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Cognitive Phenotype Shifts in Risk Taking: Interplay of Nonsuicidal Self-Injury Behaviors and Intensified Depression

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ABSTRACT

BACKGROUND: Nonsuicidal self-injury (NSSI) behavior is significantly prevalent in both adolescents and psychiatric populations, particularly in individuals with major depressive disorder. NSSI can be considered a result of risky decision making in response to negative emotions, where individuals choose self-harm over other less harmful alternatives, suggesting a potential decision-making deficit in those engaging in NSSI. This study delves into the complex relationship between NSSI and depression severity in decision making and its cognitive underpinnings.
METHODS: We assessed decision behaviors in 57 patients with major depressive disorder and NSSI, 42 patients with major depressive disorder without NSSI, and 142 healthy control participants using the Balloon Analog Risk Task, which involves risk taking, learning, and exploration in uncertain scenarios. Using computational modeling, we dissected the nuanced cognitive dimensions influencing decision behaviors. A novel statistical method was developed to elucidate interaction effects between NSSI and depression severity.
RESULTS: Contrary to common perceptions, we found that individuals with NSSI behaviors were typically more risk averse. There was also a complex interaction between NSSI and depression severity in shaping risk-taking behaviors. As depressive symptoms intensified, the individuals with NSSI began to perceive less risk and behave more randomly.
CONCLUSIONS: This research provides new insights into the cognitive aspects of NSSI and depression, highlighting the importance of considering the influence of comorbid mental disorders when investigating the cognitive underpinnings of such behaviors, especially in the context of prevalent cross-diagnostic phenomena such as NSSI behaviors.

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Nonsuicidal self-injury (NSSI), which is prevalent in adolescents (1) and psychiatric populations (2,3), particularly in individuals with depression (4,5), involves deliberate self-harm behaviors (e.g., cutting, burning, scratching, and banging or hitting) without suicidal intent. The lifetime prevalence of NSSI is 17.2% among adolescents in the community (6) and escalates to 40% to 80% among adolescents in clinical settings (7). Although distinct from suicidal behavior, it is crucial to understand NSSI due to its strong association with future suicide risk (8–10). NSSI has been described as a maladaptive form of self-help (11) often used as a coping mechanism for intense emotional distress (12–15). Similar to suicidal actions, choosing to self-harm instead of less harmful coping solutions (e.g., talking to a friend, practicing mindfulness, or seeking professional counseling) reflects maladaptive decision making (16). Therefore, our work focuses on the decision characteristics of individuals with NSSI and is aimed at identifying the potentially multifaceted cognitive dysfunctions that underlie decisions to engage in NSSI behaviors.

One early and influential hypothesis about NSSI is impulsivity (17), according to which impulsive individuals are more likely to engage in NSSI due to an attraction to the immediate emotional relief that comes with self-harm and their caring less about its long-term negative consequences. Impulsivity is often measured using self-report scales such as the Barratt Impulsiveness Scale (18) and the UPPS Impulsivity Behavior scale (19), where impulsivity refers to personal traits including lack of forethought and carelessness. Consistent with the impulsivity hypothesis, self-reported impulsivity measures are often (but not always) higher in individuals with NSSI (17) and may predict the new onset of NSSI (20). However, the impulsivity hypothesis has rarely received support from studies that have used behavioral measures of decision-making tasks (17,21), except when "impulsivity" is used as an umbrella term covering risky decision making (21,22). In risky decision making (23), someone who turns down an investment offer with a 90% probability of winning $1000 and a 10% probability of losing $2000 is not necessarily doing so due to a lack of forethought or carelessness, but rather due to aversion to risk (i.e., uncertainty in payoff) or loss.

What has emerged from the literature is that individuals with NSSI seem to make worse, less adaptive decisions than those without NSSI in risky decision tasks including the Iowa Gambling Task (21), Cambridge Gambling Task (24), and

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Balloon Analog Risk Task (BART) (22). This motivates us to consider NSSI behaviors as the result of risky decision making (23), through which perspective, individuals with NSSI would evaluate various emotion-coping options, each with its own set of risks, rewards, and losses. For these individuals, the potential benefits (e.g., emotional relief) of self-harm effectively outweigh its physical and psychological costs (e.g., pain and shame) (25), and they prefer it over less harmful solutions that nevertheless come with uncertain levels of risk, such as the challenges of potential stigma and accessibility issues (26,27). However, previous studies examining risky decision making have often yielded inconsistent results in differentiating between individuals with and without NSSI (17,22,24,28). One reason for these mixed findings could be the inherent stochasticity of risky decision tasks, where different choices lead to variable experiences and thus exert different influences on subsequent decision behaviors, rendering simple behavioral measures less effective in capturing the complexity of individuals' decision characteristics. Furthermore, the frequent comorbidity of NSSI with conditions such as depression (29–31) adds another layer of complexity, potentially confounding the interpretation of the findings. Research on depression (which often overlooks NSSI comorbidity) also has yielded mixed findings: depressive mood decreases an individual's risk aversion (32), but patients with depression may exhibit different risk preferences in different risky decision tasks, such as lower risk aversion in the Iowa Gambling Task but higher risk aversion in the BART (33). These limitations highlight the necessity of using more advanced methods to understand the characteristics of NSSI-related decisions.

In the current study, we investigated individuals with major depressive disorder (MDD; also abbreviated as D) exhibiting at least one episode of NSSI behavior within the past year (D+NSSI), contrasting them with MDD individuals without NSSI (D−NSSI) and healthy control (HC) participants. Our approach involved the use of the BART (34) alongside computational modeling to provide a comprehensive understanding of NSSI-related decision characteristics and their modulation by depression. The BART simulates real-world risk-taking behavior by requiring participants to pump a virtual balloon for potential rewards (33). It not only assesses attitudes toward risk and loss, as is widely known, but also delves into broader cognitive dimensions such as prior beliefs about risk, learning from outcomes, and behavioral consistency under risk and uncertainty. In contrast, neither the Cambridge Gambling Task nor the Iowa Gambling Task assesses prior beliefs about risk. Additionally, the Cambridge Gambling Task cannot probe learning about risk from experience because the risk is explicitly stated as part of the decision problem. Using computational modeling, we were able to disentangle these distinct cognitive dimensions from participants' decision behaviors by estimating the model parameters for each group using the hierarchical Bayesian method. Furthermore, we developed a novel statistical method to isolate the effects of NSSI, depression level, and their interaction on model parameters. This allowed us to unravel the complex interplay of NSSI and depression in shaping individual decision characteristics, thereby offering insights that would have been unattainable otherwise.

The existing literature did not allow us to fully predict the results of our study. One previous study used the BART in adolescents with or without an NSSI history (22) and found that the former made fewer pumps, which the authors interpreted as risk aversion. We hypothesized that patients with MDD who engage in NSSI behaviors would be likely to display comparable patterns of risk aversion and expect that depressive symptoms would interact with NSSI behaviors in risk-related cognitive components such as risk aversion, loss aversion, and prior belief of risk.

METHODS AND MATERIALS

Participants

From April 2022 to September 2023, we recruited 101 Chinese-speaking patients with depression from Peking University Sixth Hospital, including 48 outpatients and 53 inpatients. This cohort included 58 cases (43 inpatients and 15 outpatients) who had engaged in NSSI behaviors at least once during the past 12 months (D+NSSI) and 43 cases (10 inpatients and 33 outpatients) without NSSI behaviors (D). Additionally, 157 HC participants were recruited from 2 universities. All participants completed a custom-made questionnaire designed to collect detailed self-reported information on the presence and frequency of NSSI behaviors. All D+NSSI participants had engaged in NSSI behaviors at least once during the past 12 months, whereas all D and HC participants had no history of self-injury during their lifetime. After quality control, 241 participants were included in the final data analysis. See the Supplement for additional criteria for patient inclusion and exclusion and quality control details. The study was approved by the medical ethics committee of Peking University Sixth Hospital (ethics review No. 39 of 2021), and all participants provided informed consent.

Following previous studies (35), we used the term NSSI generally to refer to individuals who engaged in NSSI behaviors during the past year instead of more specifically to individuals with a separate diagnosis of NSSI disorder according to the DSM-5 criteria (36). Nevertheless, supplementary analyses were performed to compare the subsets of participants who engaged in NSSI behaviors for at least 5 episodes versus those with <5 episodes in the past 12 months (n = 30 for D+NSSI$^{\geq 5}$ and n = 27 for D+NSSI$^{<5}$).

Psychiatric Assessment

The Zung Self-Rating Depression Scale (SDS) (37) and Zung Self-Rating Anxiety Scale (38) were used to assess depression and anxiety levels, and raw scores were used. The SDS and Zung Self-Rating Anxiety Scale are both 20-item scales. Raw scores of 40 and 36 are typically considered indicative of clinical depression and anxiety, respectively (39,40). All assessments used Chinese versions of the scales, which were translated and validated for reliability and validity (41).

Task and Design

On each trial of the BART (Figure 1A), participants saw a virtual balloon on the screen and decided whether to pump (potentially increasing reward points) or collect points and end the trial. Each pump could increase the balloon's size and thus the

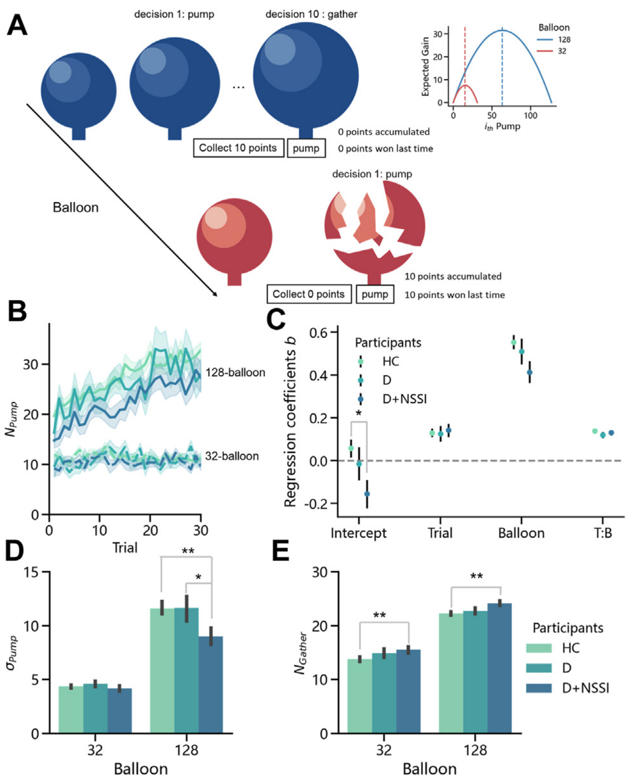

Figure 1. Balloon Analog Risk Task and behavioral measures for the 3 groups of participants. **(A)** Schematic representation of the Balloon Analog Risk Task, where at each moment, participants choose to either pump the balloon to potentially accumulate one more reward point or to collect their accumulated points. If the balloon pops, the reward points accumulated for the balloon would be lost. The risk of balloon popping increases with each pump and varies with the color of the balloon. A new balloon starts after the old balloon popped or points were collected. Each participant completed 30 red and 30 blue balloons (trials) in a random order. Inset at top right: expected gain as a function of the number of pumps. The optimal numbers for the 2 balloon types (max pump before popping: 32 and 128), as indicated by the dashed vertical lines, are 16 and 64, respectively. **(B–E)** The behavioral measures for the 3 groups of participants (N = 241). Color codes: light green indicates 142 healthy control (HC) participants, blue-green indicates 42 participants with major depressive disorder but no nonsuicidal self-injury (NSSI) behavior (D), and dark-blue indicates 57 participants with major depressive disorder and NSSI (D+NSSI). **(B)** How the mean number of pumps in non-popping trials (N_{pump}) changed over trials. Curves in dashed lines and solid lines are for the balloon types 32 and 128, respectively. Shadings denote 1 SE. **(C)** Results of the linear mixed-effects model analysis on N_{pump} predicted by group (intercept), trial, balloon, and the interaction of trial by balloon (T:B). The standardized coefficient b is plotted separately for each group (color coded). Error bars represent 1 SE of the coefficients. **(D)** SD of N_{pump} across trials (σ_{pump}) for each balloon type and participant group. **(E)** The number of nonpopping (i.e., reward gathered) trials (N_{gather}) for each balloon type and participant group. Error bars denote 1 SE. *$p < .05$, **$p < .01$. The asterisks in panel **(E)** indicate a main effect between the HC and D+NSSI groups, regardless of the balloon type.

number of reward points by 1, but with the risk of popping the balloon and nullifying the points. Thus, each trial presented a gamble between potential reward and loss. Each participant completed 60 trials of 30 red and 30 blue balloons, initially not knowing which color represented a higher risk. The higher-risk color would pop after 1 to 32 pumps (32-balloon) while the lower-risk color would pop after 1 to 128 pumps (128-balloon). Thus, the number of pumps that maximized expected reward were 16 and 64 for the 32- and 128-balloons, respectively (Figure 1A, inset). Including these 2 different levels of risk in the experimental design allowed us to infer participants' prior beliefs and learning as well as their attitudes toward loss and risk from their pumping decisions. See the Supplement for more details.

Statistical Analysis

We conducted the following linear mixed-effects model (LMM) analysis of the number of pumps, N_{pump}, in the nonpopping trials to test the potential influence of MDD and NSSI behavior on participants' decisions:

$$N_{pump} \backsim 1 + B * Group + (1 + h + B|participant) \quad (1)$$

where B denotes the balloon type (-1 for 32-balloon and 1 for 128-balloon), h is the index of the balloon in the experiment, and Group denotes categorical variables for the 3 participant groups (HC, D, and D+NSSI). The $(\cdot|participant)$ denotes the random-effects terms that vary across participants. To further examine the potential different effects of $\text{NSSI}^{<5}$ versus $\text{NSSI}^{\geq 5}$, we conducted another LMM analysis:

$$N_{pump} \backsim 1 + B * Group^4 + (1 + h + B|participant) \quad (2)$$

where $Group^4$ denotes 4 participant groups (HC, D, D+$\text{NSSI}^{\geq 5}$, and D+$\text{NSSI}^{<5}$). All data were normalized at the group level before entering LMMs. All LMMs were implemented in R, version 4.0.3.

Computational Modeling

The Model. The computational model that we used to fit participants' decision behaviors on the BART (illustrated in Figure 2A), the exponential-weight mean–variance with variance standardization (EWMV–VS) model, is an adaptation of the EWMV model of Park *et al.* (42) to improve the reliability of parameter estimation (see the Supplement for the model definition and its comparison with alternative models).

Effects-on-Parameters Analysis. To assess the joint effects of NSSI and depression severity on individuals' decision characteristics, we developed an effects-on-parameters analysis (EPA). Specifically, we built a hierarchical Bayesian model based on EWMV-VS, where each of the 5 parameters of EWMV-VS is generated from a linear combination of NSSI (coded as a binary variable of with or without NSSI behaviors), SDS score, and their interaction term. The 15 coefficients were then estimated from participants' choice data via hierarchical Bayesian modeling. For control analyses, we added age and number of years of education as regressors to the group-level linear model. SDS, age, and number of years of education were normalized before being entered into the model.

RESULTS

Demographic and Clinical Characteristics

A total of 241 participants were included in the data analysis, including 142 HC participants and 99 patients diagnosed with

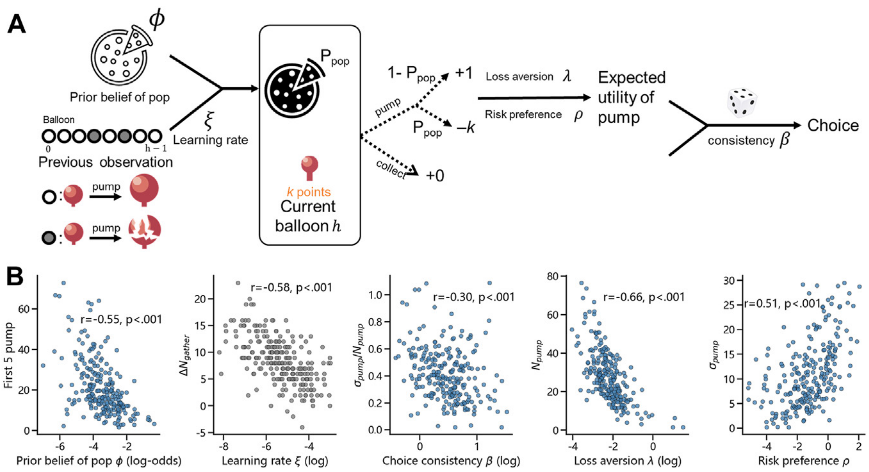

Figure 2. The computational model and the behavioral implications of its parameters. **(A)** Illustration of the computational model used to simulate participant decisions in the Balloon Analog Risk Task. The model agent integrates its prior belief of balloon popping (φ) with previous observations up to the last trial (i.e., balloon $h-1$), resulting in the updated belief of P_{pop}. How fast the prior belief is updated by increasing observations is determined by the learning rate (ξ). For the current balloon h that has accumulated k points, the agent is now faced with the decision of either pumping to gain 1 more point but with a chance of P_{pop} losing all k points or collecting the points. The agent's loss aversion (λ) and risk preference (ρ) contribute to its expected utility of pumping the balloon. The probability of choosing pumping is further modulated by the agent's choice consistency (β). **(B)** Scatter plots showing how individuals' model parameters (prior belief of pop φ, learning rate ξ, choice consistency β, loss aversion λ, and risk preference ρ) correlated with their behavioral measures in the Balloon Analog Risk Task. First 5 pump refers to the mean number of pump in the first 5 trials of the 128-balloons, which reflects the individual's prior belief of pop. ΔN_{gather} refers to the difference in the number of reward-gathered trials (N_{gather}) between the 128- and 32-balloons, which reflects how much the individual learns from experience. The N_{pump} and σ_{pump}, as in Figure 1, respectively, refer to the mean and standard deviation of the number of pumps, which and the combination of which are closely related to loss aversion, risk preference, and choice consistency. Data points are color coded to indicate whether the behavioral measure is elicited from the 128-balloons (in gray-blue) or the difference between the 128- and 32-balloons (in gray). Each dot denotes one individual participant. The correlation coefficient (r) and p value on each panel is based on Pearson correlations.

MDD, among whom were 57 cases with comorbid NSSI (D+NSSI) who exhibited at least 1 episode of NSSI behaviors during the past 12 months and 42 who reported no history of NSSI during their lifetime (D). Participants' gender, age, number of years of education, and self-reported anxiety and depression were measured (Table 1). Because anxiety is highly comorbid with depression (43), there was a high correlation between the SDS and Zung Self-Rating Anxiety Scale scores in our participants with MDD (Pearson's $r = 0.893$, $p < .001$), which made their effects practically undistinguishable. Therefore, we only report the effects of SDS.

Group Differences in Behavioral Measures

Group Differences in N_{pump}. Following the common practice of the BART (34), a primary behavioral measure that we used is participants' number of pumps in nonpopping trials (denoted N_{pump}). Consistent with classic findings, at both levels of risk, participants pumped much less than the optimal number of pumps (Figure 1B, C). When we plotted how the mean N_{pump} of each participant group changed over trials (Figure 1B), we observed differences between different groups as well as trends in learning, at least for the 128-balloons. An LMM analysis was performed on N_{pump} to identify the effects of participant group (intercept in Figure 1C), balloon type, and trial number and their interactions. This LMM analysis showed a significant main effect of participant group ($F_{2,235.63} = 3.68$, $p = .027$). Post hoc analysis (multicomparison-corrected) indicated that the D+NSSI group pumped fewer than the HC group ($b = -0.213$; SE = 0.078; $p_{\text{Holm}} = .020$; 95% CI, -0.401 to -0.025). There were no significant interactions between participant group and either balloon type or trial number.

Learning Effects. We also observed significant learning effects for all groups. The mean N_{pump} for 128-balloons was larger than that for 32-balloons ($F_{1,232.18} = 296.01$, $p < .001$). As the experiment proceeded, participants' N_{pump} increased overall ($F_{1,231.74} = 57.98$, $p < .001$) and changed differently by different balloon type (T:B in Figure 1C) and the interaction of balloon type and trial number ($F_{1,8466.29} = 340.76$, $p < .001$), with the N_{pump} increasing over trials for 128-balloons (simple

Table 1. Demographic and Clinical Characteristics of Study Participants

Characteristic	Total, $N = 241$	HC, $n = 142$	D, $n = 42$	D+NSSI, $n = 57$	χ^2/F	p Value	Effect Size
Gender							
Female	163 (67.6%)	93 (65.5%)	26 (61.9%)	44 (77.2%)	$\chi^2_2 = 3.306$	.191	$V = 0.017$
Male	78 (32.4%)	49 (34.5%)	16 (38.1%)	13 (22.8%)			
Age, Years	19.80 ± 2.36	19.30 ± 2.05	21.10 ± 2.57	20.09 ± 2.54	$F_{2,238} = 10.803$	<.001	$\eta^2 = 0.083$
Education, Years	13.49 ± 2.11	13.11 ± 1.77	14.43 ± 2.49	13.75 ± 2.36	$F_{2,238} = 7.313$	<.001	$\eta^2 = 0.058$
SAS Score	39.66 ± 14.69	31.33 ± 6.30	45.90 ± 12.46	55.82 ± 15.48	$F_{2,238} = 123.718$	<.001	$\eta^2 = 0.510$
SDS Score	45.34 ± 16.83	34.93 ± 8.00	51.90 ± 11.56	66.42 ± 13.96	$F_{2,238} = 198.908$	<.001	$\eta^2 = 0.626$

Demographic variables and scale scores are shown as n (%) or mean ± SD. Cramér's V refers to the effect size for χ^2 test, and η^2 refers to the effect size for analysis of variance.

D, major depressive disorder; HC, healthy control; NSSI, nonsuicidal self-injury; SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale.

main effect, b = 0.261; SE = 0.018; $p < .001$; 95% CI, 0.225–0.296) but staying constant for 32-balloons. We did not find significant differences between groups in the learning effects (interaction of group by trial number, $F_{2,231.84}$ = 0.07, p = .94).

Group Differences in σ_{pump} and N_{gather}. To provide a more comprehensive behavioral measurement of participants' decision characteristics on the BART, we also calculated the standard deviation of N_{pump} across trials (denoted σ_{pump}) and the number of nonpopping (i.e., reward-gathered) trials (denoted N_{gather}) for each balloon type and participant group (Figure 1D, E). Mixed-design analyses of variance for these 2 measures showed a significant participant group by balloon type interaction for σ_{pump} ($F_{2,238}$ = 3.10, p = .047, η_p^2 = 0.025), whereas no significant interaction was observed for N_{gather} ($F_{2,238}$ = 0.476, p = .622, η_p^2 = 0.004). We also observed significant main effects of participant group on σ_{pump} ($F_{2,238}$ = 3.39, p = .035, η_p^2 = 0.028) and N_{gather} ($F_{2,238}$ = 4.88, p = .008, η_p^2 = 0.039) in addition to the obvious differences between different balloon types ($F_{1,238}$ = 187.33, $p < .001$, η_p^2 = 0.440 for σ_{pump} and $F_{1,238}$ = 679.75, $p < .001$, η_p^2 = 0.741 for N_{gather}). According to the simple main effects, participants in different groups had significantly different σ_{pump} for 128-balloons ($F_{2,238}$ = 3.44, p = .034), but not for 32-balloons ($F_{2,238}$ = 0.73, p = .484) (Figure 1D). Furthermore, post hoc comparisons indicated that for 128-balloons, participants in the D+NSSI group had smaller σ_{pump} than participants in both the HC (difference mean = −2.634, SE = 0.761, t_{238} = −3.46, p_{Holm} = .004) and D (difference mean = 2.647, SE = 0.987, t_{238} = −2.68, p_{Holm} = .038) groups. Compared with the HC group, participants in the D+NSSI group also had larger N_{gather} (difference mean = 1.844, SE = 0.597, t_{238} = 3.09, p_{Holm} = .007) (Figure 1E).

Together, these behavioral measures of the BART suggest that the HC, D, and D+NSSI groups had distinct decision patterns, although all groups similarly learned from their experiences. Findings were comparable when age or number of years of education was controlled for in these models (see Supplemental Statistical Analysis). Because all behavioral measures are the joint consequence of multiple cognitive components (e.g., learning, risk attitude), the underlying cognitive differences remained elusive. We disentangle the cognitive dimensions below with the help of computational modeling.

Five Cognitive Dimensions Decomposed by the Computational Model

The computational model that we used to fit participants' decision behaviors is an adaptation of the EWMV model of Park *et al.* (42) termed EWMV-VS (see Methods and Materials), which outperforms its precedent in predictive power (see Table S1) and has good parameter recovery performance (Figure S1).

When fitted to participants' decision behaviors, the 5 parameters of the EWMV-VS model—prior belief of pop φ, learning rate ξ, choice consistency β, loss aversion λ, and risk preference ρ—can thus represent participants' characteristics on 5 distinct cognitive dimensions (see Figure 2A for details). Some of these model parameters have intuitive behavioral implications, as indicated by the correlations between individual participants' model parameters and their behavioral measures (Figure 2B).

Revealing Group-Level Cognitive Differences: Hierarchical Bayesian Modeling

To assess differences in each cognitive dimension across the 3 groups, we fit the EWMV-VS model to participants' decision behaviors using hierarchical Bayesian modeling (see the Supplement). Among the 5 parameters (Figure 3A), we observed significant group differences in the parameters of choice consistency and risk preference. In particular, choice consistency decreased in the patients with depression alone (i.e., the D group); both the D+NSSI (difference mean = 0.24; 95% highest density interval [HDI], 0.03–0.44) and HC (difference mean = 0.19; 95% HDI, 0.02–0.36) groups exhibited higher choice consistency. The D+NSSI group also had a lower risk preference than the HC group (difference mean = −0.75; 95% HDI, −1.5 to −0.029), indicating a more cautious approach to risk taking.

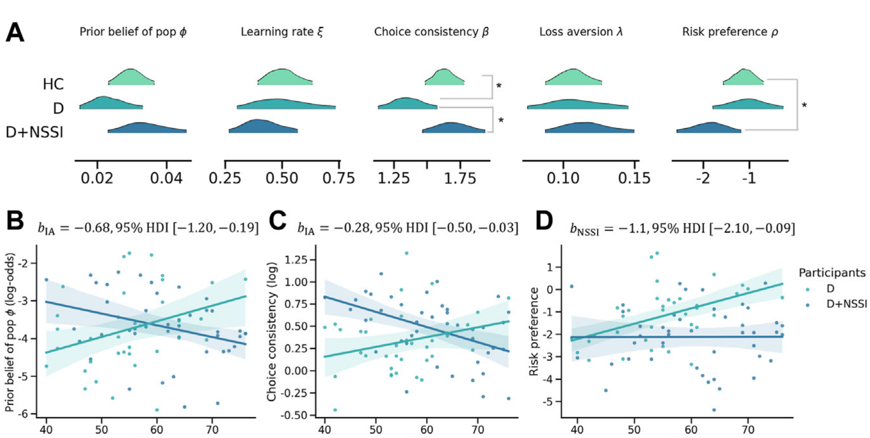

Figure 3. Estimated model parameters for different participant groups. **(A)** The 95% highest density interval (HDI) of the posterior density of the group-level model parameters estimated from hierarchical Bayesian model fitting. Significant differences between groups were found for choice consistency (β) and risk preference (ρ). **(B–D)** The joint effects of nonsuicidal self-injury (NSSI) and depression severity (as measured by the Self-Rating Depression Scale [SDS]) on model parameters, where the participants in analysis were limited to the major depressive disorder–only (D) and D+NSSI groups with an overlapping range of SDS. Each dot denotes 1 individual participant. The shading on the regression line denotes the 95% HDI. **(B)** Interaction (b_{IA}) between NSSI and SDS on prior belief of pop (φ). Higher depression severity was associated with a lower belief in pop likelihood for the NSSI group, while the reverse was true for the non-NSSI group. **(C)** Interaction (b_{IA}) between NSSI and SDS on choice consistency (β). Higher depression severity was associated with less consistent choices in the NSSI group, while the reverse was true for the non-NSSI group. **(D)** Main effect of NSSI (b_N) for risk preference (ρ). The NSSI group was less tolerant of risk than the non-NSSI group. The asterisk (*) denotes that the 95% HDI of the group difference did not contain 0 (similar to .05-level significant differences in the frequentist statistics such as t tests). HC, healthy control.

These findings, rooted in our model analysis, echo the behavioral patterns described earlier, specifically the reduced variability in the number of pumps (σ_{pump}) among the D+NSSI group (Figure 1D). While behavioral data alone may suggest that this decreased variation could stem from diminished learning, implying more uniform behavior from early to late trials, our model-based analysis mostly rules out this possibility.

Unraveling the NSSI and Depression Interplay: EPA

We noted that the D+NSSI group had significantly higher depression severity than the D group (as indicated by the SDS score in Table 1) despite both groups being diagnosed with MDD and the majority having SDS scores above the cutoff point for clinical significance (44). To distinguish the impact of NSSI behavior from depression severity, we combined 2 strategies. First, we selected the participants from the D and D+NSSI groups whose SDS fell into an overlapping range (SDS range 39–76 with 37 D participants and 44 D+NSSI participants) (see Table 2). Second, we developed a novel EPA (see Methods and Materials), which includes NSSI, SDS, and their interaction as linear predictors of the EWMV-VS model's parameters in hierarchical Bayesian modeling, providing a granular view of their joint effects on individuals' decision characteristics.

When we applied EPA to the 81 participants' decision data, we found that NSSI was still associated with a decrease in risk preference (mean = −1.1; 95% HDI, −2.1 to −0.09) even when depression severity was controlled for (Figure 3D). SDS had no significant main effect on risk preference and no interaction with NSSI. NSSI and SDS jointly influenced the prior belief of pop and choice consistency in a more complicated way, showing as interaction effects. Specifically, the prior belief of pop increased with SDS for the participants with depression only but decreased with SDS for those with NSSI behaviors (mean = −0.68; 95% HDI, −1.2 to −0.19) (Figure 3B). Choice consistency rose with SDS scores among the participants with depression only but fell among those with NSSI (mean = −0.28; 95% HDI, −0.5 to −0.03) (Figure 3C). These effects were robust because they were similar when the effects of age and number of years of education were controlled for (Figures S2 and S3).

In sum, participants with NSSI behaviors were more risk averse. However, unlike participants with depression only, as their depressive symptoms intensified, these participants demonstrated a decreased prior belief of pop and lower choice consistency, implying a perception of the environment as less risky and a tendency toward more random choices.

Similar Decision Behaviors in MDD Patients With NSSI$^{<5}$ and NSSI$^{\geq5}$

The D+NSSI group in our analyses described above comprised cases with varying frequencies of NSSI. To test the possibility that they may have had different decision characteristics, we performed supplementary analyses in which the D+NSSI group was divided into 2 subgroups according to self-reported NSSI frequency during the past 12 months, denoted as D+NSSI$^{<5}$ and D+NSS$^{\geq5}$ (27 and 30 participants, respectively).

In Figure 4A, we visualized how the mean number of pumps in nonpopping trials (N_{pump}) changed over trials for the 4 groups. To examine the effects of NSSI$^{<5}$ versus NSSI$^{\geq5}$, we first performed an LMM analysis on N_{pump} similarly as before, except that the regressor of participant group included 4 instead of 3 categories (see Methods and Materials). All the significant effects identified in the previous LMM were replicated in this new LMM (Figure 4B) (see the Supplement for details). Hierarchical Bayesian modeling analysis for the 4 participant groups also suggested that the NSSI$^{<5}$ and NSSI$^{\geq5}$ groups had similar model parameters (Figure 4C and Table S2). A further modeling analysis that compared a 3-group model to a 4-group model (see the Supplement and Table S3) also provides support for this lack of differences.

DISCUSSION

Our finding that individuals with NSSI behaviors were more risk averse instead of more impulsive as is commonly perceived is consistent with the findings of Dillahunt *et al.* (22), who found that adolescents with a history of self-injury made fewer pumps on the BART. Despite being seemingly counterintuitive, there has been other evidence that NSSI behaviors may be associated with risk aversion (45,46). Such risk aversion can be understood from the perspective of the way that NSSI serves as an emotional regulation mechanism (47). Individuals engaging in NSSI often seek relief from intense negative emotions or aim to achieve a positive emotional state, suggesting a controlled (i.e., less risky), although maladaptive, response to distress. In contrast, pumping the balloons in the BART produces less controlled (i.e., riskier) outcomes. This mirrors their preference for self-injury, a harmful but certain means of emotional relief, over less harmful coping strategies with uncertain (risky) outcomes. Furthermore, our analysis revealed reduced exploratory behavior in individuals with NSSI characterized by smaller variations in balloon pumps (σ_{pump}) and higher choice consistency (β) without an impairment in

Table 2. Participants Included in the Effects-on-Parameters Analysis

Characteristic	Total, N = 81	D, n = 37	D+NSSI, n = 44	χ^2/t	p Value	Effect Size
Gender						
Female	58 (71.6%)	23 (62.2%)	35 (79.5%)	χ^2_1 = 2.987	.084	V = 0.192
Male	23 (28.4%)	14 (37.8%)	9 (20.5%)			
Age, Years	20.85 ± 2.52	21.00 ± 2.63	20.73 ± 2.44	t_{79} = −0.484	.630	d = −0.108
Education, Years	14.27 ± 2.38	14.24 ± 2.49	14.30 ± 2.32	t_{79} = 0.098	.922	d = 0.022
SAS Score	49.22 ± 11.74	47.97 ± 11.61	50.27 ± 11.87	t_{79} = 0.877	.383	d = 0.196
SDS Score	58.09 ± 9.96	54.81 ± 8.81	60.84 ± 10.12	t_{79} = 2.832	.006	d = 0.632

Demographic variables and scale scores are shown as n (%) or mean ± SD. Cramér's V refers to the effect size for χ^2 test, and d refers to Cohen's d effect size for t test.
D, major depressive disorder; NSSI, nonsuicidal self-injury; SAS, Self-Rating Anxiety Scale; SDS, Self-Rating Depression Scale.

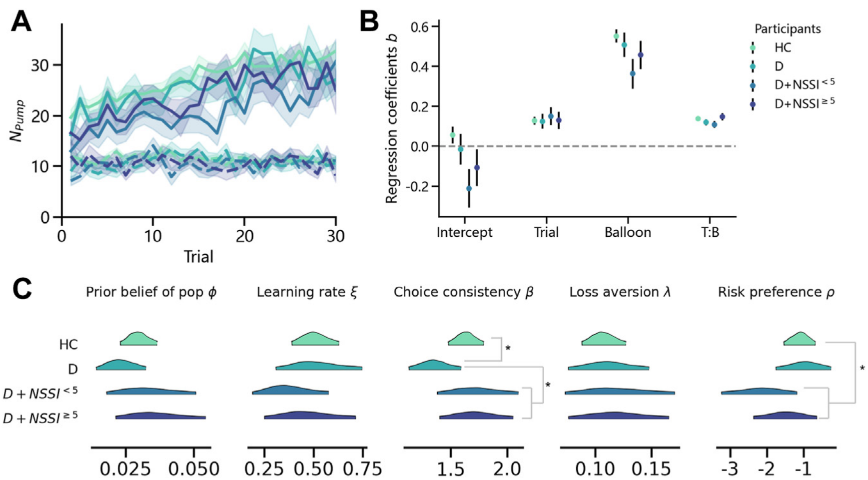

Figure 4. Behavioral measures and estimated model parameters for 4 participant groups. **(A)** How the mean number of pumps in nonpopping trials (N_{pump}) changed over trials for 4 participant groups. Curves in dashed lines and solid lines are for the balloon types 32 and 128, respectively. Shadings denote 1 SE. **(B)** Linear mixed-effects model results. *b* is the standardized coefficient of the linear mixed-effects model. Error bars represent 1 SE of the coefficients. **(C)** The 95% highest density interval of the posterior density of the group-level model parameters estimated from hierarchical Bayesian model fitting. The asterisk (*) denotes that the 95% highest density interval of the group difference did not contain 0 (similar to .05-level significant differences in the frequentist statistics such as *t* tests). No significant differences were found for the parameters of D+NSSI$^{<5}$ and D+NSSI$^{\geq5}$ groups. Asterisks on the left or right side of an ensemble of coefficients in panel **(B)** denote significant deviations from 0 for all these coefficients. *$p < .05$. D+NSSI, major depressive disorder and nonsuicidal self-injury; HC, healthy control; T:B, trial by balloon.

learning rate (ξ). Both the aversion to risk and decreased exploration reflect limited adaptive coping strategies (12).

Contrary to previous reports of risk aversion using the BART in individuals with depression (33), we did not observe fewer balloon pumps among individuals with depression only in the current study. This discrepancy underscores the necessity of accounting for sample heterogeneity given that NSSI was not examined in prior research on depression. The EPA that we developed enabled us to further disentangle the effects of NSSI and depression, revealing an interaction effect between prior belief of risk and choice consistency. Choice consistency is related to random exploration, which has been reported to be lower in patients with depression (48). Such intricate interplay between NSSI and depression may have led to the controversial results documented in previous studies (17). Furthermore, given the strong predictive value of NSSI for future suicidal behavior (8,9), managing depressive symptoms in individuals with NSSI could be a key preventive measure.

Previous research suggests that risk taking differs between younger and older adults (49) and that adolescents are more likely to engage in risky behaviors than adults (50,51). The age range in our study was relatively narrow but covered mid to late adolescence to young adulthood. Considering the significant (though small) differences between groups in age, we included age and educational level, which is highly correlated with age, as confounding variables in supplementary modeling analysis to remove their potential impact, where our major findings still hold. In addition, despite being younger than the D group, the D+NSSI group exhibited stronger risk aversion, which is in the reverse direction from that of the age-related effects suggested by previous research. Therefore, the likelihood of our findings being age driven is relatively low.

The following limitations of the current study may be addressed in future research. First, due to time constraints of outpatient visits, we did not diagnose borderline personality disorder (BPD), a condition in which NSSI is prevalent (3,30), and therefore, we did not exclude potential patients with BPD from our study. According to an epidemiologic survey in China, approximately 11.49% of 258 outpatient cases with MDD met the diagnosis criteria for BPD (52). Thus, the estimated number of potential BPD cases in our patient cohort is approximately 5 to 6. Although this number is small, controlling for BPD comorbidity would be ideal for future research. Second, although no significant differences were observed between the NSSI$^{<5}$ and NSSI$^{\geq5}$ groups, our findings may not necessarily apply to the persistence of NSSI behaviors that can lead to significant functional impairment. Expanding the study to include a larger sample (including individuals with NSSI behaviors but without mental disorder) and structured scales for assessing the frequency and severity of NSSI would enhance the robustness of the findings. Additionally, the prevalence of NSSI behavior is generally higher among adolescent girls than adolescent boys (53,54). Females reported significantly greater psychological distress and lower levels of sensation seeking and positive urgency than males (54). While no conclusive link has been established between NSSI behaviors and gender, further exploration of demographic factors such as gender and age could provide deeper insights.

Conclusions

NSSI behaviors manifest a general aversion to risk. However, as depressive symptom severity increases, individuals perceive a decrease in environmental risks and demonstrate more unpredictable behaviors. This suggests a complex interaction between depressive symptoms and NSSI behaviors in decision making. On the one hand, overestimating risks in unfamiliar environments may diminish the likelihood of exploring alternative means to cope with emotions. On the other hand, depression amplifies engagement in risky behaviors.

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REFERENCES

1. Lim K-S, Wong CH, McIntyre RS, Wang J, Zhang Z, Tran BX, *et al.* (2019): Global lifetime and 12-month prevalence of suicidal behavior, deliberate self-harm and non-suicidal self-injury in children and adolescents between 1989 and 2018: A meta-analysis. Int J Environ Res Public Health 16:4581.
2. Glenn CR, Klonsky ED (2013): Nonsuicidal self-injury disorder: An empirical investigation in adolescent psychiatric patients. J Clin Child Adolesc Psychol 42:496–507.
3. Skegg K (2005): Self-harm. Lancet 366:1471–1483.
4. Haw C, Hawton K, Houston K, Townsend E (2001): Psychiatric and personality disorders in deliberate self-harm patients. Br J Psychiatry 178:48–54.
5. Yan H, Zhang Y, Lu Z, Li M, Ge Y, Mei D, *et al.* (2023): High-risk group and functional subtypes of non-suicidal self-injury in young adults with mental disorders. Front Psychiatry 14:1098178.
6. Swannell SV, Martin GE, Page A, Hasking P, St John NJ (2014): Prevalence of nonsuicidal self-injury in nonclinical samples: Systematic review, meta-analysis and meta-regression. Suicide Life Threat Behav 44:273–303.
7. Plener PL, Kaess M, Schmahl C, Pollak S, Fegert JM, Brown RC (2018): Nonsuicidal self-injury in adolescents. Dtsch Ärztebl Int 115:23–30.
8. Barrocas AL, Jenness JL, Davis TS, Oppenheimer CW, Technow JR, Gulley LD, *et al.* (2011): Developmental perspectives on vulnerability to nonsuicidal self-injury in youth. Adv Child Dev Behav 40:301–336.
9. Mars B, Heron J, Klonsky ED, Moran P, O'Connor RC, Tilling K, *et al.* (2019): Predictors of future suicide attempt among adolescents with suicidal thoughts or non-suicidal self-harm: A population-based birth cohort study. Lancet Psychiatry 6:327–337.
10. O'Connor RC, Kirtley OJ (2018): The integrated motivational–volitional model of suicidal behaviour. Philos Trans R Soc B Biol Sci 373:20170268.
11. Favazza AR (1998): The coming of age of self-mutilation. J Nerv Ment Dis 186:259–268.
12. Ge Y, Xiao Y, Li M, Yang L, Song P, Li X, Yan H (2023): Maladaptive cognitive regulation moderates the mediating role of emotion dysregulation on the association between psychosocial factors and non-suicidal self-injury in depression. Front Psychiatry 14:1279108.
13. Hasking P, Whitlock J, Voon D, Rose A (2017): A cognitive-emotional model of NSSI: Using emotion regulation and cognitive processes to explain why people self-injure. Cogn Emot 31:1543–1556.
14. Perez J, Venta A, Garnaat S, Sharp C (2012): The difficulties in Emotion Regulation Scale: Factor structure and association with nonsuicidal self-injury in adolescent inpatients. J Psychopathol Behav Assess 34:393–404.
15. Wolff JC, Thompson E, Thomas SA, Nesi J, Bettis AH, Ransford B, *et al.* (2019): Emotion dysregulation and non-suicidal self-injury: A systematic review and meta-analysis. Eur Psychiatry 59:25–36.
16. Nock MK, Mendes WB (2008): Physiological arousal, distress tolerance, and social problem-solving deficits among adolescent self-injurers. J Consult Clin Psychol 76:28–38.
17. Hamza CA, Willoughby T, Heffer T (2015): Impulsivity and nonsuicidal self-injury: A review and meta-analysis. Clin Psychol Rev 38:13–24.
18. Patton JH, Stanford MS, Barratt ES (1995): Factor structure of the barratt impulsiveness scale. J Clin Psychol 51:768–774.
19. Whiteside SP, Lynam DR (2001): The Five Factor Model and impulsivity: Using a structural model of personality to understand impulsivity. Pers Individ Dif 30:669–689.
20. Cassels M, Neufeld S, van Harmelen A-L, Goodyer I, Wilkinson P (2022): Prospective pathways from impulsivity to non-suicidal self-injury among youth. Arch Suicide Res 26:534–547.
21. Allen KJD, Fox KR, Schatten HT, Hooley JM (2019): Frequency of nonsuicidal self-injury is associated with impulsive decision-making during criticism. Psychiatry Res 271:68–75.
22. Dillahunt AK, Feldman DA, Thomas LR, Farstead BW, Frandsen SB, Lee S, *et al.* (2022): Self-injury in adolescence is associated with greater behavioral risk avoidance, not risk-taking. J Clin Med 11:1288.
23. Platt ML, Huettel SA (2008): Risky business: The neuroeconomics of decision making under uncertainty. Nat Neurosci 11:398–403.
24. Lutz NM, Chamberlain SR, Goodyer IM, Bhardwaj A, Sahakian BJ, Jones PB, Wilkinson PO (2022): Behavioral measures of impulsivity and compulsivity in adolescents with nonsuicidal self-injury. CNS Spectr 27:604–612.
25. Hooley JM, Franklin JC (2018): Why do people hurt themselves? A new conceptual model of nonsuicidal self-injury. Clin Psychol Sci 6: 428–451.
26. Park Y, Mahdy JC, Ammerman BA (2021): How others respond to non-suicidal self-injury disclosure: A systematic review. J Community Appl Soc Psychol 31:107–119.
27. Linehan MM, Korslund KE, Harned MS, Gallop RJ, Lungu A, Neacsiu AD, *et al.* (2015): Dialectical behavior therapy for high suicide risk in individuals with borderline personality disorder: A randomized clinical trial and component analysis. JAMA Psychiatry 72:475–482.
28. Schatten HT, Andover MS, Armey MF (2015): The roles of social stress and decision-making in non-suicidal self-injury. Psychiatry Res 229:983–991.
29. Wilkinson P, Kelvin R, Roberts C, Dubicka B, Goodyer I (2011): Clinical and psychosocial predictors of suicide attempts and nonsuicidal self-injury in the Adolescent Depression Antidepressants and Psychotherapy Trial (ADAPT). Am J Psychiatry 168:495–501.
30. Zubrick SR, Hafekost J, Johnson SE, Sawyer MG, Patton G, Lawrence D (2017): The continuity and duration of depression and its relationship to non-suicidal self-harm and suicidal ideation and behavior in adolescents 12–17. J Affect Disord 220:49–56.
31. Chai Y, Luo H, Wong GHY, Tang JYM, Lam T-C, Wong ICK, Yip PSF (2020): Risk of self-harm after the diagnosis of psychiatric disorders in Hong Kong, 2000–10: A nested case-control study. Lancet Psychiatry 7:135–147.
32. Raghunathan R, Pham MT (1999): All negative moods are not equal: Motivational influences of anxiety and sadness on decision making. Organ Behav Hum Decis Process 79:56–77.
33. Lu J, Zhao X, Wei X, He G (2024): Risky decision-making in major depressive disorder: A three-level meta-analysis. Int J Clin Health Psychol 24:100417.
34. Lejuez CW, Read JP, Kahler CW, Richards JB, Ramsey SE, Stuart GL, *et al.* (2002): Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). J Exp Psychol Appl 8:75–84.
35. Turner BJ, Dixon-Gordon KL, Austin SB, Rodriguez MA, Zachary Rosenthal M, Chapman AL (2015): Non-suicidal self-injury with and without borderline personality disorder: Differences in self-injury and diagnostic comorbidity. Psychiatry Res 230:28–35.

36. American Psychiatric Association (2013): Diagnostic and Statistical Manual of Mental Disorders, 5th ed. Washington, DC: American Psychiatric Association.
37. Zung WWK (1971): A rating instrument for anxiety disorders. Psychosomatics 12:371–379.
38. ZUNG WWK (1965): A Self-Rating Depression Scale. Arch Gen Psychiatry 12:63–70.
39. Dunstan DA, Scott N (2018): Assigning clinical significance and symptom severity using the Zung scales: Levels of misclassification arising from confusion between index and raw scores. Depress Res Treat 2018:9250972.
40. Zung WWK (1973): From art to science. The diagnosis and treatment of depression. Arch Gen Psychiatry 29:328–337.
41. Wang XD (1999): Rating scales for mental health. Chin Ment Health J, rev. ed 122.
42. Park H, Yang J, Vassileva J, Ahn W-Y (2021): Development of a novel computational model for the Balloon Analogue Risk Task: The exponential-weight mean–variance model. J Math Psychol 102:102532.
43. Dozois DJA, Dobson KS, Westra HA (2004): The comorbidity of anxiety and depression, and the implications of comorbidity for prevention. The Prevention of Anxiety and Depression: Theory, Research, and Practice. Washington, DC: American Psychological Association, 261–280.
44. Dunstan DA, Scott N (2019): Clarification of the cut-off score for Zung's Self-Rating Depression Scale. BMC Psychiatry 19:177.
45. Baek K, Kwon J, Chae J-H, Chung YA, Kralik JD, Min J-A, *et al.* (2017): Heightened aversion to risk and loss in depressed patients with a suicide attempt history. Sci Rep 7:11228.
46. Millner AJ, den Ouden HEM, Gershman SJ, Glenn CR, Kearns JC, Bornstein AM, *et al.* (2019): Suicidal thoughts and behaviors are associated with an increased decision-making bias for active responses to escape aversive states. J Abnorm Psychol 128:106–118.
47. Nock MK (2010): Self-injury. Annu Rev Clin Psychol 6:339–363.
48. Wilson RC, Geana A, White JM, Ludvig EA, Cohen JD (2014): Humans use directed and random exploration to solve the explore–exploit dilemma. J Exp Psychol Gen 143:2074–2081.
49. Worthy DA, Gorlick MA, Pacheco JL, Schnyer DM, Maddox WT (2011): With age comes wisdom: Decision making in younger and older adults. Psychol Sci 22:1375–1380.
50. Defoe IN, Dubas JS, Figner B, van Aken MAG (2015): A meta-analysis on age differences in risky decision making: Adolescents versus children and adults. Psychol Bull 141:48–84.
51. Tymula A, Rosenberg Belmaker LA, Roy AK, Ruderman L, Manson K, Glimcher PW, Levy I (2012): Adolescents' risk-taking behavior is driven by tolerance to ambiguity. Proc Natl Acad Sci USA 109:17135–17140.
52. Zheng Y, Severino F, Hui L, Wu H, Wang J, Zhang T (2019): Comorbidity of DSM-IV personality disorder in major depressive disorder among psychiatric outpatients in China: A further analysis of an epidemiologic survey in a clinical population. Front Psychiatry 10:833.
53. Wilkinson PO, Qiu T, Jesmont C, Neufeld SAS, Kaur SP, Jones PB, Goodyer IM (2022): Age and gender effects on non-suicidal self-injury, and their interplay with psychological distress. J Affect Disord 306:240–245.
54. Lutz NM, Neufeld SAS, Hook RW, Jones PB, Bullmore ET, Goodyer IM, *et al.* (2023): Why is non-suicidal self-injury more common in women? Mediation and moderation analyses of psychological distress, emotion dysregulation, and impulsivity. Arch Suicide Res 27:905–921.