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Decision-making impairments according to history of suicide attempt in depression: A computational model analysis

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ABSTRACT

Background: It is well-established that individuals who have attempted suicide present decision-making impairments. However, the underlying constructs that constitute decision-making are still being explored.

Aims: To compare decision-making impairments in patients with a current or past depressive episode based on lifetime suicidal history and current depression.

Methods: 295 patients with current and past depression were recruited and divided into 4 groups according to history of suicide attempt (suicide attempters (SA) or psychiatric controls (PC)) and severity of depression (high or low). The outcome representation learning (ORL) and the Prospect Valence Learning (PVL) models were applied to the Iowa Gambling Task (IGT) to extract estimations of feedback sensitivity, learning and consistency in the decision-making process. We also explored how childhood trauma moderated the relationship between the parameters and suicide.

Results: The optimal model for our sample was the ORL. Among the five ORL parameters, low depressed PC showed lower reward learning and greater forgetfulness than SA, but higher deck perseverance was observed only when compared to high depressed SA. Moreover, punishment learning was able to differentiate SA groups in terms of depression severity. Furthermore, patients with high childhood trauma, high forgetfulness and deck perseverance were more likely to be in the SA cohort.

Conclusion: Suicide attempt may be linked to heightened feedback sensitivity to environmental contingencies, greater decision-making randomness and higher rumination. Moreover, the role of both forgetfulness and deck perseverance in trauma survivors at risk for suicide needs to be further investigated to refine their cognitive profile.

1. Introduction

Suicide is a major public health concern worldwide. In 2019, more than 700,000 people died by suicide, accounting for 1.3% of total deaths (World Health Organization, 2021). Therefore, a better understanding of the causes that drive a person to commit suicide is imperative. The stress-diathesis model (Mann et al., 1999; Van Heeringen and Mann, 2014) proposes that suicidal behaviour results from the interaction between internal or external stressors (e.g. a psychiatric disorder or economic difficulties) and diathesis towards certain cognitive dysfunctions such as impaired decision-making (Perrain et al., 2021; Sastre-Buades et al., 2021). According to the Brain Centric Model (Mann and Rizk, 2020) such impairment could derive from both genetic and epigenetic factors with early life stress being a significant contributor. Childhood maltreatment (CM) could cause HPA axis abnormalities, neurotrophic and apoptotic deficits as well as neuroinflammation which would affect cognitive functioning. Indeed, CM has been identified as a risk factor for both suicidal behaviour (Liu et al., 2017) and decision-making impairments (Stoltenberg et al., 2011; Weller and Fisher, 2013).

As proposed by the Brain Centric Model, current literature regarding

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decision-making in suicide attempters (SA) (Perrain et al., 2021; Sastre-Buades et al., 2021) seems to indicate that SAs present a dysfunction in this cognitive capacity. Nevertheless, a well-defined profile has not been delineated as yet. Several meta-analyses have revealed significant differences in decision-making between subjects with psychiatric disorders (psychiatric controls (PC)) and SAs (Perrain et al., 2021; Sastre-Buades et al., 2021). However, such discrepancies do not exist when comparing PCs and healthy controls (HC) (Perrain et al., 2021). Nevertheless, upon conducting a meticulous scrutiny of the sample used to get the former results, it became apparent that mixing both euthymic and currently depressed participants could have biased the conclusions. In studies solely including depressed patients, only one detected differences between SA and PC (Hegedűs et al., 2018) while five did not (Alacreu-Crespo et al., 2019; Alacreu-Crespo et al., 2020a; Deisenhammer et al., 2018; Gorlyn et al., 2013; Ho et al., 2018).

While acknowledging the confounding effect of depression, this disparity in the results could also be attributed to both a rudimentary understanding and assessment of the decision-making concept. To overcome this problem, several computational models which aim to replicate the cognitive, motivational and response processes involved in decision-making have been developed.

The Expectancy Valence Learning Model (EVL) (Busemeyer and Stout, 2002) divides decision-making as measured by the Iowa Gambling Task into three parameters: motivational, learning/memory and choice consistency. Thus far, two studies have applied the EVL to explore decision-making in SA and failed to find differences between groups when comparing depressed (Gorlyn et al., 2013) or euthymic (Gilbert et al., 2011) PC and SA.

Built upon the strengths of the EVL, the Prospect Valence Learning Model with delta rule (PVL-Delta) (Ahn et al., 2008, 2011) has been found to surpass its predecessor in terms of capturing the emotional nuances in decision-making. It comprises four parameters: feedback sensitivity (α) and loss aversion (λ) (formerly known as the "motivational parameter" in the EVL), consistency (c) and learning/memory (A). To date, only one study has analysed decision-making in depressed SA vs. PC vs. HC using the PVL (Alacreu-Crespo et al., 2020a). Choice consistency was lower for both SA and PC in comparison to HC. In the same vein, IGT net score, loss aversion and learning/memory were lower in SA versus HC.

A third model which has outperformed the PVL is the Outcome-Representation Learning Model (ORL) (Haines et al., 2018). The ORL extracts five parameters from the IGT: reward learning (A_{rew}), punishment learning (A_{pun}) (motivational elements), forgetfulness (K) (learning element), win perseverance (B_F) and deck perseverance (B_p) (consistency elements). To date, no study has assessed decision-making in SA using the ORL.

In light of the preceding information, we aimed to apply both the PVL and ORL to PC and SA while considering intensity of current depressive symptomatology (low vs. high). Moreover, the moderational role of both depression and childhood trauma in the relationship between parameters and suicide attempt was also evaluated. We hypothesised that: 1) low depressed SA would present greater dysfunction in the computational parameters of decision-making than low depressed PC and 2) both high depressed PC and SA would exhibit greater dysfunction in DM than low depressed patients.

2. Method

2.1. Participants

A total of $N = 295$ subjects (women 67.45%, age range: 18–77) participated in the study. The sample was recruited from the Emergency Psychiatry and Acute Care Department, University of Montpellier Hospital, France from 2016 to 2020. The included patients were admitted for a current or past major depressive episode (MDE) according to DSM-IV criteria. Psychopathology was assessed by senior psychiatrists from those departments using the French version of the Mini International Neuropsychiatric Interview (MINI 5.0) (Lecrubier et al., 1997). The exclusion criteria comprised alcohol/drug abuse, schizoaffective disorder or schizophrenia. Among the 295 patients with MDE, 165 had a lifetime history of suicide attempt (suicide attempters (SA)) while 130 had never attempted suicide (psychiatric controls (PC)). Suicide attempt was defined as a self-destructive act carried out with some intent to die and differs from self-mutilation, use of substances and non-compliance with medical treatment (Van Heeringen and Mann, 2014).

Both SA and PC were categorized according to current depressive symptomatology (none/mild vs. moderate/severe) using the Inventory of Depressive Symptomatology Clinician Rated (IDS-C) (moderate/severe≥24) (Rush et al., 1996). Moreover, in order to maximize the utility of the sample, those who did not meet the IDS-C criteria but completed the Montgomery and Åsberg Depression Rating Scale (MADRS, moderate/severe≥20) (Montgomery and Asberg, 1979) were also included in the analysis. This procedure to maximize the sample was used in previous research (Nobile et al., 2022). None/mild were attributed as "low depression" and moderate/severe were labelled as "high depression".

The final groups were low depression PC ($N = 54$), low depression SA ($N = 35$), high depression PC ($N = 76$) and high depression SA ($N = 130$).

The study was approved by the University of Montpellier Hospital Ethics Committee (CPP Sud Mediterranée). All participants signed an informed written consent.

2.2. Procedure

Participants were asked to take part in the study upon admission to the Emergency Department or during external consultation. After the consultation or the discharge from psychiatric ward, the psychiatrists communicated the research assistants the potential inclusion in the study. Afterwards, research assistants informed patients of the possibility to be included in the study and schedule an interview. After being fully informed about the study details, participants signed the written consent. They disclosed their socio-demographic characteristics (age, education level, civil status, smoking history, number of children) and current medication intake. A medication load index was computed by summing up the doses of all psychotropic drugs taken by the patient. Values ranging from 0 to 4 were assigned to each dose of every drug (Sackeim, 2001). The total medication load for each participant (which encompassed both drugs consumed and doses) was obtained by summarising all doses for each medication category. SA were also asked to report the number of suicide attempts (total, severe and violent). Afterwards, participants completed the childhood trauma questionnaire and the IGT. The remaining information, such as depressive symptomatology, was obtained from the service's routine clinical evaluation.

2.3. Clinical assessment

Depressive symptomatology was assessed using the IDS-C and the MADRS. On the one hand, the MADRS consists of 10 items which aim to evaluate different depressive symptoms. Scores range from 0 (absence of symptom) to 6 (maximum severity of the symptom) for every item (Montgomery and Asberg, 1979). By contrast, the IDS-C comprises 30 items rated from 0 to 3, with higher scores indicating greater severity (Rush et al., 1996).

Childhood maltreatment (CM) was assessed using the Childhood Trauma Questionnaire (CTQ) which evaluates physical, emotional and sexual abuse and physical and emotional neglect. Scores range from 1 (never true) to 5 (very often true) for every question. It demonstrated a Cronbach's alpha of 0.95 for the total scale (Bernstein et al., 1998).

2.4. Neuropsychological assessment

Decision-making was reviewed using the Iowa Gambling Task (IGT) (Bechara et al., 1994). In the IGT, subjects are told to maximize their monetary returns by selecting a card from 4 decks: A, B, C and D. Decks A and B provide high rewards but are disadvantageous in the long-run given that they take more money than they give. In contrast, Decks C and D provide less reward but are advantageous in the long-run given that they award more money than they take. Net scores were calculated by subtracting the number of A and B selections (disadvantageous choices) from C and D selections (advantageous choices)((C + D) – (A + B)). Higher net scores were illustrative of a better performance on the test. Differences between the first 40 trials and the 60 last trials were calculated to analyze decision-making patterns in ambiguity (first 40 trials) and risk (last 60 trials). Regarding its psychometrical properties, the IGT shows moderate test-retest reliability (0.27–0.35) (Buelow and Barnhart, 2018). Regarding validity, the IGT presents adequate internal consistency ($\alpha = 0.75$) (Orm et al., 2024). Finally, the psychometrical properties of the IGT using the ORL model are higher than using classical approaches, with a reliability of $r = 0.64$–82 (Sullivan-Toole et al., 2022).

2.5. Computational models to assess decision-making

The PVL-D (Ahn et al., 2008) was used to fragment decision-making as measured by the IGT into four components: i) feedback sensitivity (α; from 0 to 1) with higher values representing higher sensitivity to feedback, ii) loss aversion (λ; from 0 to 5) with higher values representing a greater sensitivity to losses than gains; iii) learning/memory (A; from 0 to 1) representing the degree to which previous expectancies are discounted when forming the expectancy of the valence for the current trial, with lower values indicating better learning and memory; iv) response consistency (c; from 0 to 5) with higher values representing greater adherence with the considered better option based on past events (see Supplementary material for model parametrization and equations).

Likewise, the ORL model (Haines et al., 2018) was also used to split DM into five elements: i) reward learning (Arew; from 0 to 1) with higher values representing faster reward outcome learning; ii) punishment learning (Apun; from 0 to 1) with higher values representing faster learning regarding punishment outcomes; iii) forgetfulness (K; from 0 to 242) with higher values representing worse memory for past deck choices; iv) Win perseverance (BF; from -∞ to +∞) with negative values (below 0) indicating a greater propensity to choose decks with low win frequency (Decks A and C) whereas predominantly positive values (above 0) imply a greater inclination towards decks with a higher win frequency (Decks B and D); and v) deck perseverance (BP; from -∞ to +∞) in which overly negative values (below 0) suggest a preference for exploring different decks whereas predominantly positive results (above 0) identify a propensity for consistently choosing the same deck (see Supplementary material for model parametrization and equations).

2.6. Statistical analysis

Differences between the demographic and clinical variables of the four groups (low depression PC, low depression SA, high depression PC and high depression SA) were tested using Student's *t*-test for quantitative variables and Chi-square tests for qualitative variables.

Discrepancies in the IGT net scores among groups were analysed using a one-way ANCOVA using group as the independent variable (low depression PC, low depression SA, high depression PC and high depression SA) and psychiatric comorbidity, medication load, total CTQ and sex as covariates. Moreover, a repeated measures ANCOVA was also conducted to compare the performance of the groups in the 20, 40, 60, 80 and 100 trials of the IGT, using the same covariates. Post-hoc comparisons were adjusted using Bonferroni correction.

To carry out hierarchical Bayesian analysis, the R package hBayesDM with RStan 1.19.3 for sampling the posterior distribution was applied. The Markov Chain Monte Carlo (MCMC) sampling algorithm used by the Stan is the Hamiltonian Monte Carlo (HMC). A total of 40,000 samples were drawn after burn-in of 23,333 samples for four chains (= 40,000 × 4 chains = a total of 120,000 samples; with ≈ 70,000 burn-in). For each of the parameters, the Gelman-Rubin test (Gelman and Rubin, 1992) was performed to check the convergence of the chains ($\hat{R}$). All model parameters had $\hat{R}$ values of 1.00 and $\hat{R}$ values close to 1.00 indicate that the MCMC chains converge to the target distribution. Furthermore, a visual examination of the chains to confirm convergence to the target distribution was also executed.

In order to determine if, as suggested by the literature, the ORL model had the best fit in our sample, both the ORL and the PVL-Delta were compared using the leave-one-out-information criterion (LOOIC) (Vehtari et al., 2017). The models were available in the hBayesDM package using hierarchical Bayesian Analysis (Ahn et al., 2017). The posterior distribution mean and standard deviation of each parameter was estimated for each group. To make decisions regarding group comparisons, the highest density interval (HDI) was used which encompasses parameter values with a higher probability of being within the 95% range.

Parameters of both models were calculated for each subject to compare the four groups by taking into account confounding variables. ANCOVA for each parameter were performed using group as independent variable and sex, medication load, trauma (total score of the CTQ) and psychiatric comorbidity as covariates. Post-hoc comparisons were adjusted using Bonferroni correction.

In addition, correlations among parameters and links between parameters and the total IGT score were calculated to uncover any relationships that may be present.

Moreover, we performed moderation analyses to investigate the moderating effect of childhood trauma with ORL parameters as the independent variable and suicide attempt as the dependent variable using Model 1 of the PROCESS (v3.4.) macro in SPSS (v 22.0). 95% CI intervals were bootstrapped with 10,000 samples. We introduced sex, medication load, depression, trauma (total score of the CTQ) and psychiatric comorbidity as covariates. Significant and trend interactions were decomposed using simple slopes analyses (Aiken et al., 1991).

3. Results

3.1. Socio-demographic and clinical variables

Socio-demographic characteristics of the sample (Table 1) demonstrated the presence of a greater number of women in the high depression SA cohort versus low depression PC group ($p < 0.01$). Moreover, high depression SA had a higher prevalence of anxious disorders and presenting with one psychiatric comorbidity than low depression SA (both $p < 0.01$). Furthermore, the occurrence of PTSD was greater in high depression SA versus low depression PC ($p = 0.03$).

In terms of medication, high depression SA received more antidepressants than low depression PC ($p < 0.01$) and more antipsychotics than low depression SA ($p = 0.04$). High depression SA were administered more anxiolytics than low depression SA and those, in turn, received more than low depression PC ($p < 0.01$). More lithium was prescribed to low depression PC than high depression PC ($p = 0.02$). Finally, high depression SA had a greater medication load than low depression PC ($p = 0.01$).

For clinical dimensions, high depression SA exhibited worse depressive symptomatology ($p < 0.01$), a greater number of suicide attempts ($p < 0.01$) and worse current suicidal ideation ($p < 0.05$).

Finally, high depression SA obtained a greater score in physical neglect ($p = 0.02$), emotional abuse ($p < 0.01$), emotional neglect ($p < 0.01$) and total net score ($p < 0.01$) than low depression PC for CM.

Table 1
Descriptive characteristics of the sample.

	Low depression PC (LD-PC)	High depression PC (HD-PC)	Low depression SA (LD-SA)	High depression SA (HD-SA)	*p*-values	*Post-hoc analysis*
N =	54	76	35	130		
Socio-demographic						
Age	44.94 ± 14.03	41.22 ± 14.81	44.26 ± 12.99	40.48 ± 13.90	*p* = 0.162	
Years of study	14.08 ± 2.51	13.58 ± 2.23	12.67 ± 2.18	13.21 ± 2.66	*p* = 0.058	
Women, n (%)	25 (46.3%)	52 (68.4%)	26 (74.3%)	96 (73.8%)	*p* = 0.003	HD-SA > LD-PC
Current smoker, n (%)	25 (48.1%)	29 (41.4%)	13 (46.4%)	52 (48.1%)	*p* = 0.830	
Sep./Div./Wid., n (%)	9 (18.0%)	13 (18.1%)	10 (29.4%)	26 (20.0%)	*p* = 0.544	
Current Psychiatric Comorbidity						
Anxiety disorder, n (%)	25 (47.2%)	59 (78.7%)	17 (48.6%)	86 (68.3%)	*p* < 0.001	HD-SA > LD-SA
Eating disorder, n (%)	1 (1.8%)	5 (6.7%)	3 (8.6%)	13 (10.1%)	*p* = 0.119	
Alcohol abuse, n (%)	6 (11.3%)	8 (10.5%)	5 (14.3%)	22 (17.1%)	*p* = 0.556	
Substance abuse, n (%)	5 (9.4%)	12 (16.7%)	3 (8.6%)	16 (12.4%)	*p* = 0.552	
PTSD, n (%)	3 (5.6%)	8 (10.9%)	3 (8.6%)	17 (13.6%)	*p* = 0.037	HD-SA > LD-PC
Having one psych. Comorbidity, n (%)	29 (56.9%)	57 (83.8%)	19 (55.9%)	97 (79.5%)	*p* < 0.001	HD-SA > LD-SA
Medication						
Anti-depressants, n (%)	20 (40.8%)	54 (76.1%)	21 (65.6%)	82 (70.1%)	*p* < 0.001	HD-SA > LD-PC
Anxiolytics, n (%)	14 (28.6%)	51 (71.8%)	16 (50.0%)	95 (81.2%)	*p* < 0.001	HD-SA > LD-SA > LD-PC
Anti-epileptics, n (%)	16 (32.7%)	22 (31.0%)	6 (18.8%)	28 (23.9%)	*p* = 0.386	
Anti-psychotics, n (%)	27 (55.1%)	38 (53.5%)	9 (28.1%)	65 (55.6%)	*p* = 0.043	HD-SA > LD-SA
Lithium, n	13 (26.5%)	5 (7.0%)	5 (15.6%)	15 (12.8%)	*p* = 0.025	LD-PC > HD-SA
Suicidal History and Clinical Variables						
Depressive symptomatology (MADRS)	7.37 ± 6.34	29.25 ± 7.48	10.15 ± 6.25	29.18 ± 7.21	*p* < 0.001	HD-SA > LD-SA
Depressive symptomatology (IDS-C)	9.75 ± 6.32	37.47 ± 8.81	14.07 ± 6.58	36.32 ± 8.1	*p* < 0.001	HD-SA > LD-PC HD-PC > LD-PC HD-PC > LD-SA
Bipolar disorder, n (%)	5 (7.5%)	4 (2.7%)	2 (5.7%)	8 (6.2%)	*p* = 0.644	
Worse psychological pain	5.15 ± 3.36	8.67 ± 1.48	6.33 ± 3.51	8.52 ± 1.69	*p* < 0.001	HD-SA > LD-PC
Violent suicide lifetime, n (%)	–	–	6 (17.6%)	28 (22.6%)	*p* = 0.719	
Severe suicide lifetime, n (%)	–	–	4 (6.1%)	18 (14.6%)	*p* = 0.393	
No. of suicidal attempts	–	–	1.69 ± 0.99	2.48 ± 2.01	*p* < 0.001	HD-SA > LD-SA
Current suicidal ideation, n (%)	7 (12.9%)	51 (67.1%)	11 (31.4%)	107 (82%)	p < 0.01	LD-PC > HD-PC LD-PC > LD-SA LD-PC > HD-SA
Recency of the attempt			12.5 (12.2)	11.4 (13.3)	*p* = 0.62	
CTQ						
Total score	41.08 ± 12.28	48.60 ± 17.75	47.22 ± 17.40	53.60 ± 19.76	*p* < 0.002	HD-SA > LD-PC
Moderate/Severe Physical abuse, n (%)	6 (12.5%)	10 (15.6%)	4 (11.42%)	27 (28.4%)	*p* = 0.088	
Moderate/Severe Physical neglect, n (%)	4 (7.4%)	18 (28.1%)	6 (27.3%)	36 (38.3%)	*p* = 0.002	HD-SA > LD-PC
Moderate/Severe Emotional abuse, n (%)	12 (25.0%)	27 (42.9%)	7 (31.8%)	51 (53.7%)	*p* = 0.008	HD-SA > LD-PC

(*continued on next page*)

Table 1 (*continued*)

	Low depression PC (LD-PC)	High depression PC (HD-PC)	Low depression SA (LD-SA)	High depression SA (HD-SA)	*p*-values	*Post-hoc analysis*
Moderate/Severe Emotional neglect, n (%)	15 (31.9%)	25 (39.7%)	7 (31.8%)	55 (58.5%)	$p =$ 0.006	HD-SA > LD-PC
Moderate/Severe Sexual abuse, n (%)	7 (14.3%)	15 (23.1%)	6 (27.3%)	26 (27.7%)	$p =$ 0.334	

Note: LD-PC: Low Depression-Patient Control; HD-PC: High Depression-Patient Control; LD-SA: Low Depression-Suicide Attempter; HD-SA: High Depression-Suicide Attempter. PTSD: Post-Traumatic Stress Disorder.

3.2. IGT behavioural results

A one-way ANCOVA was conducted to analyze the between-group differences in the first 40 trials, 60 last trials and the IGT total score adding psychiatric comorbidity, sex, CM, medication intake and current suicidal ideation as covariates. No inter-group variations were found in the 40 first trials (F(3)= 1,33, $p = 0.26$, $\eta^2 = 0.02$) or the last 60 trials (F(3)= 0.96, $p = 0.4$, $\eta^2 = 0.1$). However, significant differences between groups were noted for the IGT total score (F(3)= 3.7, $p = 0.01$, $\eta^2 = 0.06$). Pairwise comparisons using the Bonferroni test found significant disparities between low depression PC (M = 3.53, SD = 0.92) and low depression SA (M = −1.96, SD = 1.24)($p = 0.01$). Other comparisons did not reach statistical significance ($p > 0.05$) (Supplementary Fig. 1).

Furthermore, a repeated measures ANCOVA was conducted to compare the learning curves of the different groups in blocks of 20 trials using the same covariates. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi 2$ (9) =114.18, $p < 0.01$); using the Greenhouse-Geisser correction, ε values were above 0.75. Therefore, degrees of freedom were rectified using Huynh-Feldt correction (ε = 0.83). The results revealed that, although close to significance (F(10.04) = 1.8, $p = 0.056$, $\eta^2 = 0.01$), no between-group differences existed in any of the trials (Supplementary Fig. 1).

3.3. Computational models of decision-making

Comparison between models demonstrated that the ORL was the best-fitting model (Supplementary Table 1). A comprehensive analysis of the PVL was provided to uncover any disparities between models. The posterior distribution was sampled for both models (Supplementary Figures 2 and 3).

In terms of the ORL (Supplementary Table 3), reward learning (Arew) was lower for low depression PC in comparison to high depression PC [HDI = −0.509 -0.151], low depression SA [HDI = -0.405–0.15] and high depression SA [HDI = −0.204 -0.012]. Both low depression SA and high depression PC obtained a greater score in Arew than high depression SA ([HDI = 0.034 0.304] and [HDI = 0.038 0.407] respectively). Punishment learning (Apun) values indicated that high depression PC obtained a greater score than high depression SA [HDI = 0.006 0.07]. Forgetfulness (K) was higher in low depression PC than in low depression SA [HDI = 0.397 1.143], high depression PC [HDI = 0.047 1.1] and high depression SA [HDI = 0.249 1.032]. Low depression PC achieved a higher score in deck perseverance (βp) than both low depression SA [HDI = 0.219 3.698] and high depression SA [HDI = 0.102 3.636] groups. No between-group differences were observed in win perseverance (βf).

In the PVL (Supplementary Table 3), loss aversion (λ) was higher in low depression PC than in low depression SA and high depression SA ([HDI = 0.1 0.611] and [HDI = 0.088 0.582] respectively). Learning memory (A) was higher in high depression PC and low depression SA than in low depression PC ([HDI = −0.406 -0.082] and [HDI = −0.352 -0.069] respectively). Regarding response consistency (c), low depression PC revealed a greater score than low depression SA and high depression SA ([HDI = 0.051 0.587] and [HDI = 0.06 0.585]). No between-group differences were identified on feedback sensitivity (α).

Posterior distributions for each parameter can be found in Supplementary Figs. 2 and 3 and mean ± SD and HDI comparisons in Supplementary Table 2.

An ANCOVA was performed with sex, medication load, CTQ total score, psychiatric comorbidity and current suicidal ideation as covariates to compare the model's parameters among groups (Fig. 2 and Table 4, Supplementary Material).

For the ORL parameters of reward learning (F(3)= 17.65, $p < 0.01$, $\eta^2 = 0.23$) (Arew) and forgetfulness (F(3)= 14.17, $p < 0.01$, $\eta^2 = 0.19$) (K), all relationships remained significant ($p < 0.05$). In terms of punishment learning (F(3)= 7.27, $p < 0.01$, $\eta^2 = 0.1$) (Apun), the differences between high depression PC and high depression SA did not reach significance ($p > 0.05$). However, two new differences emerged in this parameter. Low depression SA presented higher punishment learning than low depression PC ($p = 0.01$) and high depression SA ($p < 0.01$). Regarding deck perseverance (βp), only the difference between low depression PC and high depression SA ($p = 0.02$) remained significant (F(3)= 2.7, $p = 0.04$, $\eta^2 = 0.04$) (Fig. 1A).

Sensitivity analyses were performed using the same covariables and excluding participants with current mania. Reward learning (Arew), punishment learning (Apun), forgetfulness (K) and win perseverance (Bf) confirmed that the same differences among groups persisted as when using covariables and including those with current mania. For deck perseverance (βp), already existing differences remained and low depression PC scored higher on deck perseverance than high depression PC (as in the model without covariates).

For PVL parameters, a new difference emerged in loss aversion (F(3)= 6.7, $p < 0.01$, $\eta^2 = 0.1$) (λ) indicating that low depression PC exhibited higher loss aversion than high depression PC ($p < 0.01$). In the parameter learning/memory (A) (F(3)= 5.4, $p < 0.01$, $\eta^2 = 0.08$), a new difference appeared, suggesting that high depression SA demonstrated higher forgetting levels than low depression PC ($p < 0.01$). In response consistency (c) (F(3)= 1.56, $p = 0.02$, $\eta^2 = 0.02$), all differences disappeared among the groups ($p > 0.05$). In contrast, new differences were noted in the feedback sensitivity parameter (F(3)= 6.08, $p < 0.01$, $\eta^2 = 0.09$), illustrating that high depression SA were more sensitive to feedback than high depression PC ($p < 0.01$) and that low depression SA were more easily affected by feedback than high depression PC ($p = 0.01$) (Fig. 1B).

Sensitivity analyses were performed using the same covariables and excluding participants with current mania. In this case, the same differences among groups remained as when covariables were used and including those with current mania.

3.4. Correlations with IGT total score

There was a positive relationship between reward learning and punishment learning [r(294) = 0.44, $p < 0.01$] and deck perseverance [r(294) = 0.152, $p < 0.01$]. By contrast, a negative correlation between reward learning and forgetfulness [r(294) = −0.35, $p < 0.01$] and win perseverance [r(294) = −0.15, $p = 0.01$] was uncovered. Moreover, punishment learning illustrated a positive association with deck perseverance [r(294) = 0.266, $p < 0.01$]. With respect to forgetfulness, a negative relationship with deck perseverance was identified [r(294) = −0.318, $p < 0.01$] while it demonstrated a positive correlation with win perseverance [r(294) = 0.66, $p < 0.01$]. In addition, win perseverance

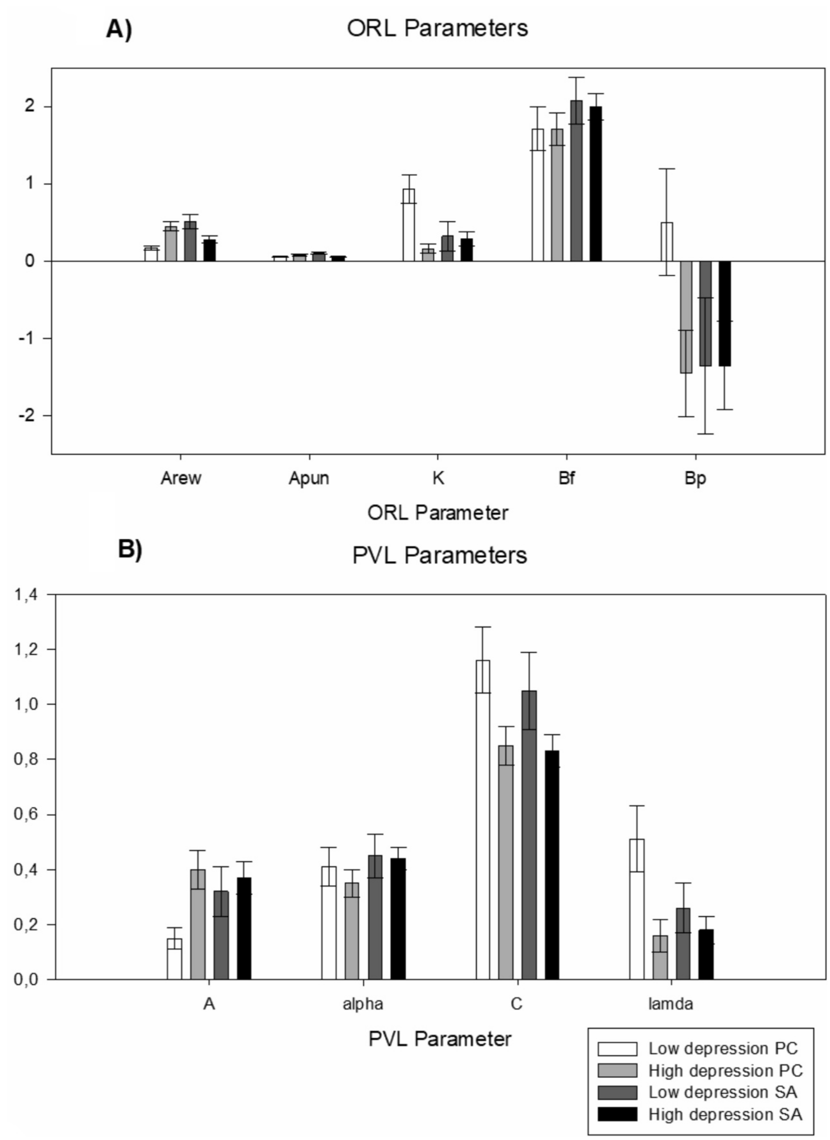

Fig. 1. Performance of the four groups on different parameters of the ORL (1A) and PVL (1B) When adjusted for sex, medication load, childhood trauma and psychiatric comorbidity.

Note: PC: Patient Control; SA: Suicide Attempter; Arew: Reward Learning; Apun: Punishment Learning; K: Forgetfulness; Bf: Win Perseverance; Bp: Deck Perseverance; A: Learning/Memory; Alpha: Feedback Sensitivity; C: Response Consistency; Lambda: Loss Aversion. LD-PC scored lower on Arew and Apun than SA groups, indicating greater sensitivity to feedback. SAs scored higher on K than LD-PC, indicating lower forgetfulness. HD-SA scored higher on Bp than LD-PC, indicating greater stochastic decision-making.

The PVL model showed that loss aversion and response consistency were higher in Low-depression controls when compared to SAs. Learning/memory was enhanced in both high-depression controls and low-depression suicide attempters when compared to LD-PC.

and deck perseverance presented a negative relationship [$r(294) = -0.37$, $p < 0.01$]. Finally, total IGT correlated unfavourably with deck perseverance [$r(294) = -0.12$, $p = 0.03$] (Table 2).

3.5. ORL parameters and trauma interaction to predict history of suicide attempt

Five moderation analyses were conducted with ORL parameters as the predictor, suicide attempt as the outcome, CTQ total score as the

Table 2
Correlation matrix among ORL parameters and total IGT.

	n	M	SD	Arew	Apun	K	$Beta_f$	$Beta_p$	Total IGT
Arew	294	0.35	0.21	–	0.448**	−0.356**	0.152**	−0.15*	−0.043
Apun	294	0.08	0.05		–	−0.98	0.266**	0.85	0.15
K		0.64	0.48			–	−0.318**	0.668**	−0.22
$Beta_f$	294	1.93	1.24				–	−0.374**	0.89
$Beta_p$	294	−1.29	4.53					–	−0.124*
Total IGT	294	1.07	5.85						–

Note: Arew: Reward Learning; Apun: Punishment Learning; K: Forgetfulness; $Beta_f$: Win Perseverance; $Beta_p$: Deck Perseverance, IGT: Iowa Gambling Task.

moderator and sex, depression severity, medication intake and psychiatric comorbidity as covariates.

The interaction between forgetfulness and trauma was statistically significant (B = 0.09, SE = 0.02, $t = 3.35$, $p < 0.01$). The conditional effect of K on suicidal attempt showed corresponding results. For those presenting with lower CTQ score (-1SD), the conditional effect was (B = −1.68, SE = 0.56, $t = -2.98$, $p < 0.01$), implying a negative relationship between forgetfulness and suicide attempt. Similarly, the conditional effect was (B = 1.61. SE = 0.68, $t = 2.35$, $p = 0.01$) for those participants with higher CTQ score (+1SD), illustrating a positive correlation between forgetfulness and suicide attempt (Fig. 2). Moreover, the overall model explained about 27% of the variance in suicide attempt probability ($r^2 = 0.27$).

Furthermore, the interaction between deck perseverance and CM was statistically significant (B = 0.005, SE = 0.002, $t = 2.55$, $p = 0.01$). For those exhibiting lower CTQ score (-1SD), conditional effects were (B = -0.15, SE = 0.05, $t = -2.91$. $p < 0.01$), evoking a negative relationship between deck perseverance and suicide attempt. For those with higher CTQ score (+1SD) no significant effect was identified (B = 0.05, SE = 0.05, $t = 0.97$, $p > 0.32$) (Fig. 2). The overall model explained about 23% of the variance in suicide attempt probability ($r^2 = 0.23$).

Interactions of the remaining model parameters with CTQ score were not statistically significant ($p > 0.05$).

4. Discussion

In this study, we determined that SA had impaired decision-making relative to PC when they presented a low severity of depression. Between the two models, the ORL had the best fit in our sample. Among the five parameters, all of them except for win perseverance exhibited significant differences. Low depressed PC demonstrated lower reward learning and higher forgetfulness versus all SA patients but higher deck perseverance when compared to high depressed SA patients. Moreover, punishment learning was able to differentiate SA in terms of depression (the lower the depression level the higher the punishment learning rate). Sensitivity analyses excluding participants with current mania did not reveal any new relationships. Finally, childhood trauma moderated the correlation between both forgetfulness and deck perseverance and history of suicide attempt.

Previous studies that compared both euthymic PC and SA did (Adan et al., 2017; Jollant et al., 2005, 2007; Richard-Devantoy et al., 2016) and did not (Gilbert et al., 2011; Moraes et al., 2013; Wyart et al., 2016) observe between-group differences for IGT total score. This discrepancy could be due to a myriad of causes, including not having controlled for violence of the attempts, as this factor significantly impairs decision-making (Deisenhammer et al., 2018; Perrain et al., 2021).

Our data adds to the arsenal of previous literature because we used two models, the PVL (already used) and the ORL, to assess decision-making. To our knowledge, no previous study has evaluated decision-making in a sample of suicide attempters using the ORL.

4.1. Motivational parameters

In previous studies using the EVL, no disparities in the motivational parameter between groups were found in euthymic patients (Gorlyn et al., 2013) (Gilbert et al., 2011). For the PVL, no differences were observed between patient groups in terms of feedback sensitivity (non-euthymic SA and PC) although HC scored higher in the loss aversion parameter than SA (Alacreu-Crespo et al., 2020a).

In our study, high depressed PC and both high and low depressed SA learned more from rewards than low depression PC. Therefore, it can be inferred that both the presence of current depression and history of suicide attempt entails a heightened sensitivity to reward. This finding contradicts prior research in which both depression (Chen et al., 2015) and suicide (Bettis et al., 2022) were related to lower reward learning. However, disparity of the methods used in both reviews for measuring the construct (e.g. total IGT scores, using other tests such as the three-armed gambit task, other computational models…) may impede the establishment of direct comparisons. High depressed PC and low depressed SA also gained more from rewards than high depressed SA, which refutes our a priori hypothesis. This could be due to several reasons such as, as mentioned previously, not having controlled the severity of the attempts. It may seem contradictory that depression could be linked with greater sensitivity to reward considering that one of its main characteristics is anhedonia (i.e. the inability to experience pleasure). However, in the context of learning, it is potentially feasible that, due to

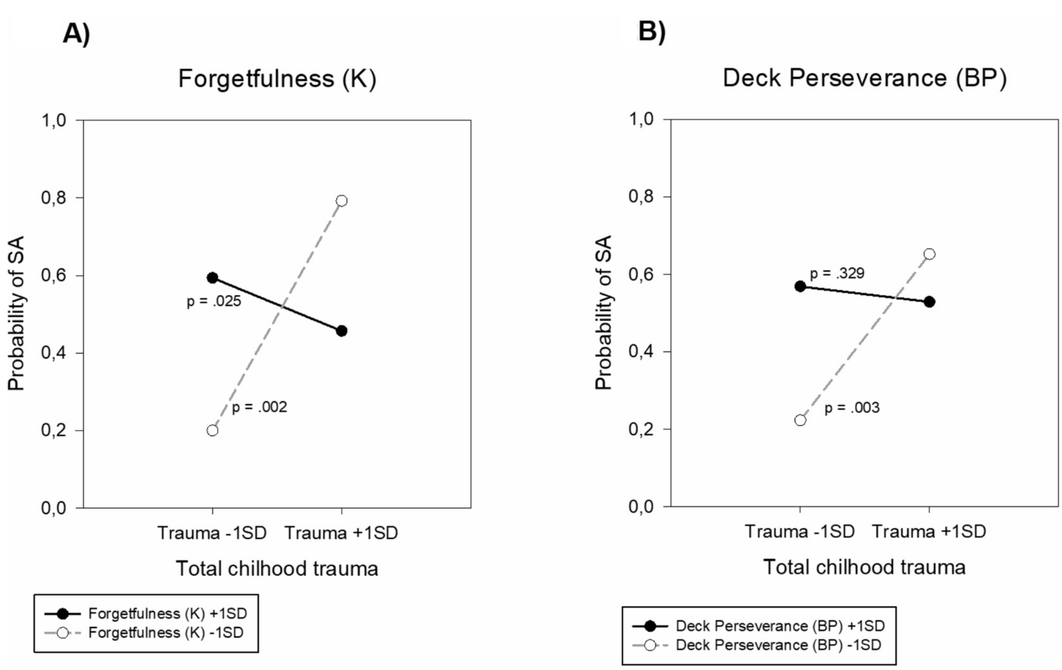

Fig. 2. Probability of being in suicide attempt group (SA) according to childhood trauma total score and forgetfulness (2A) or deck perseverance (2B). Note: Plotted points represent conditional low and high impulsiveness scores (±1 SD).

the normal depletion of rewards, rewarding experiences are more noticeable and, therefore, better remembered. This could lead to increased learning of reward contingencies as a potential coping mechanism. Another potential hypothesis is that increased reward learning is the direct byproduct of avoidance tendencies. Due to the increased reward learning the individual would rapidly learn that avoiding distressing situations causes immediate short-term relief, generating an avoidant coping loop, which has already been reported in the suicide attempt literature (Gupta et al., 2024).

In terms of punishment learning, low depression SA learned faster punishment outcomes than both low depression PC and high depression SA, implying that the model was able to differentiate the latter group in terms of both suicide attempt and depressive severity, thereby illustrating that suicide attempt, but not depression, entails heightened punishment learning. Considering that low depressive suicide attempters also presented a heightened sensitivity to reward, it could be hypothesised that this group simply presents a greater sensitivity to feedback contingencies. Indeed, previous research (Alacreu-Crespo et al., 2020b) identified that euthymic suicide attempters displayed differences in prefrontal activation versus controls to both happy and angry faces following choices in the IGT. This increased sensitivity to feedback contingencies could be making more salient punishments and, at the same time, the little amount of rewards the individual experiences, fostering hopelessness. Therefore, the heightened reward sensitivity, instead of acting as a buffer, would be acting as a reminder of the rarity of the rewards.

4.2. Learning parameters

In earlier studies using the EVL, no differences among groups were discerned in a sample of either non-euthymic patients with and without suicide attempt (Gorlyn et al., 2013) or euthymic patients with and without suicide attempt (Gilbert et al., 2011). Variations between non-euthymic SA and HC emerged in the learning/memory parameter in the PVL, with SA presenting faster forgetting levels (Alacreu-Crespo et al., 2020a).

In our study, forgetfulness (ORL) was higher in the low depressed PC versus low depressed SA, high depressed PC and high depressed SA implying that low depressed PC forget past deck choices quicker and rely more on shorter memory. These results contradict previous findings by Alacreu-Crespo et al. (2020a) using the PVL.

The fact that both SA and high depressed PC groups demonstrated greater memory for past deck choices could implicate a maladaptive memory retrieval pattern in which past experiences are frequently ruminated. This is supported by the literature given that both depression (Nolen-Hoeksema et al., 2008) and suicidal behaviour (Law and Tucker, 2018) are positively related to greater rumination tendencies. Increased rumination has been linked to overactivation of the Default Mode Network (Zhou et al., 2020). Due to the vital role of the DMN in both depression (Zhou et al., 2020) and suicide (Ho et al., 2021), its overactivation plays a crucial role in the emergence and worsening of these conditions.

Constant rumination by SA about the past coupled with their tendency to be more sensitive to both positive and negative feedback may foster a perpetual cycle of overthinking in which every memory, either positive or negative triggers a never-ending pattern of self-examination and self-critique that could affect their emotional well-being.

4.3. Consistency parameters

In terms of consistency parameters, no differences were found in either win perseverance (ORL) or consistency (PVL). This tallies with previous research using the EVL (Gilbert et al., 2011; Gorlyn et al., 2013) where no discrepancies were identified among groups in this parameter. Nevertheless, prior research using the PVL differentiated between non-euthymic SA/PC and HC demonstrated no significant disparities between patient groups (Alacreu-Crespo et al., 2020a).

In our model, substantial variations were observed between low depressed PC and high depressed SA in the deck perseverance parameter, showing that high depression SA were prone to a greater tendency for switching decks. When excluding covariates from the analysis (Table 3), substantial differences were also detected between low depressed PC and low depressed SA, which could indicate that the dimension creating their greater response randomness equates to history of suicide attempt.

The fact that SA exhibit greater stochastic decision-making could be due to several reasons. Their greater tendency to switch decks could be suggestive of a less systematic approach to risk assessment which, in conjunction with their heightened feedback sensitivity, could produce a cognitive profile characterized by impulsivity and sensation-seeking behaviours. Indeed, SA has been found to be related to higher impulsivity (Beach et al., 2022). Moreover, this group also exhibited lower forgetfulness, which could hint at a strong memory system that relies on already learned patterns. Such a combination could lead an individual to quickly make decisions based on pre-existing actions and past experiences, completely dismissing new viewpoints and engaging in a vicious cycle that would reinforce their state. Another possible explanation is that this group could have shown less interest in the task.

4.4. ORL parameters and trauma interaction to predict suicide

To the best of our knowledge, no previous study has used the ORL parameters to predict suicide attempts through childhood trauma.

In our study, higher memory for past deck choices was related to greater likelihood of SA in those with higher trauma scores. Childhood trauma survivors present greater threat hypervigilance (da Silva Ferreira et al., 2014). This increased threat sensitivity could imply that, when making a risky decision, past trauma adheres more to their memory due to a greater emotional valence (Phelps, 2004). Similarly, it has also been found that suicide is related to greater threat sensitivity (Venables et al., 2015).

Moreover, for participants with lower trauma scores, higher memory for past deck choices was related to lower chances to be SA. Lower forgetfulness in the IGT implies a greater handle of anterior outcomes and therefore better learning of the task. In this way, although childhood trauma has been related to worse decision-making, those with lower trauma would be less affected by it and produce better decision-making.

In addition, a negative relationship was identified between deck perseverance and suicide in those with lower trauma score. The low incidence of trauma in this group could be due to several factors such as better cognitive functioning. Indeed, according to current literature on the subject, trauma negatively correlates with worse decision-making (Stoltenberg et al., 2011; Weller and Fisher, 2013). This is consistent with our results in which higher deck perseverance indicates better decision-making given the correlation with total IGT.

4.5. Theoretical implications within current models of suicidal behaviour

Current suicidal models such as the Brain Centric Model (Mann and Rizk, 2020), the Motivational Volitional Model (O'Connor and Kirtley, 2018) and the 3-step theory (Klonsky and May, 2015) are consistent with the findings of the present report.

The Brain Centric Model (Mann and Rizk, 2020) proposes that both genetic and epigenetic factors (e.g childhood maltreatment) entail a disruption of the nervous system that would lead to impairments in cognition, such as a maladaptive decision-making. In line with the model, childhood trauma moderated the relationship between K and Bp, indicating that early adversity may be a distal cause for impaired decision-making. In this case, the greater reward/punishment learning rate could seem, at first glance, inconsistent with its proposals, as a higher responsiveness to positive vs negative feedback is emphasized. However, both Arew and Apun are updating weights rather than valuation weights. Therefore, higher Arew and Apun reflect a higher rate of feedback incorporation rather than a specific tilt towards rewards or punishments. Such increased sensitivity to contingencies is consistent with the Brain Centric Model as less top-down prefrontal control would imply a hyper salience of all contingencies due to the lack of contextualization. Moreover, such hypersalience of all contingencies would go in line with the lower forgetfulness rate of SAs. The feedback each deck gives is better remembered due to the higher salience of such feedbacks. Such score in K is understood as a higher tendency to ruminate past experiences instead of as crude memory, pivoting in a greater hyperactivity of the DMN, another key proposal of the model. In the same line, greater stochastic decision-making could also be a direct result of the impaired top-down control of the prefrontal and dorsal anterior cingulate cortex on the on the vmPFC.

The Motivational-Volitional Model (O'Connor and Kirtley, 2018) proposes that suicidal behaviour unfolds in phases. In the premotivational phase, different background factors such as life stressors foster the potential emergence of SA. In the motivational phase, defeat and entrapment would lead to suicidal ideation only in the presence of the right moderators. In the volitional phase, ideation progresses to attempt when volitional moderators (e.g impulsivity, acquired capability) facilitate the transition. In this case, the increased feedback sensitivity could act as a motivational moderator, increasing the sense of defeat and entrapment by rapidly updating punishments and the few rewards that the individual experiences, fostering a sense of entrapment. In the same line, lower forgetfulness would act as a tendency to ruminate that would lead the individual to reenact past experiences a foster the entrapment. This in conjunction with the greater impulsivity (as reported by the greater stochastic decision-making) could ultimately lead the person to commit suicide.

In the same line, the 3-step theory of suicidal behaviour (O'Connor and Kirtley, 2018) also proposes that suicide unfolds in 3 distinct steps. First, the individual experiences a high degree of psychological pain and hopelessness that lead to suicidal ideation. If social connectedness in the individual is high, ideation decreases. To try to commit suicide, the individual must possess an acquired capability, developed through a growing tolerance to pain that leads to overcome the fear of death.

In the first stage, higher punishment learning could cause losses to be integrated more rapidly, amplifying psychological pain. Moreover, the high score in reward learning could reinforce avoidance tendencies. The individual would learn that avoiding distressing situations yields immediate but short-lived relief. However, as the sources of distress are not confronted, the same source of punishments persist. Coupled with high rumination tendencies (low forgetfulness) and the tendency to present an inconsistent decision-making pattern, hopelessness may arise, as the individual quickly integrates the punishments while continues to avoid distressing situations.

In the second stage, this tendency to rapidly incorporate punishments, to avoid confrontation of distressing situations and the high tendency to ruminate could potentially overshadow connectedness, while more stochastic decision-making may further disrupt stable interpersonal relationships.

In the third stage, the individual would be desensitized to pain due to the cumulative effects of distressing experiences, avoidance and disadvantageous decision-making, fostering an acquired capability for suicide.

4.6. Limitations

Regarding the limitations of the study, there are several issues that need to be addressed. Firstly, although we ensured medicine control, it is potentially feasible that patient medication could have affected their decision-making capacity in some extent. Secondly, we did not differentiate groups into violent and non-violent attempters. This is important given that violent attempters exhibit greater impairment in decision-making than non-violent attempters (Perrain et al., 2021) and, therefore, could present a different cognitive profile. Furthermore, the lack of a healthy control group hinders comparisons to a normative standard. Moreover, it is important to remark that scores on the computational parameters come from momentary assessments in the IGT that may not reflect real life characteristics. In addition, the cross-sectional design impairs the establishment of causal inferences.

Finally, as our goal was to understand the decision-making process in depression alone, we excluded patients with substance abuse and psychotic disorders to reduce hetereogeneity. This may limit generalizability to other suicidal populations as these comorbidities often co-occur with depression (Álvarez et al., 2022; Rioux et al., 2021).

4.7. Conclusion

In summary, our results indicate that, in some instances, the depressive state could be related to heightened reward learning, acting as a potential coping mechanism or as a distal factor that fosters avoidance tendencies. Moreover, suicide could be related to enhanced punishment sensitivity to environmental contingencies and increased stochastic decision-making. Moreover, the role of both forgetfulness and deck perseverance in childhood trauma survivors at risk for suicide should be further investigated.

Distinctively mapping the cognitive profile of both depression and suicidal behaviour would help to improve current psychological treatments oriented towards these patients. In light of our findings, therapeutical techniques that aim to balance maladaptive responsiveness to feedback contingencies (due to the higher Arew and Apun), address impulsive decision-making (due to the lower Bp) and manage tendencies towards excessive rumination (due to the higher K) are encouraged. To this end, treatments that fall under the cognitive behavioural approach such as Acceptance and Commitment Therapy (ACT) would be advisable. The mindfulness component in ACT would help the patient to better manage both their impulsive tendencies as well as their maladaptive rumination. Moreover, the acceptance component would aid in accepting feedback contingencies whether they are positive or negative. Moreover, it could also help to reduce avoidance-based coping tendencies. Indeed, ACT has been shown to be effective in reducing depression (Bai et al., 2020) and suicidal ideation (Ducasse et al., 2018). Finally, the results from this study suggest promising advances regarding both suicide prevention and depression management within the digital therapy landscape, where the use of computational models further enhances these developments by providing a finer grasp of the neuropsychological profile, facilitating both treatment and early detection.

Authors statement

PC, AA-C and EO. Designed the study; PC and EO: Recruited sample; RM and AA-C. Reviewed the specific literature: RM, AA-C, and FM. Analysed data: RM. Wrote the paper. All authors reviewed and approved the final version of paper.

CRediT authorship contribution statement

R.M. Moret: Writing – review & editing, Writing – original draft. **A. Alacreu-Crespo:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **F. Molins:** Data curation. **E. Olié:** Writing – review & editing. **Ph. Courtet:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization.

Ethical statement

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Moreover, the study was and approved by the Montpellier Hospital Ethics Committee.

Declaration of competing interest

The authors declare no competing interests that could have influenced the results or interpretation of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pnpbp.2026.111732.

Data availability

Data will be made available on request.

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