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Unpleasant mood reverses satiety's effect on tobacco reinforcement

Víctor Martínez-Loredo [a,*,1], Jorge L. Ordoñez-Carrasco [b,2]

[a] Department of Personality, Assessment and Psychological Treatment, University of Seville, Seville, Andalucía, Spain
[b] Department of Psychology and Sociology, University of Zaragoza, Teruel, Aragón, Spain

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ABSTRACT

Introduction: Despite empirical support of goal-directed behavior models of dependence, the role of mood on substance use is unclear. The Reinforcer Pathology (RP) model may be useful to describe it specific effects in substance-related variables. This study aims to test mood induction's effect on tobacco demand and integrate results into the RP model.

Methods: Sixty-two participants from the general population, aged 18–34, who smoked at least five cigarettes daily and presented no severe mental health conditions completed the study using a two-group design (between-subject factor: pleasant vs unpleasant mood induction; within factor: pre-, post-induction). They complete measures of mood status, tobacco reinforcing efficacy, delay discounting, depressive, anxiety and stress symptoms, environmental reinforcement, negative/positive urgency and tobacco-related/free reinforcement. Before mood induction, all participants were sated with nicotine after being asked to smoke freely.

Results: While pleasant mood reduced intensity, O_{max} and breakpoint and increased elasticity, unpleasant mood produced the opposite pattern. This effect was dose dependent and effect sizes were large ($f = 0.39$–0.50). Mood induction did not significantly affect delay discounting significantly. The association between classical RP variables and new candidates (emotional symptoms, pleasant/negative urgency, tobacco-related/free reinforcement) was differently influenced by mood valance ($r = |.359$–$.532|$).

Conclusion: Results support the goal-directed behavior model of dependence and extend the RP model by integrating the role of mood induction. The effect of mood seems particularly large in intensity, O_{max}, and elasticity and this effect may depend on emotional regulation skills and contextual variables, such as substance-free reinforcement and environmental reward.

1. Introduction

Several theories and models have been proposed to explain substance use and dependence (Hogarth, 2020). These theories can be grouped into two categories: theories focusing on antecedent-based control of behavior (*e.g.*, cue-induction, compulsion theories) and those focusing on the reinforcing value of the addictive object (*e.g.*, positive/negative reinforcement theories), seeing substance use as goal-directed behaviors (Hogarth, 2022). Evidence-based treatments support dependence as goal-directed behaviors. For example, contingency management is highly effective (Pfund et al., 2024), while stand-alone stimulus control/cue exposure treatments have limited evidence (Kiyak et al., 2023).

Goal-directed theories suggest that negative affect and/or withdrawal symptoms increase the expected value of substance use. Mood induction procedures have been widely used and validated in experimental psychology to manipulate affective states reliably (Westermann et al., 1996). For example, unpleasant mood and depressive symptoms promote substance use (Conklin and Perkins, 2005; Hogarth and Hardy, 2018; Perkins et al., 2010). Two studies showing no impact of mood on substance use either did not induce mood changes (Shiftman et al., 2004) or the magnitude of induction was limited (Dora et al., 2024). Nonetheless, subgroup analysis on participants with significant mood induction yielded significant association. Also, mood-induced increases in drug choice correlate with severity of use (Dora et al., 2024; Hogarth and Hardy, 2018). However, the effect of mood in substance use is unclear, with some studies finding changes in pleasant affect more relevant (Fucito and Juliano, 2009; Tovmasyan

* Correspondence to: Department of Personality, Assessment and Psychological Treatment, University of Seville, Calle Camilo José Cela s/n, Seville 41018, Spain.
E-mail address: loredo@us.es (V. Martínez-Loredo).
[1] Orcid ID: 0000-0002-0403-5273
[2] Orcid ID: 0000-0002-2259-2639

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et al., 2022) and other finding no effects (Hogarth et al., 2015). Due to the different designs, variables and methodology used, the role of affect as conditioned or discriminative stimulus or motivating operation is still being debated.

Experimental studies using outcome-devaluation procedures under extinction also favored the goal-directed account of dependence (Hogarth, 2022). This procedure is interesting for unraveling the process by which withdrawal and unpleasant states increase substance use, as it allows to test choices between substance-related and non-substance-related alternatives without experiencing the outcomes. Hogarth et al. (2015) demonstrated that unpleasant (but not pleasant) mood induction abolished the effect of nicotine satiety during an extinction test, which suggests it acted as a motivating operation increasing tobacco choice. Importantly, this effect depended on the magnitude of mood change rather than absolute mood levels, as only participants experiencing higher increase in unpleasant mood increased their tobacco choice. Despite the relevance of these results (which were replicated in alcohol users Hogarth and Hardy (2018), some limitations need to be noted. It is argued that mood-induced changes in tobacco choice must be mediated by the expectation of the tobacco outcome, as the test was performed under extinction. Nonetheless, as the setting was the same as in the training condition and participants performed the same task involving interactions with the same apparatus, the unique contribution of expectations cannot be isolated from potential effects of discriminative/conditioned stimuli. That is, during incipient extinction, behavior may persist temporarily due to its history of reinforcement, a phenomenon often referred to as resistance to extinction (Pierce and Cheney, 2017).

To overcome this limitation, this study used hypothetical tasks (delay discounting and cigarette purchase task) to assess participants' expected behaviors in controlled scenarios. These tasks are not performed in a context previously associated with substance reinforcement and do not involve actual consumption, which reduces the influence of conditioned cues or residual reinforcement history. Thus, they allow a cleaner assessment of the effect of mood on decision-making. Second, Hogarth et al.'s protocol was not individualized, whereas the present study used a procedure based on episodic memory, which has shown to modify mood status (Bickel et al., 2017; Busby et al., 2021; Grant and Wilson, 2021; Williams et al., 2022).

One model based on the excessive reinforcing value of commodities promoting dependent-like behaviors is the Reinforcer Pathology (RP). The RP proposed that addictive patterns emerge due to high discounting of delayed reinforcers (associated to abstinence or healthy behaviors) and/or high relative reinforcing efficacy of substances (or substance demand) (Bickel et al., 2020). However, the role of mood on RP-related variables has not been deeply analyzed, with most evidence regarding reinforcing efficacy coming from observational or alcohol-related experimental studies (Amlung and MacKillop, 2014; Dora et al., 2024; Owens et al., 2015; Rousseau et al., 2011). Previous studies often focused on a single demand index (Dora et al., 2024; Rousseau et al., 2011), restricting potential findings. For example, the only experimental study on cigarette demand (Dahne et al., 2017) found that depressive symptoms predicted trait P_{max} and breakpoint (indices related to contextual constraints) after stress induction, but only among individuals with greater increases in negative affect. Among those with lower change from baseline, depressive symptoms only predicted intensity of demand (an index related to absolute reinforcing efficacy). However, the absence of baseline measures limits the ability to assess mood-induced changes in reinforcing efficacy.

In contrast with the above, evidence of the role of mood on DD focused on general population and was not tested in relation to substance use. However, emerging evidence points to DD reductions under pleasant emotions (Ifcher and Zarghamee, 2011) and DD increases under unpleasant emotions (Lerner et al., 2013).

Recent extensions of the model (Acuff et al., 2023; Martínez-Loredo, 2023) have highlighted the relevance of individual differences in variables closely related to mood status and regulation (*e.g.*, urgency, substance-free reinforcement, behavioral activation). Although these variables may help explain the effect of mood in classical RP variables, to date their specific role in mood-induced changes in delay discounting and tobacco demand remains unexplored.

This study aimed to replicate previous findings on mood induction's effect on tobacco choice (Hogarth et al., 2015) by integrating results into the RP model. Specifically, this study tested if mood induction reverses tobacco devaluation produced by satiety (*i.e.,* reduced motivation to consume tobacco following recent consumption) and if this effect depends on the degree of induction. To overcome previous limitations, we induced mood changes via episodic past thinking on delay discounting and hypothetical cigarette demand. Additionally, we explored the effect of RP-related variables on the experimental effects. We hypothesized that unpleasant mood induction increases tobacco demand and delay discounting, especially among participants experiencing greater mood changes. Due to the exploratory nature of the analyses, no specific hypotheses were made about the specific role of RP-related variables. Design, hypotheses and analytic strategy were preregistered (https://doi.org/10.17605/OSF.IO/D8GCM).

2. Method

2.1. Participants

Sixty-four participants were recruited from the community and universities of Zaragoza and Seville (Table 1). Following the original study (Hogarth et al., 2015), the inclusion criteria were: 1) aged 18–34, 2) smoking at least 5 combustible cigarettes per day and 3) agreeing to participate. Participants were excluded if they reported a current or past severe mental disorder or substance use disorders. Participants were scheduled between 10:00 a.m. and 3:00 p.m. and were requested to attend with a minimum abstinence period of 3 hours (CO $\leq$ 6 ppm). After completing the 1-hour study, participants blindly selected a 0€, 5€ or 10€ voucher from a fishbowl. Informed consent was obtained during the assessment and the study was approved by the Ethics Committee of Aragón (Ref. RAT 2022–35), observing the privacy rights of participants.

A priori power analysis suggested that a sample size of $n = 62$ was enough to detect effect sizes of $f = .15$ (i.e., small-medium) for analysis involving the most varying measure,[3] with a 95 % Confidence Interval and 80 % power. Two participants were excluded from delay discounting (DD) analysis and two from the Cigarette Purchase Task (CPT) after checking quality of data. The final sample was 62 for DD and CPT analyses.

2.2. Measures

2.2.1. Sociodemographic variables

Participants were asked to report their sex (male, female) and educational level (elementary, high school, vocational, university, master/PhD), marital (single, married/couple) and work status (student, in full-time/part-time employment, unemployed), and monthly income**.**

2.2.2. Smoking-related variables

Participants provided their history of tobacco use and reported their daily cigarette use (CPD) and whether they used rolling tobacco or not. They also reported their desire to smoke before and after the break (1 = very low; 7 = very high) and the pleasure from each puff taken during the break on a visual analogue scale from 0 % to 100 % (an index of cigarette devaluation). During the baseline assessment, they also

[3] Few et al. (2012) reported an r = .76 between two trait Breakpoint measures one week apart. As in the present study we used state-dependent measures, a lower correlation was considered.

Table 1
Descriptive statistics of the study sample.

Variables *M* (SD)	Total sample (N = 64)	Unpleasant group (*n* = 31)	Pleasant group (*n* = 33)	*p*
Sociodemographic variables				
Sex[a]	67.2 %	67.7 %	66.7 %	.927
Age	23.39 (4.90)	22.77 (4.58)	23.97 (5.18)	.333
Education level				.536
Primary education	1,6 %	3,2 %	0 %	
Secondary education	1,6 %	3,2 %	0 %	
Intermediate vocational training	1,6 %	0 %	3 %	
Higher vocational training	4,7 %	6,5 %	3 %	
Baccalaureate/University entrance qualification	48,4 %	51,6 %	45,5 %	
University graduate	29,7 %	29 %	30,3 %	
Postgraduate degree	9,4 %	3,2 %	15,2 %	
Doctorate	3,1 %	3,2 %	3 %	
Employment Status				.274
Full-time employment	18.8 %	19,4 %	18.2 %	
Part-time employment	3.1 %	0 %	6.1 %	
Unemployed (receiving benefits)	3.1 %	0 %	6,1 %	
Unemployed (no benefits)	1.6 %	0 %	3 %	
Student	73,4 %	80,6 %	66.7 %	
Civil status				.051
Single	84.4 %	93.5 %	75.8 %	
Married or cohabiting	15.6 %	6.5 %	24.2 %	
Income levels				.759
< 600€	68.8 %	71 %	66.7 %	
601€−900€	4.7 %	3.2 %	6.1 %	
901€−1200€	10.9 %	12.9 %	9.1 %	
1201€−1500€	6.3 %	3.2 %	9.1 %	
1501€−2000€	7.8 %	9.7 %	6.1 %	
2001€−3000€	1.6 %	0 %	3 %	
Smoking-related variables				
Rolling tobacco[b]	71.9	71	72.7	.876
Cigarettes/day	8.73 (3.57)	8.16 (3.06)	9.27 (3.97)	.216
FTCD	2.44 (1.99)	2.45 (2.06)	2.42 (1.95)	.957
CPT trait				
Intensity	12.48 (5.60)	11.42 (5.14)	13.48 (5.91)	.142
O_{max}	5.24 (3.77)	4.54 (3.10)	5.90 (4.24)	.149
P_{max}	1.32 (1.58)	1.46 (1.93)	1.19 (1.17)	.495
Breakpoint	2.43 (1.97)	2.31 (1.82)	2.55 (2.11)	.646
Elasticity	0.029 (0.017)	0.033 (0.018)	0.025 (0.015)	.089
CO baseline	4.07 (1.55)	3.87 (1.52)	4.27 (1.57)	.303
CO post	9.08 (2.92)	8.87 (3.11)	9.27 (2.76)	.586
Number of puffs	14.98 (3.27)	15.06 (3.40)	14.91 (3.20)	.851
Pleasure first puff	73.93 (24,90)	69.72 (26.45)	77.89 (23.06)	.192
Pleasure last puff	51.44 (25.58)	48.11 (23.05)	54.59 (27.74)	.315
Desire smoking baseline	4.77 (1.62)	4.55 (1.83)	4.97 (1.40)	.302
Desire smoking post	1.91 (1.28)	1.71 (1.04)	2.09 (1.47)	.237
Mood baseline	3.78 (1.46)	3.81 (1.49)	3.76 (1.46)	.895
Mood post	4.36 (2.54)	**6.06 (2.11)**	**2.76 (1.73)**	**< .001**

Note. [a] % female [b] Yes. Statistically significant differences shown in **bold**
FTCD = Fagerström Test of cigarette dependence; CPT = Cigarette Purchase Task; CO = carbon monoxide (parts per million)

completed the Spanish version of the Fagerström Test for Cigarette Dependence (Becoña and Vazquez, 1998), which showed adequate internal consistence (α =.70). FTCD total score ranges from zero (less dependence) to 10 (more dependence).

2.2.3. *Mood-related variables*

Participants were asked to report their current mood (1 = very happy; 5 = neutral; 9 = very sad) before and after the mood induction. The depression and anxiety scales of the Spanish version of the Depression, Anxiety and Stress Scale (DASS-21; Bados et al. (2005)) were used to assess the level of depressive (DASS-D; α =.74), Stress (DASS-S; α =.73) and anxiety (DASS-A; α =.78) symptoms in the past seven days.

2.2.4. *Reinforcer pathology variables*

Trait and state tobacco reinforcing efficacy was assessed via CPT (Gonzalez-Roz et al., 2019). Participants reported the number of cigarettes they would purchase on a daily basis (vs today in the state version) at 26 increasing prices (0€, from 0.05€ to 0.50€ in 0.05€ increases, from 0.60€ to 1€ in 0.10€ increases, from 1.20€ to 2€ in 0.20€ increases, from 3€ to 4€ in 1€ increases, and from 6€ to 10€ in 2€ increases). The five demand indices were used: intensity (*i.e.*, consumption at zero cost), O_{max} (*i.e.*, maximum expenditure), P_{max} (*i.e.*, price associated to O_{max}), breakpoint (*i.e.*, price that suppresses consumption), elasticity (*i.e.*, sensitivity to increases in costs). Higher scores in all indices but elasticity indicate higher cigarette reinforcing efficacy. Delay discounting (DD) was assessed using a computerized task based on an amount-adjusting procedure (Holt et al., 2012). Participants were presented with a series of choices between smaller amounts of money available immediately and a larger amount (€1000) available after delays of one day, one week, one month, six months, one year, five years, and 25 years. The DD index used was AUC_{logd} (Borges et al., 2016), where a higher value corresponds with larger area under the curve and thus lower discounting.

2.2.5. *Other potentially relevant variables*

Negative and positive urgency were assessed using the Spanish version of the short UPPS-P (Cándido et al., 2012). Overall, subscales showed good internal consistency (α =.67–.85). Perceived environmental reward was assessed using the Spanish version of the EROS (Barraca and Pérez-Álvarez, 2010), which also showed good internal consistency in the current sample (α =.75). Alternative reinforcement was assessed using a smoking version of the Reinforcement Survey Schedule (RSS; Murphy et al. 2015). Participants in the RSS reported the frequency of past month engagement (0 = zero to 4 = more than once a day) and enjoyment (0 = unpleasant or neutral to 4 = extremely pleasant) of 16 different activities. Smoking-related and smoking-free reinforcement were calculated by the mean cross product of frequency and enjoyment. Total reinforcement ratio (TRR) was calculated by dividing smoking-related reinforcement by the sum of smoking-related and smoking-free reinforcement.

2.3. *Procedure*

The procedure was based on Hogarth et al. (2015) except for the mood induction. Participants were screened, consented and completed questionnaires in the following order: FTCD, CPT-trait, DASS-21 and -A, EROS, UPPS-P, RSS, delay discounting, CPT-state, and smoking desire. They then took a 10–15-minute break to smoke a cigarette, during which they were randomly assigned to either the unpleasant or pleasant mood induction group. After the break, participants provided a CO sample, reported their smoking desire (to ensure satiation) and current mood and were told which group they were assigned to.

Pleasant and unpleasant mood was inducted using an episodic past thinking procedure, in which participants retrieved and vividly visualized a personal autobiographical memory associated with a strong emotional valence (Bickel et al., 2017; Szpunar, 2010). Participants were first instructed to recall a specific personal memory that was strongly associated with either a pleasant or unpleasant emotional experience, depending on the condition to which they had been assigned. They were given oral instructions emphasizing the importance of selecting a vivid, detailed memory that involved contextual elements such as the location, people present, emotions felt, and activities taking place. Participants then wrote a brief description of the chosen memory, including as much detail as possible about the event. Following this, they were seated in a comfortable armchair and instructed to close their eyes and vividly imagine the selected memory for a period of three minutes. To enhance the emotional valence of the memory, participants listened through headphones to either Barber's Adagio for Strings (for the unpleasant condition) or Mozart's *Eine kleine Nachtmusik* (for the pleasant condition) while engaging in this visualization exercise. After the induction, participants rated their current mood and completed again the CPT-state and delay discounting task.

2.4. Data analysis

First, the three-criterion algorithm based on Stein et al. (2015) was used to identify non-systematic demand data. No cases of non-systematic data were found but a total of seven outliers (0.45 %) at baseline and nine outliers (0.58 %) at post-test were detected in the raw CPT data and replaced by a value one unit higher than their next lowest non-outlying value. Two outliers at index level were identified at baseline (O_{max} and P_{max}) and post-test (O_{max} and elasticity). All indices were subjected to log transformations to improve data distribution (baseline: skewness (Sk) ranged between −0.13 and 0.62; kurtosis (K) ranged between −0.63 and 0.50; post-test: Sk = -0.82, 0.87, K = -0.37, 2.18). All CPT indices were observed except for elasticity, which was calculated using the Koffarnus et al.(Koffarnus et al., 2015) formula ($k = 2.22$ and 1.85 at baseline and post-test, respectively).

Following Smith et al. (2018) recommendations on reporting non-systematic data in DD task, we modified the first criterion of Johnson and Bickel (2008), based on previous studies (Martinez-Loredo et al., 2017). Data were considered non-systematic if 1) There were at least two indifference points greater than the preceding point by a magnitude greater than or equal to 20 %, or 2) if the last indifference point was not less than the first indifference point by at least a magnitude equal to 10 %. Two participants met the second criteria at baseline and three at post-test. Nonetheless, as the study was aimed at testing the modification of DD by emotional induction, only participants violating the second criterion at both assessments ($n = 1$; 1.59 %) were excluded.

Descriptive statistics and differences at baseline between both groups were performed in sociodemographic data, tobacco-related variables and dependent variables. Differences were calculated either via *t*-test or χ^2 test. Two 2 × 2 analyses of variance (ANOVA) were used to test the effect of both satiation and mood induction procedures.

To test if mood induction reverses tobacco devaluation produced by satiety (pre-registered objective), we used three ANOVA, with one within- (time: pre-test, post-test) and one between-subject (group: unpleasant mood, pleasant mood) variables. Effect sizes were calculated using Cohen's f ($f = \sqrt{\eta_p^2/1 - \eta_p^2}$; small =.10, medium =.25; large =.40).

To examine if the effect depends on the degree of induction, we used zero-order Pearson correlations between differential scores of mood change, DD and CPT. Also, participants were median split divided into four groups according to their change in mood status (high-unpleasant, low-unpleasant, low-pleasant, and high-pleasant), as per the original study. As both low induction groups did not differ significantly, they were merged into the same group. Welch's correction for violation of homoscedasticity was used when needed. Pairwise comparisons were performed using either Šidák or Games-Howell post-hoc tests, according to the homoscedasticity test.

Finally, to explore the effect of other RP-related variables (DASS, NU, PU, EROS and RSS) on the experimental effects, three analyses were performed. First, we calculated baseline mean differences on those variables between induction groups (unpleasant mood vs pleasant mood) and subgroups (high unpleasant vs low vs high pleasant). Second, the association between those variables and changes in mood, CPT and DD was calculated via zero-order Pearson correlations. Finally, multiple linear regressions explored the predictive power of these candidates on post-test RP variables (Block 1: pre-, post-test and differential scores in mood; Block 2: DASS, EROS, NU, PU, substance-free and tobacco reinforcement or TRR. Minimum zero-order correlation to enter in the model $r = .1$).

3. Results

3.1. Preliminary results

There were no statistically significant differences between groups in any of the explored sociodemographic characteristics ($p = .106$–.999) or tobacco-related variables ($p = .089$–.999). Also, participants did not differ in levels of DD ($p = .627$) or any CPT index at baseline ($p = .07$–.678) (Table 1).

The satiation procedure succeeded as shown by the main effect of time (pre-satiation, post-satiation) on the pleasure of puffing [$F(1) = 27.36, p < .001, f = 0.66$] and on the desire to smoke [$F(1) = 190.90, p < .001, f = 1.76$]. Groups (unpleasant, pleasant mood) did not differ in their satiety experience in either variable ($p = .844$ and $p = .923$, respectively). Thus, participants in both groups were equally satiated.

Regarding mood induction, the ANOVA yielded a statistically significant interaction between time (pre-test, post-test) and group (unpleasant, pleasant mood) [$F(1) = 51.58, p < .001, f = 0.91$]. Although the mood induction protocol was effective in both groups in the hypothesized direction (Table 1), mood change was larger in the unpleasant ($f = 0.88$) than in the pleasant group ($f = 0.40$).

3.2. The effect of mood induction on tobacco reinforcing efficacy and delay discounting

The pre-registered analyses (H1a) showed that mood induction on DD had no effect [$F(1) = .768, p = .384, f = 0.12$]. Despite lacking clear evidence of interactive effects of time [$F(1) = .258, p = .614, f = 0.06$], the effect size of reductions in DD among participants in the pleasant mood group was four times larger than among those in the unpleasant mood group ($f = 0.13$ vs.03).

Regarding CPT indices (H1b), there was a significant time*group interaction [$F(4) = 4.61, p = .003, f = 0.57$] for all indices except P_{max}. Effect sizes were large across indices ($f_{intensity} = 0.47$; $f_{Omax} = 0.50$; $f_{elasticity} = 0.50$). As some participants ($n = 6$) did not present breakpoint in the CPT task, this index was analyzed independently with similar results [$F(1) = 8.22, p = .006, f = 0.39$]. Post hoc comparisons suggested that while intensity, O_{max} and breakpoint decreased and elasticity increased in the pleasant mood induction group, only O_{max} and breakpoint increased after the unpleasant mood induction.

3.2.1. Relationship between the magnitude of mood induction, tobacco reinforcing efficacy and delay discounting

Last pre-registered analyses (H1c) showed that changes in self-reported mood correlated significantly with changes in intensity ($r = .497, p < .001$), O_{max} ($r = .379, p = .002$) and elasticity ($r = -.321, p = .011$). That is, greater increases in unpleasant mood was associated with greater increases in intensity and O_{max}, and with greater decreases in elasticity. Conversely, increases in pleasant mood were associated with reductions in intensity and O_{max}, and increases in elasticity (Table 1S).

To test the effect of the magnitude of mood induction on dependent variables, participants were grouped into high vs low self-reported mood change following a median split procedure. An ANOVA on differential scores in mood yielded a significant main effect [$F(3, 32.04) = 87.03$, $p < .001$]. Specifically, post-hoc test showed that the high-unpleasant group ($n = 15$) presented a significantly lower mean than low-unpleasant ($n = 16$), low-pleasant ($n = 16$) and high-pleasant ($n = 17$) sub-groups (all $p < .001$). Also, the high-pleasant group presented a significantly higher mean than the other three groups (all $p < .001$). Both low-induction groups did not differ significantly from each other ($p = .495$), thus they were merged (Fig. 1).

ANOVAs on differential scores in RP variables between the three groups (high unpleasant vs low vs high pleasant) yielded statistically significant differences for intensity ($p = .002$), O_{max} ($p = .007$) and elasticity ($p = .031$) but not for DD ($p = .877$), P_{max} ($p = .282$) or breakpoint ($p = .052$). Specifically, pleasant (vs unpleasant) mood induction promoted greater changes in tobacco reinforcing efficacy. Baseline values in RP variables did not differ between groups (all $p \leq .292$), ruling out potential confounding effects.

3.3. Effect of individual differences in other RP-related variables on the experimental effects

Beyond pre-registered analyses we explored the relationship between baseline individual differences in depressive, anxiety and stress symptoms, urgencies, environmental reinforcement, substance-free/ tobacco reinforcement, CPT, DD and mood induction. There were no statistically significant differences at baseline between groups ($p < .205$) or subgroups ($p < .085$) in any of the explored variables.

Among those in the unpleasant mood group, stress level correlated significantly with P_{max} at post-test ($r = .443$, $p = .013$) and anxiety with P_{max} ($r = .482$, $p = .006$), O_{max} ($r = .439$, $p = .013$), elasticity ($r = -.363$, $p = .045$) and DD ($r = -.475$, $p = .007$) at post-test. Also, negative urgency correlated with intensity ($r = .389$, $p = .031$) and DD ($r = -.432$, $p = .015$), while positive urgency only correlated with DD ($r = -.454$, $p = .010$). Finally, tobacco reinforcement correlated with all RP variables at post-test ($r = |.454 - .604|$) (Table S2).

For the pleasant mood group, anxiety correlated with DD ($r = -.457$, $p = .049$) at post-test, and environmental reward with changes in P_{max} ($r = -.362$, $p = .045$). Also, negative urgency correlated with DD ($r = -.532$, $p = .002$). Finally, while substance-free reinforcement correlated with post-test and changes in intensity ($r = -.359$, $p = .047$, and $r = .442$, $p = .013$, respectively), tobacco reinforcement correlated with all CPT indices post-test ($r = |.425 - .433|$) except for breakpoint. Relatedly, reinforcement ratio correlated significantly with post-test intensity, O_{max} and elasticity ($r = |.417–.521|$), as well as changes in DD ($r = -.417$, $p = .020$) and P_{max} ($r = -.365$, $p = .043$). (Table S2)

Multiple linear regressions showed that, in the unpleasant mood group, only post-test breakpoint was predicted by baseline environmental reward ($\beta = .542$, $p = .042$) in addition to baseline scores ($\beta = .556$, $p = .013$). Regarding the pleasant group, post-test breakpoint and O_{max} were predicted by baseline depressive symptoms ($\beta = -.389$, $p = .018$ and $\beta = -.235$, $p = .049$, respectively) in addition to baseline scores ($\beta = .748$ and $\beta = .836$, respectively, $p < .001$). Also, post-test P_{max} was predicted by baseline reinforcement ratio ($\beta = .400$, $p = .015$, 95 % CI = 0.195, 1.661) in addition to baseline scores ($\beta = .527$, $p = .001$, 95 %CI = 0.271, 0.921) (Table S3).

4. Discussion

The current study aims to replicate previous evidence on the effect of mood induction on nicotine satiety and expand evidence on the RP model. In our design, all participants were first sated, and the key question was whether mood induction could restore the reinforcing value of tobacco under conditions of satiety. This approach allowed us to isolate the specific contribution of emotional state on tobacco demand within a controlled satiety context, and to examine its implications for the RP model. Our hypothesis was partially confirmed through two main findings: 1) While pleasant mood induction decreased tobacco reinforcing efficacy, unpleasant mood induction increases intensity, O_{max}

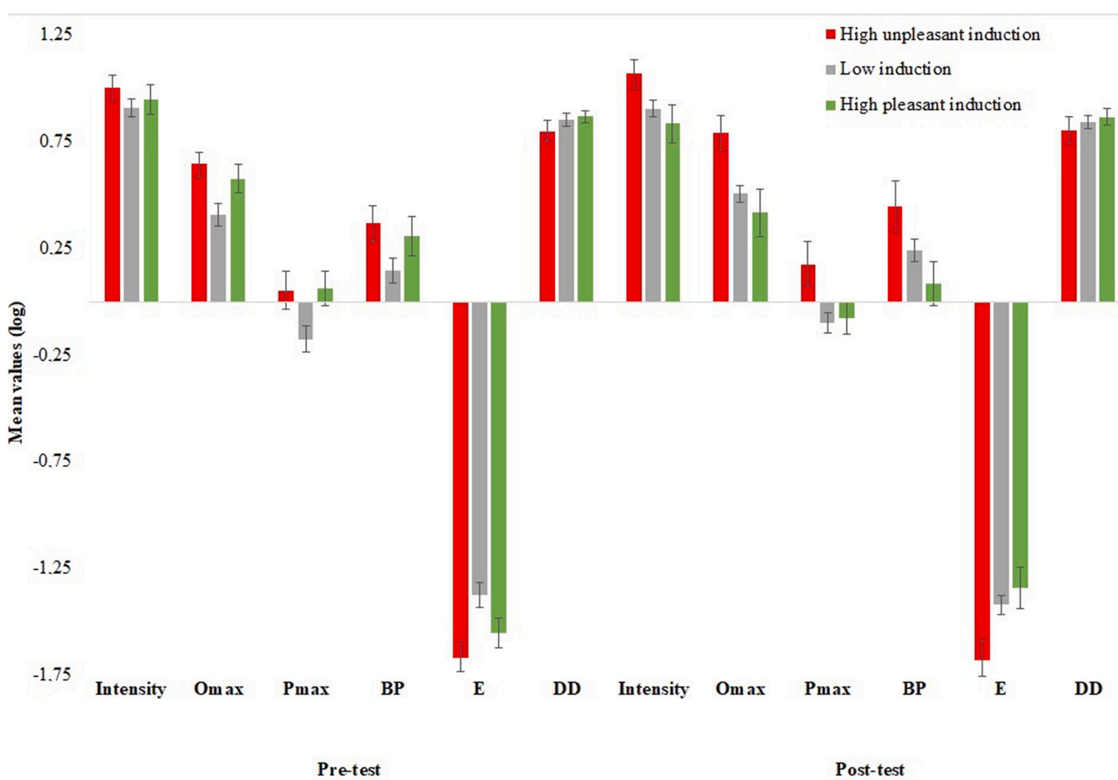

Fig. 1. Mean value of reinforcer pathology variables pre- and post-induction according to self-reported change in mood. **Legend**. BP = Breakpoint; E = Elasticity; DD = Delay discounting.

and breakpoint and decreases elasticity, in a dose-dependent manner; 2) post-induction scores in RP variables were associated with different baseline variables in each group.

Consistently with the original study (Hogarth et al., 2015) and our hypothesis, unpleasant mood works as a motivating operation. High unpleasant mood not only abolished the effect of nicotine satiation but also increased intensity, breakpoint and O_{max} while decreasing elasticity. These results align partially with a previous study suggesting that changes in negative affect predict breakpoint, O_{max} and elasticity (Dahne et al., 2017) and with meta-analyses highlighting the relevance of intensity, O_{max} and elasticity (Gonzalez-Roz et al., 2019, 2023; Martinez-Loredo et al., 2020), and their sensitivity to mood induction (Acuff et al., 2020). O_{max} measures the maximum expenditure required to obtain tobacco, and its increase under high unpleasant mood indicates the expected cost of smoking to regulate emotions (Weiss et al., 2022), which may be learned in the context of abstinent-induced negative affect (Piper et al., 2011). This prior learning could make unpleasant emotions serve as context for augmental rule-governed behavior (*i.e.,* a rule that changes the degree to which events function as reinforcers/punishers through relational framing) (Hayes et al., 2004), which also increases the unconstrained reinforcing value (intensity of demand). The decrease in elasticity and participants' satiation status support this explanation, as elasticity measures the insensitivity to incremental costs – a property of rule-governed behaviors (Kissi et al., 2017). Given the potential relevance of rule-governed behavior in mood and behavioral control, future studies should integrate the role of metacognition on RP. Specifically, metacognition as a description of private experiences modifies emotional events (Mansueto et al., 2024) which may evoke impulsive behaviors (i.e., urgency) and ultimately modify levels of DD or demand (Spada et al., 2007).

Participants under high pleasant mood (vs low pleasant) showed lower intensity and O_{max} and higher elasticity, contrary to the original study finding no differences in tobacco choice (Hogarth et al., 2015). This finding suggests that a significant increase of pleasant mood may act as an establishing operation for alternative behaviors that support abstinence, by decreasing the reinforcing value of tobacco more effectively than satiety. This is supported by the fact that participants were asked about the cigarettes they *expected* to purchase *later in the day*, not *immediately*. Thus, even if tobacco reinforcing efficacy was completely abolished, participants still expected to smoke later. The higher reduction in certain CPT indices (specifically those increased by unpleasant mood) under high pleasant mood induction suggests that this induction may protect against tobacco use.

The lack of evidence supporting mood effects on DD may be due to diverse factors beyond a genuine null effect, which we consider unlikely, given prior evidence of mood-induced changes in discounting (Ifcher, 2011; Lerner et al., 2013), and present findings of greater reduction in the pleasant (vs unpleasant) mood group and the association between DD and other mood-related variables. The main factor may be the non-specificity of the measure, as it assessed the discounting of money rather than cigarettes, which may reduce sensitivity to affective manipulations. This limitation has been noted in prior work on commodity-specific discounting (Odum et al., 2020; Rasmussen et al., 2024). Additionally, a general discounting index might not be sensitive enough to detect mild mood changes. Most participants were university students, which might have reduced data variability, limiting the ability to detect significant differences. Furthermore, the limited measure of emotional status might have prevented detecting any significant effects. Future studies should explore the effect of emotions on DD using a more in-depth mood assessment.

The effect of mood on DD may depend more on emotional regulation than on acute mood status. Our study shows that higher NU was associated with higher DD after both mood inductions, and higher PU was associated with higher DD after pleasant mood induction. These results align with previous studies (Park et al., 2016) and theoretical propositions (Martínez-Loredo, 2023). Post-induction DD was also linked to emotional symptoms in both groups, highlighting the role of emotional regulation. In fact, Lawyer and Jenks (2020) found no direct effect of mood induction on DD but observed that engaging in emotion suppression did reduce discounting, reinforcing the idea that regulation processes may be more influential than emotional valence. This interpretation is also consistent with Song et al. (2021), who found that reductions in discounting were better explained by enhanced cognitive control and perceived certainty, rather than by emotional valence itself. Thus, RP 3.0 should consider not only NU but emotional regulation more broadly. The association between DD and reinforcement ratio supports theoretical work (Acuff et al., 2023; Martínez-Loredo, 2023).

The association between environmental reward and breakpoint or emotional symptoms with O_{max}, P_{max} and elasticity is consistent with previous studies (Secades-Villa et al., 2018) and suggests that increasing response-contingent positive reinforcement may help prevent substance use by making individuals more sensitive to the cost of tobacco use, thus reducing the threshold where tobacco demand starts to decrease. Present findings also suggest that increasing the availability and accessibility to alternative *appetitive* activities (which enhance substance-free reinforcement and reduce substance reinforcement ratio) may serve as effective preventive strategies, as these variables are associated with reduced intensity of demand and DD in the context of pleasant mood (*e.g.,* hobbies, value-oriented activities) (Murphy et al., 2024).

Present findings should be interpreted considering the study limitations. First, mood status was evaluated using a 9-point scale ranging from very sad to very happy. Although this method is common (including in the original study), it may limit data variability and accuracy, potentially affecting result significance. Future studies should use a composite measure with multiple items, such as the PANAS (Watson et al., 1988). Second, participants were light smokers, which limited their dependence levels and primary outcome measures, potentially impacting the hypotheses tested. Replicating the present study with heavy smokers could clarify these relationships in more dependent individuals. Also, the large number of exploratory analyses increases the risk of type I errors and there was no control group (i.e., no mood induction group), although post-hoc analysis divided the sample according to mood change. Therefore, these results should be considered as preliminary and future studies should test specific hypotheses to confirm or refute these findings. Lastly, as per the original study, CPT and DD were assessed only after mood induction and not also after smoking. The effect of smoking satiety on these measures remains unknown; CPT indices might decrease, but expectations about smoking satiety on these measures remain unchanged. Future studies should explore the effect of satiation on state-CPT.

Despite these limitations, present results confirm previous findings on unpleasant mood's effects on substance choice and provide specific effects on individual indices of tobacco reinforcing efficacy. Also, they provide new evidence on the relationship between mood, substance-related variables and individual characteristics, contributing to theoretical development and suggesting potential intervention strategies for prevention and behavior modification. To our knowledge, this is the first study providing empirical relations between the variables proposed by the RP 3.0 and suggests updates (RP 3.1) to the model by integrating emotional regulation skills as moderators of the effect of mood on DD and substances reinforcing efficacy.

CRediT authorship contribution statement

Jorge L. Ordoñez-Carrasco: Writing – review & editing, Methodology, Formal analysis. **Victor Martinez-Loredo**: Writing – original draft, Visualization, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization.

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Declaration of Competing Interest

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

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.drugalcdep.2025.112733.

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