ANOVA and Fisher's LSD test, as described in the first step of the analysis, were completed for each subgroup separately.

Lastly, relationships between clinical manifestations and the Affective Posner Task in autistic adolescents, correlations were run between all clinical variables, FRN, and response times to better understand the subjects included in the study (See Appendix Table 3).

Results

FRN Amplitudes and Response Times in the Successive Trial by Condition

Looking at the average EEG signals at channel Cz in Fig. 2, the average FRN had the most negative deflection for the "Too Slow" feedback followed by the "Wrong" feedback and then the "Correct" feedback.

In addition to graphically, the repeated measures ANOVA test confirmed that the FRN was significantly different across the three feedback conditions $F(2, 90) = 6.229$, $p = 0.003$. Figure 3 provides the mean values for the average FRN for each of the feedback conditions along with the 95% confidence intervals. Again, the mean value for the average FRN was the most negative for the "Too Slow" feedback condition followed by the "Wrong" feedback and then the "Correct" feedback. Conducting a Fisher's LSD test, there was a significant difference between the average FRN corresponding to the "Correct" and "Too Slow" feedback conditions, $p < 0.001$. Average "Wrong" FRN values were not statistically different from either "Correct," $p = 0.060$, or "Too Slow," $p = 0.109$, feedback conditions.

There were no significant differences between the response times in the successive trial for each of the feedback conditions, $F(2, 90) = 0.152$, $p = 0.860$.

FRN Amplitudes Relating to Response Time in the Successive Trial

The linear regression models were fit between average response time in the successive trial and average FRN for each of the feedback conditions separately. Figure 4 gives the three regression lines and the original data points. A more negative FRN deflection corresponded to faster response times on the next trial on average for both the "Wrong" ($\beta = 0.007$, $p = 0.029$) and "Too Slow" ($\beta = 0.004$, $p = 0.006$) conditions. For the "Correct" condition, regression models indicated a lack of response time change when the FRN was varied, $\beta = 0.001$, $p = 0.702$.

FRN Amplitudes Relating to Reactivity Scores

Figure 5 shows how FRN was related to reactivity scores for each of the feedback conditions with the original datapoints and best-fit regression lines. For the "Correct" condition, a higher reactivity score corresponded to a more negatively deflected FRN, $\beta = -0.220$, $p = 0.043$. For the "Wrong" ($\beta = -0.093$, $p = 0.221$) and "Too Slow" ($\beta = 0.046$, $p = 0.723$) conditions, regression models indicated a lack of FRN sensitivity to different reactivity scores.

Lastly, the reactivity scores were compared with the average response times in the successive trial and no significant relationship was found within any of the three feedback conditions, $p > 0.221$ (See Appendix Table 2).

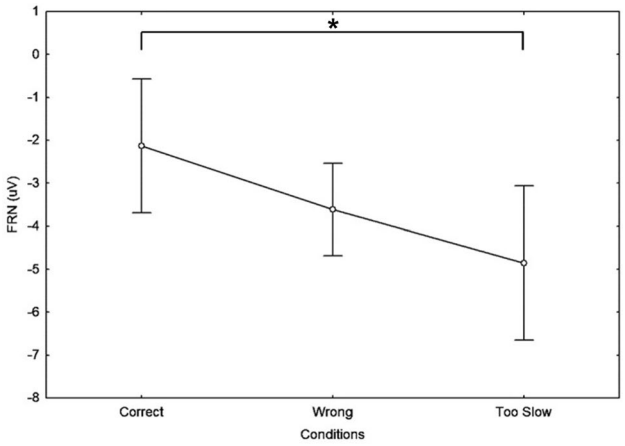

Fig. 3 Mean FRN Values for Each Feedback Condition. The mean FRN values for each feedback condition with their 95% confidence intervals are shown in the figure. *$p < .001$

Subgroup Analysis

The repeated measures ANOVA test for the non-elevated EDI subgroup showed that the FRN was significantly different across the three feedback conditions, $F(2, 26) = 6.985$,

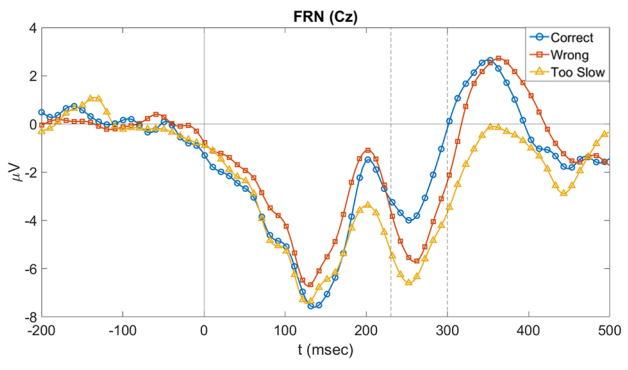

Fig. 2 Average EEG Signals at Cz Within Feedback Conditions. The figure presents the preprocessed EEG data at channel Cz averaged across participants for each feedback condition separately. This figure was used to select the appropriate window to calculate the FRN. The window selected is from 230 to 300 ms and is denoted by the dashed lines in the figure

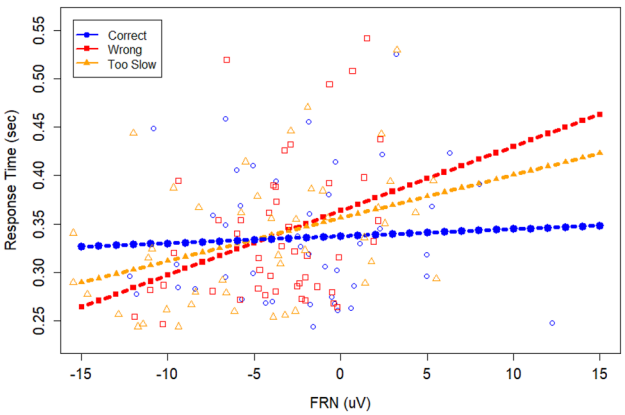

Fig. 4 Response Time in the Successive Trial Regressed on FRN Simple Linear Regression. The figure shows simple linear regression between response time in the successive trial and FRN for each feedback condition separately. The original data points are provided as a scatter plot in addition to the regression lines

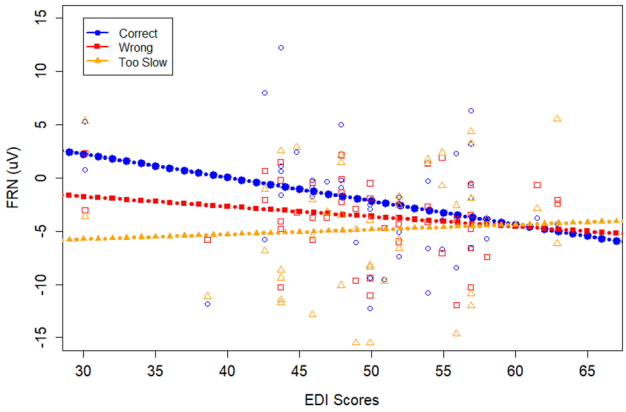

Fig. 5 FRN Regressed on Reactivity Scores Simple Linear Regression. The figure demonstrates simple linear regression between FRN and reactivity scores (from EDI) for each feedback condition separately. The figure includes the original data points as well as the regression lines

$p = 0.004$ (See Appendix Fig. 7). Conducting a Fisher's LSD test, average "Correct" FRN values were significantly different from "Wrong," $p = 0.042$, and "Too Slow," $p < 0.001$. There was no significant difference in average FRN values between "Wrong" and "Too Slow," $p = 0.125$. For the elevated EDI subgroup, the FRN was not significantly different across any of the three feedback conditions, $F(2, 62) = 1.359$, $p = 0.265$ (See Appendix Fig. 6).

Correlations with Clinical Assessments

Running correlations between clinical variables, FRN, and response times revealed several statistically significant relationships (See Appendix Table 3). Some key clinical findings were EDI reactivity positively correlated with EDI dysphoria ($r = 0.483$, $p = 0.001$). PROMIS anxiety and depression scores also had a positive correlation ($r = 0.608$, $p < 0.001$). CBCL/ABCL aggression scores positively correlated with both EDI reactivity ($r = 0.645$, $p < 0.001$) and dysphoria ($r = 0.328$, $p = 0.034$).

Discussion

The purpose of this study was to identify if the FRN could be used as an instantaneous biological measurement of emotional reactivity in autistic adolescents. Results revealed a significant difference between the average FRN to "Correct," "Wrong," and "Too Slow" feedback. The average FRN given "Too Slow" feedback was more negative than the average FRN given "Correct" feedback as expected. In previous literature, the FRN has been shown to be more negative for negative feedback than for positive feedback when frustrated (Deveney, 2019). Although we did not find statistically significant separation between the average FRN to "Wrong" feedback and either of the other two feedback conditions, the mean value of the average FRN values are highest for "Correct" followed by "Wrong" and then "Too Slow." Because the mean of the average FRN values decreases almost linearly across the three feedback conditions, this suggests that the FRN may be able to be used to separate between different levels of distress as previously suggested (Bellebaum et al., 2010). The fact that the "Too Slow" feedback results in a more negative mean FRN than the "Wrong" feedback for autistic youth and adolescents suggests these individuals may be sensitive to deceptive feedback.

Deveney et al. found that response times were faster overall when the deceptive "Too Slow" feedback was introduced to a similar game with a non-clinical sample of adult females (Deveney, 2019). In this research, we broke down the response time analysis further for each feedback condition separately. Average response times following "Correct" feedback had no significant correlation to the average FRN following "Correct" feedback. This suggests that when participants won a trial, there was no need to change behavior. However, for the "Wrong" and "Too Slow" feedback conditions, average response times in the successive trial got faster with more negative average FRN values. It is likely that participants with the more negative FRN values were more frustrated than the participants with higher FRN values. This means that the participants who were more averse to the negative feedback conditions may have adapted more to the feedback resulting in faster response times in the following trials.

Frustration is associated with anger, which is an approach-motivated emotion (Carver & Harmon-Jones, 2009). In the current task, more frustrating feedback corresponded to faster response times following "Too Slow" feedback than after "Correct" feedback. It is possible that this is a sign of increased approach motivation. It would make sense that motivation increased following frustrating feedback if individuals still felt that they had the possibility to earn positive feedback. Previous work with the FRN component measured in response to positive feedback, called the Reward Positivity, has demonstrated that approach motivation enhances Reward Positivity amplitudes to positive feedback (Threadgill & Gable, 2020). In the current results, it appears that increased approach motivation resulted in larger FRN amplitudes to frustrating loss feedback than positive feedback. In conjunction with past work, approach motivation may have an influence on the FRN, such that FRN amplitudes are enhanced by approach-motivated frustration during losses (current results) as well as wins (Threadgill & Gable, 2020) for individuals with non-elevated reactivity.

The reactivity scores were only significantly correlated to the average FRN following "Correct" feedback. Participants with higher reactivity scores had, on average, more negative FRN values. This could be a result of participants with higher reactivity scores not being able to regulate emotions as well as participants with lower reactivity scores. This is supported by the subgroup analysis since participants with elevated reactivity did not show statistically significant differences in FRN across the different feedback conditions. In other words, the participants with elevated reactivity scores appear to discriminate less well between feedback conditions compared to the non-elevated group.

Correlations with clinical assessments enhanced understanding of the participant population. EDI reactivity and dysphoria positively correlated, consistent with prior research indicating these are related though separate constructs (Mazefsky et al., 2021a, 2021b). Conceptually, this relationship makes sense because EDI reactivity measures more short-term sustained emotional reactions and dysphoria measures general unease, low motivation, and low positive affect, which often go hand-in-hand (Conner et al., 2021; Mazefsky et al., 2018). EDI reactivity and dysphoria also positively correlated with CBCL/ABCL aggression scores with reactivity correlating more strongly. Again, these relationships make sense because EDI reactivity captures emotional reactions which may manifest through aggression. EDI dysphoria is more associated with lethargy and poor affect, which may be tangentially related to aggression (Mazefsky et al., 2018). PROMIS depression and anxiety scores were positively correlated with each other. It is common for these assessments to be highly correlated in previous work on autistic youth (Conner et al., 2019; Mayes et al., 2011).

The main limitation of this research is the lack of a typically developing control group. All 52 participants were diagnosed with ASD. However, within this sample, we can compare FRN amplitudes, reactivity scores, and response times in the successive trial for three different feedback conditions. Considering the fairly large sample size and numerous comparisons within the analysis, this research remains relevant. A future direction should include a typically developing comparison group.

Conclusions and Future Work

The goal of the FRN analysis was to find separation between non-distress and distress by comparing the average FRN at the vertex for different feedback conditions. We found that autistic participants were more distressed when receiving the "Too Slow" feedback than the "Wrong" feedback on average suggesting that the FRN may be able to be used to quantify different levels of distress. This confirms the findings in previous work that the FRN amplitude codes the negative deviation from reward expectations (Bellebaum et al., 2010, 2014). There was not statistical significance in the separation in FRN between the "Wrong" feedback condition and either the "Correct" or "Too Slow" feedback condition, but this should be explored further possibly including more frontal and central channels in analysis.

We also demonstrated that negative feedback leads to faster response times in the next trial on average. Future work should be done to figure out whether the faster response times are a result of increased focus after receiving negative feedback or random key pressing due to extreme frustration.

Lastly, we found that participants with higher reactivity scores had more negative FRN on average in the non-distress condition. Through subgroup analysis we confirmed that participants with higher reactivity scores have similar FRN values regardless of the feedback condition. This means that the FRN may only be useful in separating stress and non-distress for autistic individuals with non-elevated reactivity scores. Future work should consider the reactivity score from the EDI when studying the FRN as reactivity scores can affect the separation of FRN amplitude across feedback conditions. Furthermore, the current study only considered the FRN between 230 and 300 ms post feedback. In future research it could be insightful to also explore other ERPs, such as late feedback positivity after 500 ms post feedback. It could be interesting to see if reactivity scores have similar effects on other ERPs across feedback conditions.

From this study, the FRN amplitude has shown to change based on frustration for autistic individuals with non-elevated reactivity scores. These findings support using the FRN to better understand emotion regulation processes for autistic adolescents with non-elevated reactivity scores in future work. However, this also suggests the need for alternative strategies for interpreting emotion regulation processes for autistic individuals with elevated reactivity.

Appendix

See Tables 2, 3 and Figs. 6, 7

Table 2 Overall F(1, 44) results from simple linear regression

Feedback	Response time regressed on FRN	FRN regressed on EDI	Response time regressed on EDI
Correct	0.148 ($p=0.702$)	4.345 ($p=0.043$*)	1.657 ($p=0.205$)
Wrong	5.109 ($p=0.029$*)	1.541 ($p=0.221$)	0.115 ($p=0.736$)
Too slow	8.321 ($p=0.006$*)	0.127 ($p=0.723$)	1.567 ($p=0.217$)

*$p<0.05$

Table 3 Clinical correlation table

	FRN correct	FRN wrong	FRN slow	RspTime correct	RspTime wrong (next)	RspTime slow (next)	Reactivity	Dysphoria	SRS	Depression	Anxiety	Aggression
FRN correct	1 p=–	0.448 p=0.003*	0.436 p=0.004*	0.093 p=0.557	0.279 p=0.073	0.157 p=0.320	− 0.297 p=0.056	− 0.149 p=0.345	− 0.037 p=0.815	− 0.193 p=0.220	− 0.226 p=0.150	− 0.083 p=0.601
FRN wrong	0.448 p=0.003*	1 p=–	0.655 p=0.000*	0.280 p=0.073	0.342 p=0.027*	0.293 p=0.060	− 0.169 p=0.284	− 0.145 p=0.358	0.270 p=0.083	0.024 p=0.882	− 0.064 p=0.688	− 0.020 p=0.900
FRN slow	0.436 p=0.004*	0.655 p=0.000*	1 p=–	0.303 p=0.051	0.382 p=0.013*	0.398 p=0.009*	0.054 p=0.736	0.084 p=0.599	0.190 p=0.229	0.084 p=0.597	− 0.014 p=0.929	0.234 p=0.136
RspTime correct	0.093 p=0.557	0.280 p=0.073	0.303 p=0.051	1 p=–	0.526 p=0.000*	0.638 p=0.000*	0.203 p=0.198	− 0.010 p=0.949	0.182 p=0.248	− 0.070 p=0.661	− 0.102 p=0.521	0.169 p=0.284
RspTime wrong (next)	0.279 p=0.073	0.342 p=0.027*	0.382 p=0.013*	0.526 p=0.000*	1 p=–	0.642 p=0.000*	− 0.052 p=0.746	0.124 p=0.435	0.374 p=0.015	-0.046 p=0.773	− 0.106 p=0.502	− 0.135 p=0.394
RspTime slow (next)	0.157 p=0.320	0.293 p=0.060	0.398 p=0.009*	0.638 p=0.000*	0.642 p=0.000*	1 p=–	0.141 p=0.372	0.150 p=0.342	0.233 p=0.137	− 0.014 p=0.932	− 0.107 p=0.500	0.106 p=0.505
Reactivity	− 0.297 p=0.056	− 0.169 p=0.284	0.054 p=0.736	0.203 p=0.198	− 0.052 p=0.746	0.141 p=0.372	1 p=–	0.483 p=0.001*	0.283 p=0.070	0.084 p=0.597	0.149 p=0.346	0.645 p=0.000*
Dysphoria	− 0.149 p=0.345	− 0.145 p=0.358	0.084 p=0.599	-0.010 p=0.949	0.124 p=0.435	0.150 p=0.342	0.483 p=0.001*	1 p=–	0.214 p=0.173	0.186 p=0.239	0.085 p=0.592	0.328 p=0.034*
SRS	− 0.037 p=0.815	0.270 p=0.083	0.190 p=0.229	0.182 p=0.248	0.374 p=0.015*	0.233 p=0.137	0.283 p=0.070	0.214 p=0.173	1 p=–	0.103 p=0.516	− 0.105 p=0.508	0.172 p=0.275
Depression	− 0.193 p=0.220	0.024 p=0.882	0.084 p=0.597	-0.070 p=0.661	− 0.046 p=0.773	− 0.014 p=0.932	0.084 p=0.597	0.186 p=0.239	0.103 p=0.516	1 p=–	0.608 p=0.000*	0 p=0.800
Anxiety	− 0.226 p=0.150	− 0.064 p=0.688	− 0.014 p=0.929	− 0.102 p=0.521	− 0.106 p=0.502	− 0.107 p=0.500	0.149 p=0.346	0.085 p=0.592	− 0.105 p=0.508	0.608 p=0.000*	1 p=–	0 p=0.375
Aggression	− 0.083 p=0.601	− 0.020 p=0.900	0.234 p=0.136	0.169 p=0.284	− 0.135 p=0.394	0.106 p=0.505	0.645 p=0.000*	0.328 p=0.034*	0.172 p=0.275	0.040 p=0.800	0.140 p=0.375	1 p=–

*$p < 0.05$

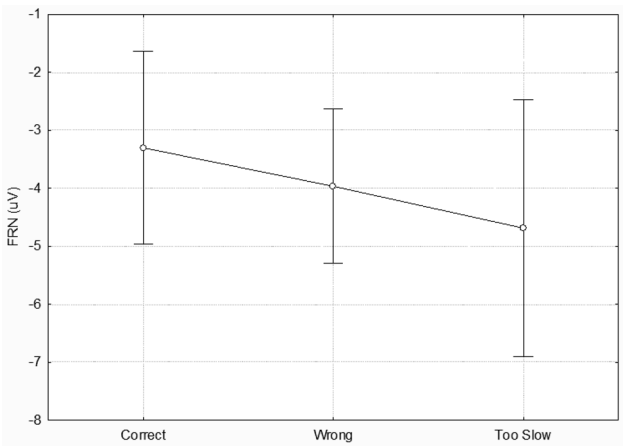

Fig. 6 Mean FRN Values (Elevated EDI-Reactivity). The mean FRN values for each feedback condition with their 95% confidence intervals are shown in the figure. The elevated EDI-Reactivity subgroup has a negative FRN for all feedback conditions

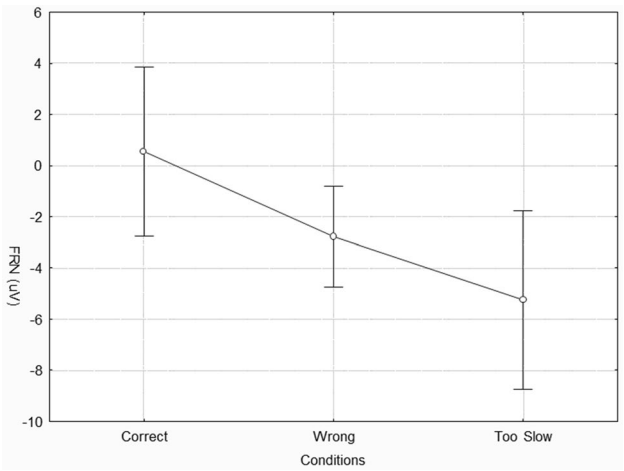

Fig. 7 Mean FRN Values (Non-Elevated EDI-Reactivity). The mean FRN values for each feedback condition with their 95% confidence intervals are shown in the figure. The non-elevated EDI-Reactivity subgroup has a positive FRN to "Correct" feedback and the most negative FRN to "Too Slow" feedback

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Declarations

Conflict of interest There are no relevant financial or non-financial competing interests to report.

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