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Neural responses to social decision-making and their associated factors among nonsuicidal self-injured adolescents: An event-related potentials study

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ABSTRACT

Objective: The neuroelectrophysiology mechanisms of the connection between nonsuicidal self-injury (NSSI) and impairment of social decision-making function remain unknown. As the event-related potentials (ERPs) technique has been widely used in neurobiology research because of its advantage of high temporal resolution, we conducted this study to explore the ERPs of decision-making function among adolescents with NSSI.
Method: This study was designed to compare patients with mood disorder plus NSSI with mood disorder patients without NSSI using a 2:1 ratio. Participants aged 12–18 years were recruited from the outpatient department of psychiatry at Nanfang Hospital. Sociodemographic and psychological data were collected. The Ultimatum Game, a task examining individuals' social decision-making, was conducted with the ERP technique to record participants' neural responses. The associations between ERPs characteristics and psychological factors were examined by using correlation analysis and regression analysis.
Results: In total, 90 participants were eligible, with 60 in the NSSI group and 30 in the non-NSSI group. N1 latency in the unfair condition was positively correlated with Difficulties in Emotion Regulation Scale scores ($r = 0.257$), whereas P2 latency in the fair condition was correlated with agreeableness personality ($r = 0.250$). Regression analysis revealed that N1 latency in the unfair condition was positively associated with NSSI (ORs ranged 1.07–1.10), whereas P2 latency in the fair condition was negatively associated (ORs ranged 0.95–0.97).
Conclusion: NSSI patients tended to exhibit impairment in decision-making function including initial cognitive value judgment, attentional allocation, and working memory process. ERPs characteristics including N1 latency and P2 latency may be predictors of NSSI.

1. Introduction

Nonsuicidal self-injury (NSSI) is defined as intentional and self-inflicted damage to an individual's body without suicidal intent, which is not socially sanctioned (Lloyd-Richardson et al., 2007). NSSI is the most prevalent among adolescents and the prevalence of repetitive NSSI behaviors is approximately 50 % (Brown and Plener, 2017). NSSI has become a severe global health problem that threatens the physical and mental health of adolescents.

Multiple factors, such as family conflict, being bullied, negative affect and internalizing psychopathology, are associated with NSSI (Liu et al., 2022). Furthermore, a previous study found that personality traits such as neuroticism were related to NSSI (Kang et al., 2021). However, the underlying mechanisms by which these factors contribute to NSSI remain unknown. In recent years, many studies have argued that the deficiency of decision-making functions is a vital mechanism of NSSI (Oldershaw et al., 2009). Patients with NSSI make more adverse and impulsive decisions in response to negative emotions (Allen et al., 2019;

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Lutz et al., 2022). However, these studies merely collected behavioral data that they failed to explain the mechanism.

As electroencephalograms (EEGs) have become common and increasingly applied in neurobiology research, the event-related potentials (ERPs) technique has also been widely used because of its advantage of high temporal resolution. In Zhou's study, P3 amplitudes were found to be greater in the NSSI group than in the healthy group under exposure to self-injury cues, suggesting that NSSI adolescents require more neural resources to complete response inhibition (Zhou et al., 2022). Furthermore, Tsypes's study revealed that children with a history of NSSI presented more feedback-negativity (ΔFNs), reflecting greater neural responsiveness to losses than to rewards (Tsypes et al., 2018). In addition, patients with NSSI were found to have a reduced amplitude of the N2 component of laser-evoked potentials, which was associated with conditioned abnormal pain modulation (Leone et al., 2021). Nevertheless, to our knowledge, there have been no ERPs studies among NSSI patients that relate to social decision-making function.

Since NSSI is highly correlated with suicide, patients with NSSI may exhibit similar but different decision-making-related ERPs characteristics than patients with attempted suicide. According to an ERPs study assessing suicide, patients with suicide attempts had a decreased P2 amplitude and a prolonged P2 latency when receiving unfair offers in the Ultimatum Game (Liu et al., 2023). Similar changes may be expected in patients with NSSI.

Although a few studies have investigated decision dysfunction among NSSI patients, they have only measured patients' behavior. However, studies investigating the underlying neuro-electrophysiological mechanisms are still lacking. Moreover, most previous studies concerning NSSI patients focused only on the amplitudes and latencies of ERPs components, but few studies have explored the relationships between these ERPs characteristics and patients' socio-demographic and psychological factors, which left the gap in understanding changes in ERPs components with relation to decision making function in NSSI. Therefore, we conducted this study to evaluate the ERPs characteristics related to decision-making function and to explore the relationships between the ERPs characteristics and psychological characteristics among adolescents with NSSI.

2. Method

2.1. Participants

Participants were patients recruited from the outpatient department of psychiatry at Nanfang Hospital between February 2023 to May 2024. All adolescent patients diagnosed with mood disorders by psychiatrists were further interviewed by the researchers to determine if they met the inclusion and exclusion criteria for the study.

2.1.1. Inclusion criteria

2.1.1.1. NSSI group. (1) meeting the diagnostic criteria of NSSI according to the Diagnostic and Statistical Manual of Mental Disorders-5 (DSM-5); (2) being diagnosed with mood disorders (including depressive disorders and bipolar and related disorders); and (3) being aged 12–18 years.

2.1.1.2. Non-NSSI group. Except for not meeting the diagnostic criteria of NSSI, the other criteria were the same as those of the NSSI group.

2.1.2. Exclusion criteria

The two groups shared the same exclusion criteria as follows:

(1) Suffering from serious neurological illness or physical illness; (2) having uncorrectable impairment in eyesight or color vision; and (3) having received transcranial magnetic therapy (TMS), electroconvulsive therapy (ECT), or modified electroconvulsive therapy (MECT) in the previous month before inclusion in the study.

2.2. Sample size calculation

This study was designed to compare patients with mood disorder plus NSSI with mood disorder patients without NSSI using a 2:1 ratio. The sample size was calculated via PASS software version 15. Based on a previous behavioral study, 66 patients (44 in the NSSI group and 22 in the non-NSSI group) were required to detect a difference between the two groups at $p = 0.05$ (two-tailed), with a power of 90 % (Oldershaw et al., 2009). Considering patient drop-out or poor EEG data quality, the exclusion rate is expected to be less than 20 %, which results in a final sample size of 83 to ensure the reliability of the study. Expanding the sample size further could help reduce random errors.

2.3. Study procedure

Informed consent was first obtained from the guardians of the participants. Questionnaires concerning the participants' demographic data and psychological status were collected. Finally, EEGs during the Ultimatum Game task were recorded. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Nanfang Hospital, Southern Medical University (No. NFEC-2023-397).

2.4. Instruments

The 24-item Hamilton Rating Scale for Depression (HAMD-24) and Hamilton Rating Scale for Anxiety (HAMA) were used to assess participants' depressive and anxiety symptoms respectively (HAMILTON, 1960; Maier et al., 1988). The Difficulties in Emotion Regulation Scale (DERS) and the Childhood Trauma Questionnaire-Short Form (CTQ-SF) were used to evaluate difficulties in emotion regulation and childhood trauma (HAMILTON, 1960; He et al., 2019; Li et al., 2018; Maier et al., 1988). In addition, the Chinese Big Five Personality Inventory-15 (CBF-PI-15) was used to measure personality traits (Zhang et al., 2019). These scales were used in the Chinese language and have shown good reliability and validity in previous studies.

2.5. EEG recording

2.5.1. The Ultimatum Game (UG) and experimental procedures

The UG is a widely used socioeconomic decision-making task (Sanfey et al., 2003). In this study, UG was modified based on Liu's study (Liu et al., 2023). The participants were asked to play as the "responder" to accept or reject the distribution offer of 10 yuan (i.e., 5/5, 6/4, 7/3, 8/2, and 9/1). In total, 100 trials were distributed across five schemes, in which 5/5 and 6/4 were considered fair offers, and 8/2 and 9/1 were considered unfair offers. Before the experiment, the participants were informed that they would play with an anonymous partner. However, all offers were actually assigned by the computer randomly. The participants were also asked to try to maximize their gains. The detailed procedure of UG is illustrated in Fig. 1.

2.5.2. EEG data recording

The participants were seated in an electric and magnetic insulated room. EEGs were recorded via the Neuroscan Curry8 system with 64-electrode caps that were positioned following the 10/20 international electrode placement system. The sampling rate was set at 1000 Hz. An extra independent electrode was used as the online reference. For all electrodes, the impedance was kept below 10 kΩ during recording.

2.6. Data processing and analysis

2.6.1. ERPs analysis

MATLAB 2018a and the EEGLAB toolbox were used to conduct

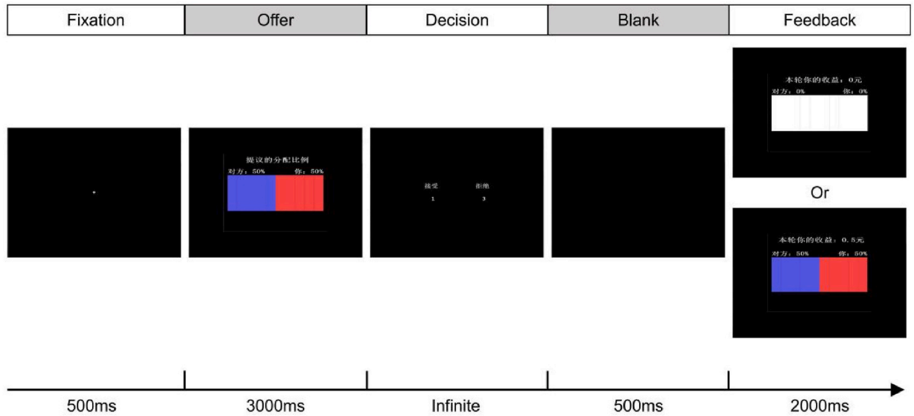

Fig. 1. The procedure of the Ultimatum Game (UG). As the subjects were Chinese, all instructions in the paradigm were in Chinese.

offline EEG analyses. The steps of EEG preprocessing were as follows: 1) resampling to 250 Hz, 2) FIR bandpass filter of 0.1–30 Hz, 3) bad channel interpolation, 4) extracting epochs (data were extracted from 200 ms before the offer stimulation to 800 ms after the stimulation, and the 200 ms before the stimulation was used as baseline correction), 5) removing false epochs, 6) independent component analysis (ICA) and manual ICA-based artifact removal, and 7) re-referencing to bilateral mastoids and categorizing epochs by conditions. Patients with excessive data artifacts (>20 % false epochs) were considered to have poor data quality and were disqualified for final analysis. Finally, the mean waveforms were computed for each condition and participant, and these waveforms were used for further analyses.

N1, P2, and P3 components were characterized by a cluster of 9 electrodes (Fz, F1, F2, FCz, FC1, FC2, Cz, C1 and C2), 6 electrodes (FCz, FC1, FC2, Cz. C1, and C2), and 9 electrodes (Pz, P1, P2, POz, PO3, PO4, Oz, O1 and O2), respectively. For each condition, N1 amplitude was scored as the mean amplitude in the time window of 120–160 ms poststimulus, whereas P2 and P3 amplitudes were scored as the mean amplitudes in the time windows of 200–260 ms and 250–350 ms, respectively. The clusters of electrodes and time windows were chosen for analysis based on a previous study (Gong et al., 2022).

2.6.2. *Statistical analysis*

The continuous variables are presented as means and standard deviations, whereas the categorical variables are reported as frequencies and percentages. T-test and chi-square test were used in the univariate analyses. Repeated-measures analysis of variance (ANOVA) with groups (NSSI and non-NSSI) as the between-subjects factor and condition (fair and unfair) as the within-subjects factor was performed for ERPs data analysis. Post hoc simple effect analyses were conducted for group comparisons. Furthermore, Spearman correlation analysis and logistic regression analysis were used to identify the ERPs characteristics associated with NSSI and other psychological factors. All the statistical analyses were two-tailed with an alpha level set at $p < 0.05$ and were

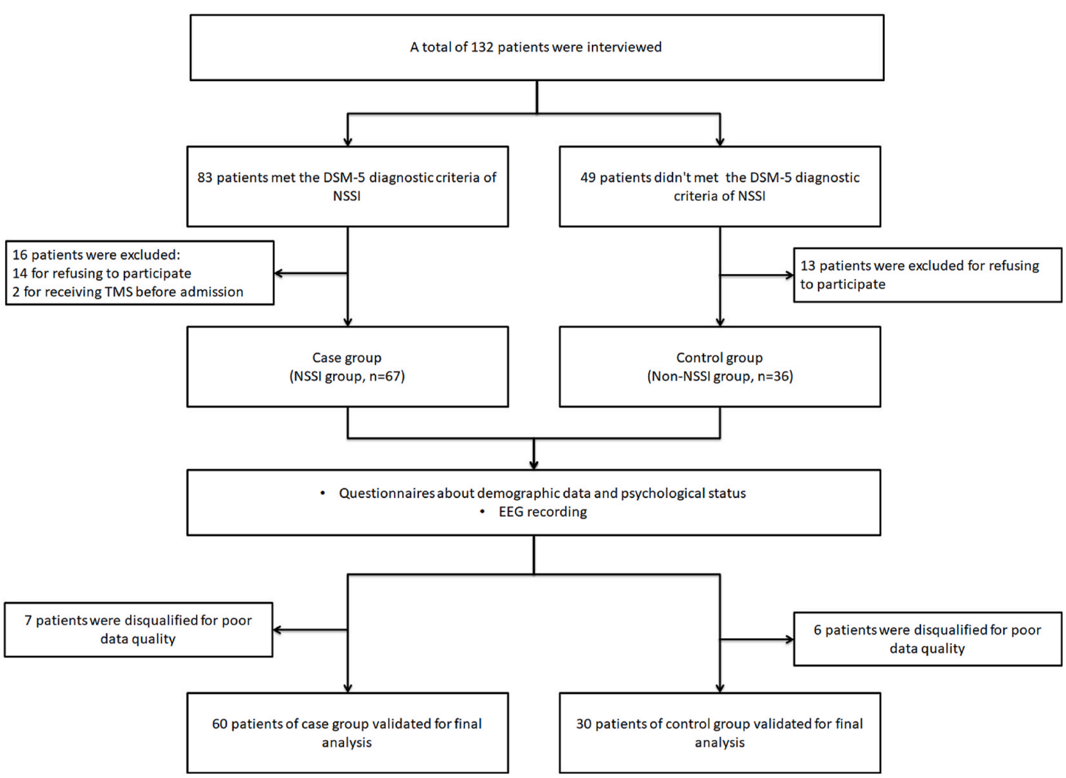

Fig. 2. Flowchart of the study.

conducted in SPSS software version 22.0.

3. Result

3.1. Demographics and psychological characteristics

In total, 132 patients were initially interviewed, 27 of whom declined to participate, and two were excluded due to receiving TMS therapy in the previous month before the study. Another 13 patients were excluded due to poor data quality. Finally, 90 participants, consisting of 60 in the NSSI group and 30 in the non-NSSI group, were eligible for analysis (Fig. 2).

Table 1 shows the demographic and psychological characteristics of the two groups. Significant differences between the two groups were found in the DERS scores, HAMA, HAMD, the emotional neglect dimension of the CTQ-SF, and the conscientiousness and agreeableness dimensions of the CBF-PI-15.

3.2. Electrophysiological data

3.2.1. ERPs

Fig. 3 depicts the grand-average ERPs waveforms for the NSSI group (black line and black dotted line) and the non-NSSI group (red line and red dotted line) in each condition.

3.2.2. N1

For N1 amplitude, no significant main effects or interaction effects were found. For N1 latency, a significant effect of condition (F = 6.62, p = 0.012) as well as an interaction effect (F = 10.22, p = 0.002) were observed. Simple effect analysis revealed that N1 latency was greater in the NSSI group than in the non-NSSI group in the unfair condition (p = 0.048). Furthermore, N1 latency was greater in the fair condition than in the unfair condition in the non-NSSI group (p = 0.001) [Fig. 4 (A)].

3.2.3. P2

The main effect of the group was significant (F = 4.41, p = 0.039), indicating that the NSSI group presented greater P2 amplitudes than did the non-NSSI group. However, no significant interaction effect was observed between conditions and groups. Simple effect analysis revealed that P2 amplitude was greater in the NSSI group than in the non-NSSI group in the unfair condition (p = 0.040).

Moreover, for P2 latency, there was a significant main effect of group (F = 5.99, p = 0.016), indicating greater P2 latency in the non-NSSI group than in the NSSI group. However, there was no significant interaction effect between the condition and the group. Simple effect analysis revealed that P2 latency was greater in the non-NSSI group than in the NSSI group in the fair condition (p = 0.004) [Fig. 4 (B)].

3.2.4. P3

There were no significant main or interaction effects for P3 amplitude. However, a borderline significant condition effect was found (F = 3.90, p = 0.051), indicating that a greater P3 amplitude was exhibited in the unfair condition than in the fair condition. Simple effect analysis revealed that the NSSI group had greater P3 amplitudes in the unfair condition than in the fair condition (p = 0.003).

For P3 latency, neither a main effect of group or condition nor an interaction effect was found. However, further simple effect analysis revealed that P3 latency was greater in the fair condition than the unfair condition in the NSSI group (p = 0.038) [Fig. 4 (C)].

3.3. Correlation analyses

Correlation analyses revealed that N1 latency in the unfair condition was positively correlated with the scores on the HAMA and two subscales of the DERS, whereas it was negatively correlated with the scores on the sexual abuse dimension of the CTQ-SF. N1 amplitude in the fair condition was positively correlated with the scores of two subscales of the DERS, the neuroticism personality trait, and the HAMD-24 score (Table 2).

For P2, P2 latency in the fair condition was positively correlated with the agreeableness dimension of the CBF-PI-15 but negatively correlated with the scores on the emotional abuse dimension of the CTQ-SF. P3 latency in the fair condition was correlated with two dimensions of the DERS. Additionally, P3 amplitude in the fair condition was correlated with neuroticism, and P3 amplitude in the unfair condition was

Table 1
Demographic and psychological characteristics between the NSSI group and the non-NSSI group (N = 90).

	NSSI group (n = 60)	Non-NSSI group (n = 30)	$t/\chi2$	p
Demographic Factors				
Age (mean ± SD)	15.20 ± 1.54	15.73 ± 1.55	t(88) =1.546	0.126
Gender (Female)	51(85.0 %)	23(76.7 %)	$\chi^2(1)$= 0.920	0.338
Ethnicity (Han)	58(96.7 %)	30(100 %)	$\chi^2(1)$= 1.645	0.200
Chronic physical disease (Yes)	10(16.7 %)	5(13.3 %)	$\chi^2(1)$= 0.173	0.678
Family history of mental disorders (Yes)	9(15.0 %)	1(3.3 %)	$\chi^2(1)$= 3.296	0.069
Psychological Factors				
DERS (mean±SD)	124.12 ± 16.46	110.20 ± 25.79	t(88) =-3.108	**0.003**
Non-acceptance of Emotional Responses	17.28 ± 5.70	15.57 ± 7.14	t(88) =-1.236	0.220
Difficulties Engaging in Goal-Directed Behavior	21.60 ± 2.83	19.33 ± 4.80	t(39)[a] =-2.387	**0.022**
Impulse Control Difficulties	21.05 ± 5.28	17.93 ± 6.09	t(88) =-2.508	**0.014**
Lack of Emotional Awareness	20.13 ± 4.17	19.30 ± 5.45	t(88) =-0.805	0.423
Limited Access to Emotion Regulation Strategies	30.67 ± 5.45	24.90 ± 6.96	t(88) =-4.308	**<0.001**
Lack of Emotional Clarity	13.38 ± 3.81	13.17 ± 4.44	t(88) =-0.241	0.810
CTQ-SF (mean±SD)	51.52 ± 12.82	45.00 ± 11.36	t(88) =-2.359	**0.021**
Physical abuse	7.35 ± 3.43	6.27 ± 2.42	t(88) =-1.545	0.126
Emotional abuse	12.45 ± 4.94	10.40 ± 4.39	t(88) =-1.924	0.058
Sexual abuse	5.57 ± 2.20	6.13 ± 3.28	t(88) =0.974	0.333
Physical neglect	9.40 ± 3.01	8.27 ± 2.75	t(88) =-1.731	0.087
Emotional neglect	16.75 ± 4.75	13.93 ± 6.24	t(46)[a] =-2.176	**0.035**
CBF-PI-15 (mean±SD)				
Neuroticism	14.87 ± 2.53	13.87 ± 3.71	t(43)[a] =-1.330	0.191
Conscientiousness	8.57 ± 3.03	10.20 ± 3.93	t(88) =2.180	**0.032**
Agreeableness	9.15 ± 3.29	11.50 ± 3.10	t(88) =3.259	**0.002**
Openness	7.67 ± 3.90	8.50 ± 3.88	t(88) =0.957	0.341
Extraversion	7.02 ± 3.07	7.60 ± 3.22	t(88) =0.836	0.405
HAMA (mean±SD)	21.75 ± 7.67	16.67 ± 8.23	t(88) =-2.893	**0.005**
HAMD-24 (mean±SD)	34.18 ± 9.24	26.33 ± 9.81	t(88) =-3.724	**<0.001**

1. [a]: Due to the heterogeneity of variances, correction t-tests were used.
2. Abbreviation: SD = standard deviation; DERS=The Difficulties in Emotion Regulation Scale; CTQ-SF=The Childhood Trauma Questionnaire-Short Form; CBF-PI-15 = The Chinese Big Five Personality Inventory-15; HAMA=Hamilton Rating Scale for Anxiety; HAMD-24 = Hamilton Rating Scale for Depression-24; NSSI = nonsuicidal self injury.

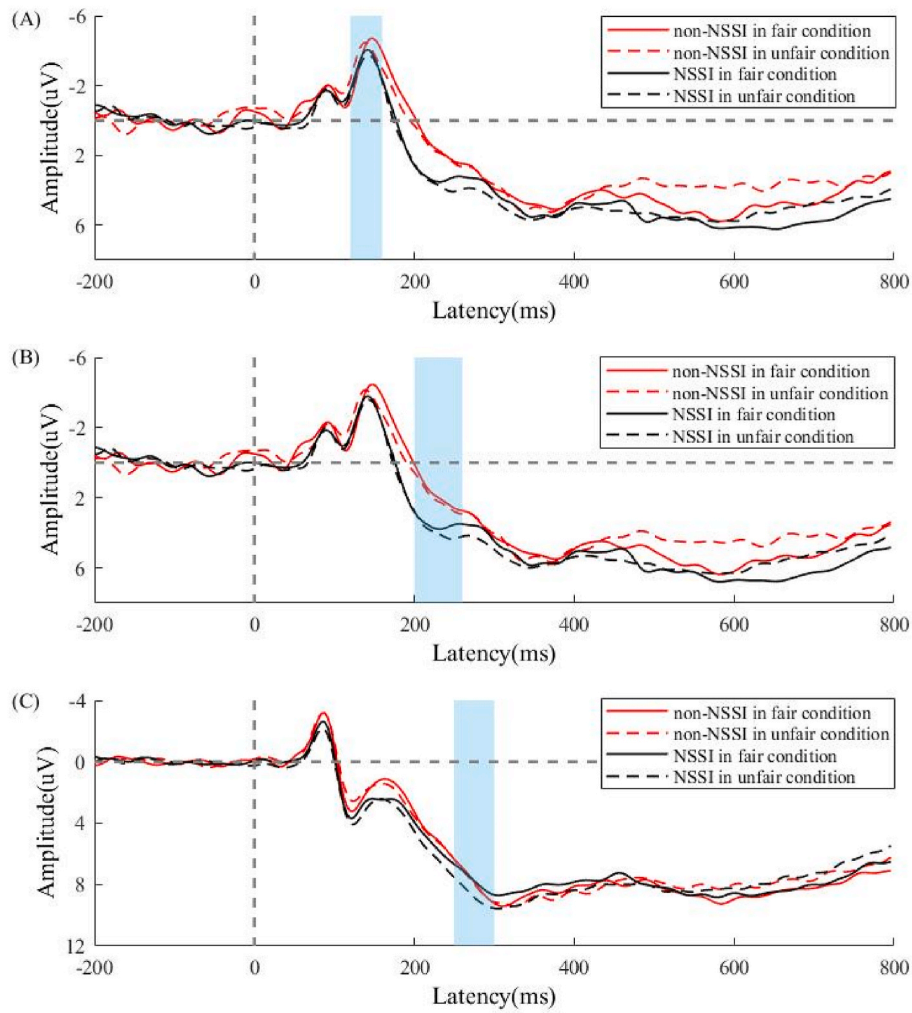

Fig. 3. The grand average ERP waveforms at the stage of the offer for the NSSI and the non-NSSI group, following the fair conditions (5/5; 6/4) and the unfair conditions (8/2; 9/1). The blue regions (windows) showed the measurement window for the three ERP components. (A) Waveforms of N1 component. (B) Waveforms of P2 component. (C) Waveforms of P3 component. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

correlated with emotional abuse (Table 2).

3.4. Logistic regression analysis

The ERPs component characteristics (amplitudes and latencies) were selected as independent variables, whereas NSSI status was selected as the dependent variable in the logistic regression analysis. The results revealed that N1 latency in the unfair condition and P2 latency in the fair condition were statistically significant in all three models (Table 3). The areas under the receiver operating characteristic (ROC) curves of the three logistic regression models were 0.77, 0.81, and 0.86, respectively (Fig. 5).

4. Discussion

In the present study, we examined NSSI patients' ERPs characteristics in terms of their social decision-making function via the UG paradigm and explored the correlation between ERPs and psychological characteristics. Compared with non-NSSI patients, NSSI patients presented larger P2 amplitudes. Moreover, they had prolonged N1 latencies in the unfair condition and shortened P2 latencies in the fair condition. We also found that ERPs characteristics were correlated with difficulties in emotion regulation, childhood trauma, and the personality traits of agreeableness and neuroticism.

In our task, NSSI patients did not vary much from fair to unfair conditions. However, non-NSSI patients exhibited reduced N1 latency in the fair condition. The fronto-central N1 wave component is expected to be associated with the visual processing of a functional representation of the stimulus and reflects proactive cognitive control to enable an active motor response (Antal et al., 2000; Miraghaie et al., 2022). Therefore, non-NSSI patients may maintain better abilities to quickly orient attention, identify unfavorable situations, and initiate further active responses. In contrast, NSSI patients may have already suffered from dysfunction in such decision-making abilities, resulting in blunting responses when facing negative events or feelings. This may explain why some NSSI patients hurt themselves due to a lack of emotional awareness or aberrant pain perception (St and Hooley, 2013; Wolff et al., 2019). This dysfunction may also be reflected in the correlation that we found between N1 latency and difficulties in emotion regulation, in which childhood trauma, such as sexual abuse, likely plays an initiating role. Additionally, N1 latency in the unfair condition was found positively correlated with anxiety symptoms while increased N1 latency in the unfair condition was exhibited in the NSSI group than the non-NSSI group. The NSSI group was also found to experience more severe anxiety symptoms. A previous study illustrated that anxiety exerted a direct effect on NSSI, and the relationship was mediated by cognitive reappraisal (Richmond et al., 2017). It may be inferred that high level of anxiety symptoms in patients could lead to their cognitive as well as

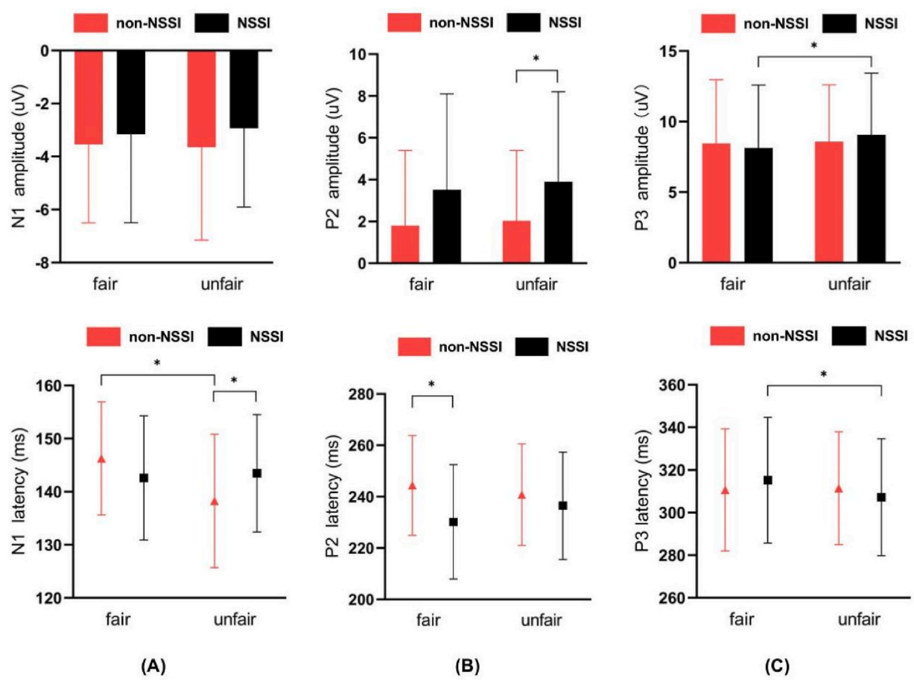

Fig. 4. In the fair (5/5; 6/4) and the unfair conditions (8/2; 9/1), the amplitudes and latencies of N1, P2, and P3 in the non-NSSI and the NSSI group were measured. $^{*}p < 0.05$.

their decision making function impairment, resulting in their self-injury behaviors. However, more studies are required to clarify the mechanisms in the future.

Another finding in our study was that the NSSI group presented significantly greater P2 amplitudes than the non-NSSI group in the unfair condition, but not in the fair condition. The P2 component is usually considered to be modulated by attention, and a reduction in P2 represents a reduction in the allocation of attention (Miller et al., 2011). This may suggest that NSSI patients need to expend more effort in attentional resource allocation, which means that they may be more sensitive in social interactions related to decision-making. Furthermore, the P2 component is related to motor inhibition, which prevents irrelevant sensory features from being processed further to protect the system from initiating erroneous actions (Bedoin et al., 2019). An increased P2 amplitude may indicate the impediment of the protective mechanisms, ultimately leading to an incorrect response (Porth et al., 2024). This tendency of impairment in decision-making function among NSSI patients may be the reason for their difficulties in emotion regulation, which leads to the failure to suppress harmful behaviors such as self-injury.

Concerning P2 latency, we found a significant difference in reduced P2 latency between the NSSI group and the non-NSSI group in the fair condition. A reduced latency usually indicates an acceleration of cognitive processes (Hajcak et al., 2010). The NSSI patients were faster in discriminating and classifying the 'offer' information, especially fair information. Combined with the findings concerning P2 amplitude mentioned above, NSSI patients seemed to be more sensitive to fair–unfair conflict when making decisions than non-NSSI patients were, which is in line with the findings of a previous behavioral study (Carbajal et al., 2017). Consistent with our findings, a previous study revealed a longer P2 latency among patients with suicide intentions than the healthy control (Liu et al., 2023). This might be due to different mechanisms between suicide and self-injury that would result in variations and great distinctions of neural responses to stimulus. In the future, uncovering how responses to unfairness influence NSSI would be valuable for understanding patients' intentional self-injury.

Notably, the P3 amplitude varied between the fair and unfair conditions in the NSSI group but not in the non-NSSI group. P3 is another vital ERPs component that reflects an information processing cascade when attentional and memory mechanisms are both engaged (Polich, 2007). P3 amplitude is not only responsive to the interactive association of attentional allocation but is also affected by fundamental memory processing. Stimulus encoding that promotes successful memory storage increases the P3 amplitude (Azizian and Polich, 2007). Hence, our findings suggest that NSSI patients' sensitivity to fair-unfair decision-making challenges occurs not only in the attentional allocation process but also in the working memory process.

Notably, neuroticism was found to be negatively correlated with the P3 component. Our finding is consistent with a previous study that used an auditory discrimination paradigm but inconsistent with Carrito's study which used an image oddball paradigm (Carrito et al., 2021; Gurrera et al., 2001). Numerous studies link a reduced P3 amplitude to psychopathology, whereas a high level of neuroticism is considered positively associated with multiple psychiatric disorders (Castro et al., 2019; Glazer et al., 2019; Zhang et al., 2021). The relationship between a lower P3 amplitude and a higher level of neuroticism may be common due to patients' psychiatric disorders but is independent of any specific type of mental illness. This may explain why the P3 amplitude of the NSSI patients did not differ from that of the non-NSSI patients in this study. Further study is needed to elucidate the exact mechanisms of the impact of neuroticism on the P3 component.

According to the above findings, we speculate that NSSI patients have the tendency to be deficient in their decision-making function, including initial cognitive value judgment, attentional allocation, and working memory process.

5. Limitation

Our study has several limitations. Firstly, the Ultimatum Game paradigm may be unable to simulate the real-life context of decision-making completely. The stimuli of the paradigm may not be strong enough to arouse participants' emotions, making it difficult for the participants to react as they do in the real world. Secondly, we measured only participants' neural responses linked to the offer-presenting stimuli

Table 2
Correlations between N1, P2, P3 component characteristics and psychological characteristics.

	N1 amplitude in fair condition	N1 latency in fair condition	N1 amplitude in unfair condition	N1 latency in unfair condition	P2 amplitude in fair condition	P2 latency in fair condition	P2 amplitude in unfair condition	P2 latency in unfair condition	P3 amplitude in fair condition	P3 latency in fair condition	P3 amplitude in unfair condition	P3 latency in unfair condition
DERS												
Non-acceptance of Emotional Responses	**0.234***	0.020	**0.257***	0.130	0.073	−0.036	0.117	−0.115	−0.115	**0.256***	−0.107	−0.049
Difficulties engaging in Goal-Directed Behavior	0.059	0.002	−0.051	**0.248***	0.178	−0.081	0.094	−0.195	−0.078	0.156	−0.115	−0.007
Impulse Control Difficulties	**0.290***	0.018	0.182	**0.239***	0.205	−0.060	0.153	0.017	−0.079	0.056	0.017	−0.006
Lack of Emotional Awareness	0.057	0.137	0.126	0.175	−0.108	−0.028	−0.038	−0.087	−0.003	**−0.209***	0.097	−0.201
Limited Access to Emotion Regulation Strategies	0.179	−0.051	0.157	0.169	0.136	−0.201	0.064	−0.165	−0.148	0.156	−0.110	−0.018
Lack of Emotional Clarity	−0.116	−0.123	−0.035	−0.047	−0.058	−0.161	−0.066	−0.119	−0.142	−0.095	−0.104	−0.135
CTQ-SF												
Physical abuse	−0.008	−0.036	0.130	−0.025	−0.015	−0.135	0.067	0.160	−0.108	0.045	−0.184	0.044
Emotional abuse	0.083	−0.138	0.010	0.088	−0.026	**−0.233***	−0.101	−0.046	−0.204	0.102	**−0.208***	0.075
Sexual abuse	0.143	−0.087	0.170	**−0.237***	0.017	−0.089	−0.042	−0.038	−0.159	0.052	−0.179	0.139
Physical neglect	0.015	−0.017	0.117	0.098	−0.048	−0.098	0.091	−0.187	−0.035	<0.001	0.032	−0.158
Emotional neglect	0.183	0.070	0.141	0.166	−0.002	−0.070	−0.035	0.047	0.035	−0.059	0.015	−0.154
CBF-PI-15												
Neuroticism	**0.285***	−0.043	0.163	0.134	0.053	−0.094	−0.033	−0.187	**−0.227***	0.178	−0.176	0.035
Conscientiousness	−0.060	0.058	0.015	−0.090	−0.116	0.075	−0.071	0.143	0.171	−0.030	0.162	−0.059
Agreeableness	0.033	0.002	−0.148	−0.179	0.015	**0.250***	−0.009	0.106	0.201	0.009	0.121	−0.039
Openness	−0.058	0.082	−0.027	0.002	0.147	0.002	0.199	0.079	0.149	−0.123	0.126	−0.073
Extraversion	0.007	0.039	−0.015	−0.038	−0.084	0.069	−0.034	0.056	0.118	−0.107	0.076	−0.175
HAMA	0.190	0.021	0.161	**0.235***	0.025	−0.015	0.024	−0.128	−0.120	0.057	−0.065	−0.070
HAMD-24	**0.253***	−0.029	0.133	0.117	0.022	−0.027	−0.023	−0.025	−0.076	0.012	−0.022	−0.076

1. Spearman correlation analyses were conducted.
2. **Abbreviation:** DERS=The Difficulties in Emotion Regulation Scale; CTQ-SF=The Childhood Trauma Questionnaire-Short Form; CBF-PI-15 = The Chinese Big Five Personality Inventory-15; HAMA=Hamilton Rating Scale for Anxiety; HAMD-24 = Hamilton Rating Scale for Depression-24; *: $p < 0.05$.

Table 3
Logistic regression analyses of ERP component characteristics related to NSSI.

	NSSI	
	OR/Adjusted OR (95 % CI)	*p*
Model 1[a]		
N1 latency in fair condition	0.95 (0.89–1.00)	0.055
N1 latency in unfair condition	1.07 (1.01–1.13)	**0.017**
P2 amplitude in fair condition	1.21 (1.02–1.44)	**0.033**
P2 latency in fair condition	0.97 (0.95–0.99)	**0.025**
P3 amplitude in fair condition	0.74 (0.56–0.96)	**0.025**
P3 amplitude in unfair condition	1.31 (1.02–1.67)	**0.036**
Model 2[b]		
N1 latency in fair condition	0.93 (0.87–1.01)	0.067
N1 latency in unfair condition	1.10 (1.01–1.19)	**0.021**
P2 amplitude in fair condition	1.28 (1.03–1.61)	**0.030**
P2 latency in fair condition	0.96 (0.93–0.99)	**0.015**
P3 amplitude in fair condition	0.67 (0.49–0.92)	**0.014**
P3 amplitude in unfair condition	1.41 (1.05–1.88)	**0.021**
Model 3[c]		
N1 latency in unfair condition	1.09 (1.00–1.18)	**0.045**
P2 amplitude in unfair condition	1.56 (1.17–2.06)	**0.002**
P2 latency in fair condition	0.95 (0.91–0.99)	**0.008**

1. The reference group in the three models was the non-NSSI group.
2. [a] : In Model 1, ERP characteristics were put into the binary logistic regression analysis with Backward Likelihood Ratio method.
[b] : Model 2 was further controlled for age, gender, HAMA scores and HAMD scores with Enter method.
[c] : Model 3 was controlled for age, gender, HAMA scores, HAMD scores and the other psychological factors statistically significant in the univariate analyses with Enter method.
3. **Abbreviation**: OR= odds ratio; CI= confidence interval; ERP= event-related potential; NSSI= Nonsuicidal self-injury.

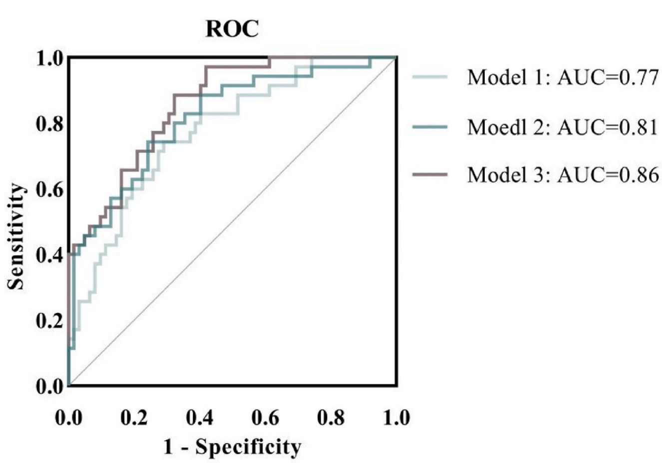

Fig. 5. Receiver operating characteristic (ROC) curve analysis graph for the three logistic regression models.

of each current trial. However, previous offerings and feedback may also influence participants' responses. Third, we did not divide the patients into specific mood disorders, such as major depressive disorder or bipolar disorder. Further study is expected to reveal the differences in social decision-making functions between different types of mental disorders. Thirdly, we didn't exclude the patients who had received medication or psychotherapy, which could have influenced our results. Finally, our study focused on NSSI patients' neural responses by examining their ERPs characteristics but lacked behavioral measures. The exact meanings and corresponding psychological processes of the ERPs should also be clarified. It will be meaningful to investigate intensively in future studies.

6. Conclusion

NSSI patients tended to exhibit deficiencies in their decision-making function such as initial cognitive value judgment, attentional allocation, and working memory process. ERPs characteristics including N1 latency and P2 latency may be predictors of NSSI. The ERPs characteristics were correlated with difficulties in emotion regulation, childhood trauma, neuroticism, and agreeableness. Intervention to improve patients' decision-making abilities may reduce their NSSI behaviors.

CRediT authorship contribution statement

Huafeng Wei: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Qianqian Xin:** Writing – original draft, Supervision, Software, Project administration, Data curation. **Yihong Cheng:** Resources, Investigation, Data curation. **Zhihong Lv:** Software, Formal analysis, Data curation. **Wenjuan He:** Data curation. **Miaoqin Tan:** Investigation, Funding acquisition. **Meiqi Lin:** Data curation. **Shuqiong Zheng:** Formal analysis. **Junlong Guo:** Writing – original draft, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **Bin Zhang:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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