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Research paper

Aesthetic chills modulate reward learning in anhedonic depression

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ABSTRACT

Objective: This study aimed to examine the potential of experiencing aesthetic chills to enhance reward learning in individuals with elevated depressive symptoms, specifically anhedonia, by investigating the effect of chills on participants' ability to modulate behavior as a function of rewards.
Methods: A total of 103 participants with elevated depressive symptoms took part in the experiment. Among them, 59 participants had depressive symptoms (BDI $\geq$ 20), with 26 classified as "High Anhedonic" (HA) and 33 as "Low Anhedonic" (LA). Additionally, 39 participants without elevated depressive symptoms (BDI $<$ 20 and SHAPs $<$32) were included as the control group. We utilized ChillsDB, an open-source database of validated audiovisual stimuli known to elicit chills in the US population.
Results: Anhedonic participants who experienced chills demonstrated a significant increase in response bias (p = .004) towards rewards compared to those who did not experience chills. Highlighting specificity, no significant difference in reward bias was observed among LA participants.
Conclusions: These findings suggest that the experience of chills has the potential to impact reward learning in anhedonic individuals, aligning with the known neurobiology of this phenomenon. These results highlight the potential of aesthetic chills as a novel approach to elicit and enhance positive affect in depressed populations.

1. Introduction

Major Depressive Disorder (MDD) is a pressing public health crisis affecting 121 million individuals globally and contributing to 850,000 deaths per year (Bromet et al., 2011). For the majority of patients, Selective Serotonin Reuptake Inhibitors (SSRI) remain the treatment of choice (Weilburg, 2004). However, up to 70 % of individuals with MDD experience anhedonia, a general decrease in hedonic tone (Pizzagalli, 2022), a condition that SSRIs side effects can aggravate—i.e., sexual dysfunctions, sleepiness, and weight gain (Goodwin et al., 2017; Price et al., 2009; Hirschfeld, 2003; Cascade et al., 2009). Further, anhedonic symptoms predict poor treatment outcomes in MDD (Vrieze et al., 2014). While most interventions reduce negative affect in depression (Boumparis et al., 2016), we still lack reliable methods to induce and enhance positive affect non-pharmacologically in depressed populations (Craske et al., 2019). Recently, researchers have been interested in inducing peak positive emotions to improve hedonic tone (Boumparis et al., 2016; Craske et al., 2019; Taylor et al., 2017; Vara et al., 2020). Additionally, switching to antidepressants that enhance dopaminergic and noradrenergic activity seem to afford a therapeutic advantage over serotonergic antidepressants (SSRI) in the treatment of symptoms associated with reward dysfunctions (Nutt et al., 2007). Nonetheless, the field still falls short of clinically valid and widely accessible treatment options for personalized positive affect exposure.

To address this gap and build on previous studies (Jain et al., 2022; Schoeller et al., 2024b), we investigated whether experiencing aesthetic chills—a peak emotional response to stimuli such as film or music (Schoeller et al., 2023b; Blood and Zatorre, 2001; Schoeller and Perlovsky, 2016, Schoeller, 2015c) characterized by shivers and goosebumps (Benedek and Kaernbach, 2011; de Fleurian and Pearce, 2021)—could improve hedonic tone in people with depression. Specifically, this study concentrates on positive, rewarding chills (Blood and Zatorre, 2001), while setting aside the topic of negative, aversive chills (Zald and Pardo, 2002). This exploratory study extends preliminary findings

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suggesting that the experience of chills mitigates maladaptive cognitions in depression (Schoeller et al., 2024b). Aesthetic chills are known to engage dopaminergic release in the striatum (Salimpoor et al., 2011; (Blood and Zatorre, 2001; Chabin et al., 2020; Ferreri et al., 2021; L et al., 2023; Salimpoor et al., 2011; Zald and Pardo, 2002; Salimpoor et al., 2011) as well as activity in reward and salience regions (Nucleus Accumbens [NAcc], Orbitofrontal cortex [OFC], Ventral Tegmental Area [VTA]) (Blood and Zatorre, 2001). Indeed, dopamine contributes significantly to the pathophysiology of depression (Brown and Gershon, 1993; Yadid and Friedman, 2008) and dopamine precursors, agonists, and reuptake inhibitors show therapeutic efficacy in depression (Kapur and Mann, 1992).

In this exploratory study, we leveraged the Probabilistic Reward Task (Pizzagalli et al., 2005), to implicitly gauge reward learning in individuals with depression, both before and after exposure to videos specifically crafted to induce chills (Schoeller et al., 2023a, 2023b). Importantly, the responses among subjects were not uniform; some experienced chills, while others did not – a common phenomenon due to a host of psychosociocultural factors (Schoeller et al., 2024a, 2024b, 2024c). This variation provides a unique opportunity to assess the role that emotional chills may play in modulating reward learning mechanisms. This study builds on existing research, which has indicated that individuals with depression often demonstrate a reduced capacity for reward-based decision-making as evidenced by their performance on the PRT (Pizzagalli et al., 2008), as well as impaired probabilistic learning (Kunisato et al., 2012). Moreover, prior studies using EEG and MRI technologies have found decreased striatal activity in depressed subjects during both the anticipation of rewards and the reception of partially unpredictable rewards, as compared to healthy controls (Keren et al., 2018; Pizzagalli et al., 2009). We hypothesized that experiencing aesthetic chills will increase reward learning, as measured by potentiated response bias towards a more frequently rewarded stimulus, in individuals with high anhedonia compared to those who do not experience chills. Further, the experience of aesthetic chills should lead to an increase in positive affect, indicated by higher self-reported valence and arousal scores, in all three populations (high anhedonia, low anhedonia, and control) compared to those who do not experience chills. To test these hypotheses, we utilized a within-subjects experimental design administering the Probabilistic Reward Task and self-report affect measures before and after exposure to validated aesthetic chills stimuli. It is well-established that individuals vary in their emotional responses to the same stimuli, and these differences can provide valuable insights into the mechanisms of emotion (Hamann and Canli, 2004). Following a within-subject design, we compared differences in reward processing between participants who experienced chills to those who did not, when exposed to the same stimulus. While this method may seem to lack traditional control conditions, it provides a more precise isolation of the chills effect itself as alternative designs using non-chill-inducing stimuli as controls would fundamentally fail to capture the specific phenomenon of interest, potentially conflating the absence of chills with the absence of emotionally evocative content altogether. Using non-responders as controls can help isolate the specific neural or psychological processes associated with the emotional experience (here, chills) by contrasting them with those who do not experience the same response (see e.g., Nummenmaa and Saarimäki, 2019; Ochsner et al., 2002; Jacobsen et al., 2006), allowing for a focused examination of chills effects while controlling for stimulus content.

2. Methods

2.1. Procedure

Participants were recruited through an online platform (Prolific) and screened for depression and anhedonia. First, they signed a consent form, provided their sex and age and answered demographic questions (age, sex, ethnicity). They then filled out the Beck Depression Inventory (BDI) and Snaith-Hamilton Pleasure Scale (SHAPS). Next, they completed three blocks of the PRT for a total duration of 15 min. Afterward, participants indicated their levels of emotional valence and arousal on 10 items analog rating scales and were randomly assigned to view one of two audiovisual stimuli (5 min). Following exposure to the stimulus, participants were asked to rate their emotional valence and arousal, their chills frequency, duration, and intensity, frequency and intensity of goosebumps, as well as some qualitative questions about the experience. Finally, they completed another three blocks of the PRT. The total study length was roughly 50 min (Fig. 1).

2.2. Materials

2.2.1. Beck Depression Inventory (BDI)

The BDI-1A is a 21-item, self-report rating inventory that measures characteristic attitudes and symptoms of depression (Beck et al., 1961). The BDI takes approximately 10 min to complete and respondents require a fifth – sixth grade reading level to adequately understand the questions (Groth-Marnat, 1990). Following (Beck et al., 1988), scores of 20 or greater indicated a participant was classified as depressed.

2.2.2. Snaith-Hamilton Pleasure Scale (SHAPS)

We used the original international version of the Snaith-Hamilton Pleasure Scale (SHAPS), developed by (Snaith et al., 1995), to measure hedonic tone. SHAPS is a well-established tool commonly used to assess an individual's capacity for experiencing pleasure and their anticipation of pleasurable experiences. The scale consists of 14 items, and participants are asked to indicate their level of agreement or disagreement on a four-point Likert scale, ranging from "strongly agree" to "strongly disagree." A recent meta-analysis (Trøstheim et al., 2020) found a mean SHAPs score of 33.1 with 95 % CI ranging from 32.0 to 34.1 for current MDD Anhedonic patients. Based on this we chose SHAPs score of 32 and higher as cutoff identifying anhedonic participants.

2.2.3. Probabilistic Reward Task (PRT)

The PRT is a computerized task rooted in signal detection theory (Pizzagalli et al., 2005, 2008, 2020). On each trial, participants are asked to determine, via key press, whether one of two difficult-to-differentiate stimuli had been presented. Similar to prior PRT studies (Pizzagalli et al., 2008), this study used three blocks of 100 trials to limit task duration. For each trial, participants were presented with images of dogs and cats (presented for 375 ms) in ratios of 6:10 and were instructed to identify whether more dogs or cats were present by pressing the correct key press ("z" or "/", counterbalanced). Per design, the brief stimulus presentation time (375 ms) and small physical difference between the stimuli make discrimination challenging. Critically, and unbeknownst to participants, the task includes an asymmetrical reinforcement schedule such that one of the two stimuli (the "rich" stimulus) is rewarded ("Correct!! You Won 20 Cents") four times more frequently than the "lean" stimulus (32 vs. 8 times per block). Participants were instructed that not all correct responses would be followed by rewards and to respond as quickly and accurately as possible in order to maximize task earnings. Further a variation of the stimulus ("dog" vs "bunny") with slightly increased presentation time (425 ms) - to approximate difficulty across task versions - was used in the second PRT task to maintain novelty and capture the key variables. The stimuli type and key presses were counterbalanced across all trials.

Discriminability is computed as:

$$logd = \frac{1}{2} log\left(\frac{(Rich_{correct} + 0.5)*(Lean_{correct} + 0.5)}{(Rich_{incorrect} + 0.5)*(Lean_{incorrect} + 0.5)}\right)$$

Response bias is computed as:

$$logb = \frac{1}{2} log\left(\frac{(Rich_{correct} + 0.5)*(Lean_{incorrect} + 0.5)}{(Rich_{incorrect} + 0.5)*(Lean_{correct} + 0.5)}\right)$$

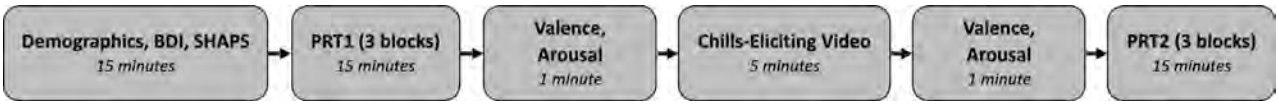

Fig. 1. Online study design where participants completed questionnaires and tasks before and after viewing a chills-eliciting video (Total duration = 50 min). PRT: Probabilistic Reward Task (Pizzagalli et al., 2008).

2.2.4. Chills stimuli

To identify the stimuli, we used ChillsDB, an open-source database of validated audiovisual stimuli that are known to elicit aesthetic chills (goosebumps, psychogenic shivers) in a US population (Schoeller et al., 2022). The stimuli were extracted from the "Gold Standard" of the top 6 validated videos. Both stimuli have a probability ≥80 % of eliciting chills in a US population ($N = 30$) (Table 1).

2.3. Participants

359 participants were consented and screened for the experiment. Participants were screened through an online platform with comprehensive pre-screening features commonly used to recruit participants (Prolific.ac). Prolific is a specialized tool designed to connect researchers with a diverse global pool of participants for research studies, offering tailored participant recruitment through a range of pre-screening tools including mental health diagnoses, medication, age, gender identity, nationality, and employment status (Palan and Schitter, 2018). All participants reported a prior physician-diagnosed depression. In addition, all participants were administered the Beck Depression Inventory (BDI) and Snaith-Hamilton Pleasure Scale (SHAPS) to assess their depression and anhedonia level at the time of the experiment. 134 participants completed the first PRT and 129 completed the second. Two subjects were removed due to excess time taken for completion of the procedures (>100 mins). Following quality control, which consisted of removal of participants who failed data quality checks of PRT (see supplementary material), 103 participants' data were analyzed. Fifty-nine ($N = 59$) participants met the criteria of depression (BDI ≥20). We further identified "High Anhedonic" (HA) participants based on SHAPS (≥32). The remaining MDD participants were labeled as "Low Anhedonic" (LA). Twenty-six participants met the qualifications for HA and 33 for LA. 39 Participants who had BDI < 20 and SHAPs <32 were included as part of the control group. Remaining 5 participants who had SHAPs ≥32 and BDI < 20 were not included in the analyses. A total of 98 participants' data were compiled for the final analysis (Table 2).

2.4. Ethics

The experiment is in compliance with the Helsinki Declaration. The study was approved by the Committee on the Use of Humans as Experimental Subjects at the Massachusetts Institute of Technology (MIT). All participants gave their voluntary informed consent and we followed the Ethics Code of the American Psychological Association. All participants were informed about the purpose of the research, their right to decline to participate and to withdraw from the experiment, and the limits of confidentiality. The specifics of the PRT were not disclosed to them prior to the experiment. We also provided them with a contact for any questions concerning the research and with the opportunity to ask any questions regarding the phenomenon under study (aesthetic chills) and receive appropriate answers. All participants reacted positively to the experiment.

Table 1
Stimuli description (see details in Schoeller et al., 2022).

Giving (3 min, 2013)	In this famous Thai commercial, a young boy is helped by a store owner after being accused of theft. Years later, the store owner's kindness is repaid when the boy, now a doctor, saves his life. The ad gained significant popularity on YouTube, reaching 3.5 million views in 5 days.
Misere Mei, Deuis (5:14)	Tenebrae Choir performs Gregorio Allegri's Miserere mei, Deus at St. Bartholomew the Great, in London. The work's title, Latin for "Have mercy on me, O God," is from Psalm 51. The Renaissance composition has historically been shrouded in secrecy and mystique dating back to its first performances at the Sistine Chapel.

3. Results

Thirteen (N = 13) HA subjects reported chills (Mean Intensity = 5.46, STD = 1.27), thirteen (N = 13) LA subjects reported chills (Mean intensity = 6.31, STD = 2.90) and twenty four (N = 24) control subjects reported chills (Mean intensity = 5.83, STD = 2.56). A chi-square test of independence showed that there was no significant association between groups and chills count ($\chi^2 = 3.52$, $p = .172$). Thirty (N = 30) participants reported chills for the Giving stimulus (out of 53 exposed (56.6 %)) and twenty (N = 20) for the Miserere stimulus (out of 45 exposed (44.4 %)). Across all groups, chills intensity was positively correlated with age ($r = 0.293$, $p = .003$), arousal at baseline ($r = 0.253$, $p = .012$), and arousal and valence post experiment (arousal ($r = 0.422$, $p < .001$), valence ($r = 0.473$, $p < .001$)). Within each group, there was no significant difference in BDI and SHAPS score in the participants who reported chills compared to those who did not. There was no statistical significant difference in chills intensity between groups (Kruskal-Wallis Test, $\chi^2 = 2.53$, $p = .283$). Further there was no statistically significant difference in chills intensity between genders (Kruskal-Wallis Test, $\chi^2 = 3.00$, $p = .223$).

To test our primary hypothesis regarding the interaction between group membership, chills experience, and pre-post video exposure on PRT performance, we conducted a three-way repeated measures ANOVA. This analysis included Group (HA, LA, Control) and Chills (Yes, No) as between-subjects factors, and Time (Pre, Post) as a within-subjects factor. Reward Bias (RB) served as the dependent variable. We chose to exclude Block as a factor in this analysis to focus on our main hypotheses and avoid a complex four-way interaction. The analysis revealed a significant three-way interaction between Group, Chills, and Time ($F(2,576) = 4.110$, $p = .017$). This interaction indicates that the effect of experiencing chills on changes in reward bias from pre- to post-video exposure differed significantly across the three groups (HA, LA, and Control).

3.1. High vs low anhedonia in reward task

In order to evaluate further the global disparity in reward sensitivity with respect to the severity of anhedonia, we employed an analysis of variance (ANOVA) model with Group (HA, LA, Control) and Block (1,2,3) as independent variables, and reward bias (RB) from pre-exposure PRT as dependent variables. The Block effect was significant ($F(2,285) = 9.4$, $p < .001$), but Block*Groups did not show any significant differences ($F(4,285) = 0.508$, $p = .730$) (Fig. 2).

3.2. Effect of chills exposure on reward learning

Group × chills × pre-post
ANOVA - RB

(continued on next page)

Table 2
Demographic and psychological characteristics of high anhedonic, low anhedonic, and control groups with respect to chills response.

	High Anhedonic (HA) $N = 26$				Low Anhedonic (LA) $N = 33$				Control $N = 39$			
Chills	Yes ($N = 13$)		No ($N = 13$)		Yes (N = 13)		No ($N = 20$)		Yes ($N = 24$)		No ($N = 15$)	
On Medication	10 (76.9 %)		10 (76.9 %)		13 (100 %)		19 (95 %)		23 (95.8 %)		15 (100 %)	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Age	33.3	10.09	40.5	12.24	38.4	9.24	34.4	11.27	45.5	12.15	33.5	11.50
BDI	32.5	7.93	33.3	8.41	31.0	7.97	28.8	6.19	13.8	3.92	11.2	5.13
SHAPS	37.4	3.71	36.6	4.86	27.4	2.81	27.1	3.80	23.2	4.82	24.7	4.76
Sex												
Males	7		3		5		4		7		4	
Females	6		9		8		15		15		10	
Non Binary	0		1		0		1		2		1	
Race												
White	12		11		12		17		21		13	
African American	0		2		1		1		2		1	
Hispanic	0		0		0		1		1		0	
Mixed	1		0		0		1		0		1	

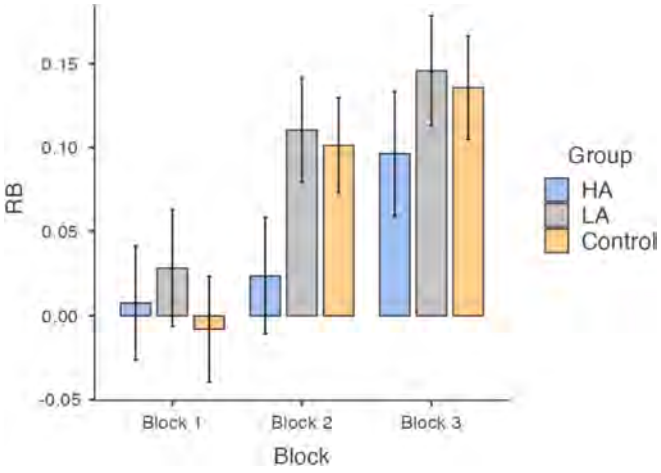

Fig. 2. Reward Bias (RB) before the experiment. The High Anhedonia (HA) group shows a lower response bias than the Low Anhedonia (LA) and Control group.

(*continued*)

ANOVA - RB

	Sum of Squares	df	Mean Square	F	p
	Sum of Squares	df	Mean Square	F	p
Group	0.0649	2	0.0324	0.805	0.448
Chills	0.0138	1	0.0138	0.342	0.559
Time	0.4700	1	0.4700	11.668	< 0.001
Group * Chills	0.1460	2	0.0730	1.812	0.164
Group * Time	0.0704	2	0.0352	0.874	0.418
Chills * Time	6.55e-7	1	6.55e-7	1.63e-5	0.997
Group * Chills * Time	0.3311	2	0.1656	4.110	0.017
Residuals	23.2016	576	0.0403		

In order to assess the impact of chills exposure on the High Anhedonia (HA) group during post-exposure PRT, we conducted an analysis of variance (ANOVA) using Chills Exposure (Yes, No), Block (1, 2, 3), and Time (PRT1, PRT2) as independent variables, while RB served as the dependent variable. Analysis revealed a significant Chills*Time interaction ($F(1,144) = 5.30$, $p = .023$). Bonferroni-corrected post hoc analysis revealed a significant increase in RB from PRT1 to PRT2 in subjects who experienced Chills ($t = 3.45$, $p = .004$) (Fig. 3); the groups did not differ pre-exposure ($p = 1.0$). Expanding RB performance blockwise showcases increased reward learning (Fig. 4).

Chills group showed an RB increase in post exposure compared to pre (see Table 3). The mean increase for participants exposed to chills was 0.145 whereas for no chills group was merely 0.008. To test differences in Response Bias, we selected a threshold of 0.05 (RB_{PRT2} - RB_{PRT1} $\geq$0.05), while seemingly insignificant, this increment is essential for discerning differences, since using a value of 0 could skew the statistics due to the learning effect (see Table 4). 10 out of 13 participants demonstrated an increase in response bias of 0.05 or more (binomial p (10/13) = 0.035). In contrast, only 6 out of the 13 subjects who did not experience chills showed a similar increase in response bias (binomial p (6/13) > 0.2).

Similarly to HA, we conducted an analysis of variance (ANOVA) in the Low Anhedonia (LA) group, using Chills Exposure (Yes, No), Block (1, 2, 3), and Time (PRT1, PRT2) as independent variables, while RB served as the dependent variable. There was no significant interaction of chills in the LA and control group (Fig. 5). In the LA group Block effect was significant $F(2,186) = 3.580$, $P = .030$. Similarly, in the control group, Block effect was significant $F(2,222) = 8.357$, $P < .001$.

Finally, to examine further the relationship between depression severity, anhedonia, and reward bias, we conducted generalized linear

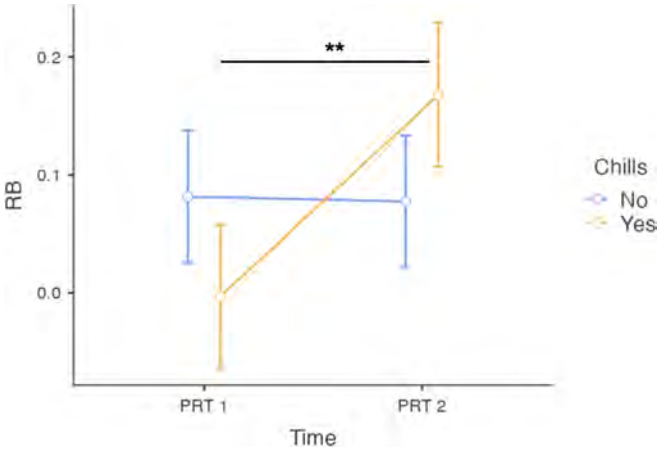

Fig. 3. Difference in reward bias (RB) for the HA group only, comparing PRT before (1) and after (2) exposure to chills. HA participants who experienced chills showed a significant improvement in RB after exposure to the chills as compared to HA participants who did not experience chills.

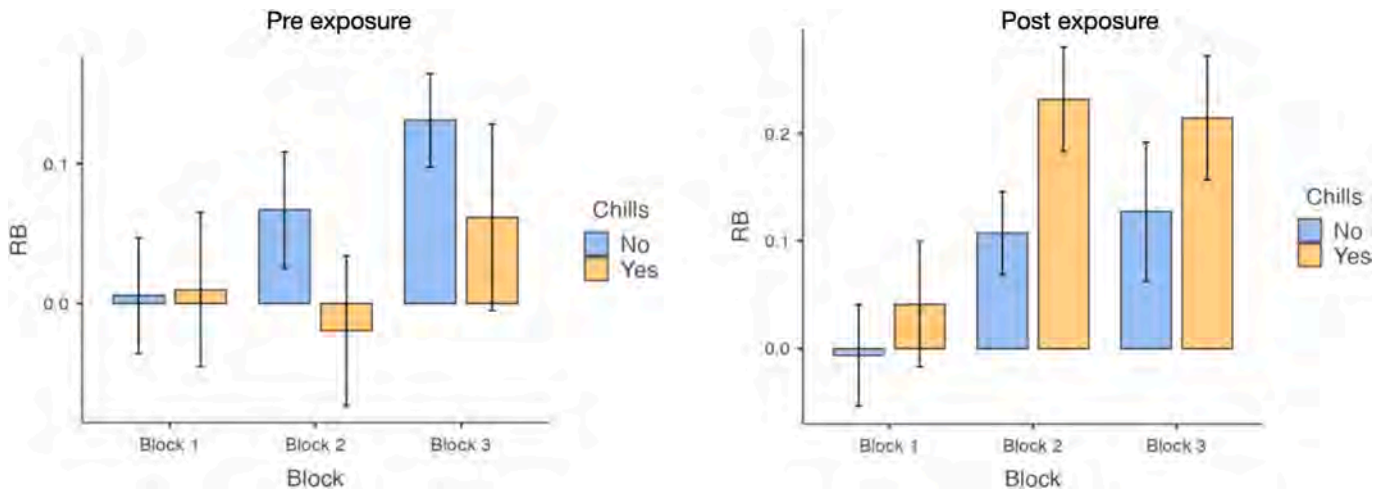

Fig. 4. Block wise changes in reward bias for anhedonic (HA) group.

Table 3
Estimated marginal means - chills * time.

				95 % Confidence Interval	
Time	Chills	Mean	SD	Lower	Upper
PRT 1	No	0.0679	0.0298	0.00910	0.1267
	Yes	0.0173	0.0298	−0.04155	0.0761
PRT 2	No	0.0761	0.0298	0.01724	0.1349
	Yes	0.1624	0.0298	0.10356	0.2212

Table 4
Number of participants showing increase of RB for (RB_{PRT2} - RB_{PRT1}) thresholds of 0, 0.05 and 0.1.

(RB_{PRT2} - RB_{PRT1})	Chills Exposure = Yes	Binomial	Chills Exposure = No	Binomial
≥0	11	p(11/13) = 0.01	10	p(10/13) = 0.035
≥0.05	10	p(10/13) = 0.035	6	p(6/13) = 0.21
≥0.1	8	p(8/13) = 0.15	5	p(5/13) = 0.15

models using continuous BDI and SHAPS scores rather than categorical groupings. For the BDI model, there was a significant three-way interaction between Chills experience, Time, and BDI score ($\chi2(15) = 37.5$, $p = .001$). The two-way interactions between Chills and BDI ($\chi2(15) = 24.2$, $p = .062$) and Time and BDI ($\chi2(15) = 21.2$, $p = .131$) were not significant. There was a significant main effect of BDI score ($\chi2(15) = 25.2$, $p = .048$). For the SHAPS model, there was a significant three-way interaction between Chills experience, Time, and SHAPS score ($\chi2(15) = 25.8$, $p = .040$). There was also a significant two-way interaction between Chills and SHAPS score ($\chi2(15) = 53.2$, $p < .001$). The two-way interaction between Time and SHAPS score was not significant ($\chi2(15) = 13.8$, $p = .541$). There was a marginally significant main effect of SHAPS score ($\chi2(15) = 24.7$, $p = .054$). These results confirmed that the effect of experiencing chills on changes in reward bias from pre- to post-video exposure varied based on participants' levels of depression and anhedonia. The relationship between anhedonia and reward bias appears to be particularly influenced by the experience of chills.

3.3. Effect of chills exposure on emotional state

In order to evaluate the effects of chills on the participant's affective state we analyzed the baseline and post exposure valence and arousal rating. Due to small sample size and violation of normality in various parameters, we used Mann-Whitney *U* test to compare the changes in affective scores across the participants who experienced chills versus those who did not. Among the HA group, those who reported chills had significantly higher valence scores post-exposure compared to those who did not report chills (see Table 5). Interestingly, the post-exposure scores for the HA chills group reached similar levels to the pre-exposure scores of the LA and control groups (see Fig. 6). In the LA group, those who experienced chills reported affective scores post-exposure comparable to the post-exposure scores in the control group who experienced chills.

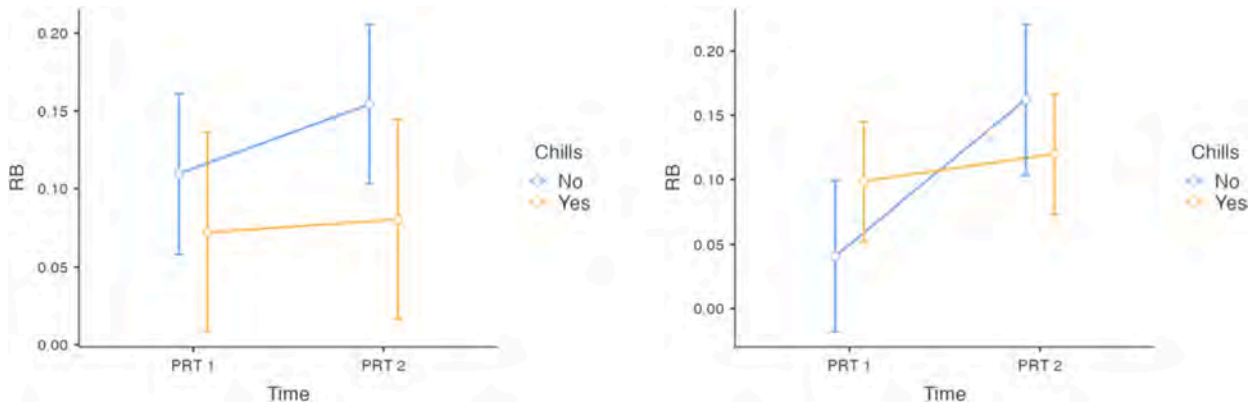

Fig. 5. Reward bias (RB) for the low anhedonia (LA) group (left) and the control group (right).

Table 5
Affective scores across different groups and time points, segregated by chills experience.

Group	Time	Measure	Chills	N	Mean	SD	Statistic	Statistic value	p
HA	Baseline	Valence	No	13	3.54	1.81	Mann-Whitney U	81.5	0.897
			Yes	13	3.31	2.1	Mann-Whitney U		
		Arousal	No	13	1.54	1.45	Mann-Whitney U	75	0.631
			Yes	13	1.85	1.63	Mann-Whitney U		
	Post	Valence	No	13	4.31	2.36	Mann-Whitney U	39	0.019
			Yes	13	6.31	1.49	Mann-Whitney U		
		Arousal	No	13	2.15	1.72	Mann-Whitney U	49.5	0.069
			Yes	13	3.38	1.56	Mann-Whitney U		
LA	Baseline	Valence	No	20	3.45	2.35	Mann-Whitney U	108	0.419
			Yes	13	4.23	1.83	Mann-Whitney U		
		Arousal	No	20	2.35	2.25	Mann-Whitney U	106.5	0.39
			Yes	13	3	2.16	Mann-Whitney U		
	Post	Valence	No	20	5.9	2.79	Mann-Whitney U	77.5	0.052
			Yes	13	7.54	2.03	Mann-Whitney U		
		Arousal	No	20	4.2	2.61	Mann-Whitney U	74	0.039
			Yes	13	6.08	2.6	Mann-Whitney U		
Control	Baseline	Valence	No	15	6.13	2.1	Mann-Whitney U	165	0.671
			Yes	24	5.83	1.86	Mann-Whitney U		
		Arousal	No	15	3.13	1.92	Mann-Whitney U	128	0.133
			Yes	24	4.25	2.52	Mann-Whitney U		
	Post	Arousal	No	15	3.8	2.51	Mann-Whitney U	120.5	0.087
			Yes	24	5.79	3.56	Mann-Whitney U		
		Valence	No	15	5.67	2.41	Mann-Whitney U	89	0.008
			Yes	24	7.79	2.15	Mann-Whitney U		

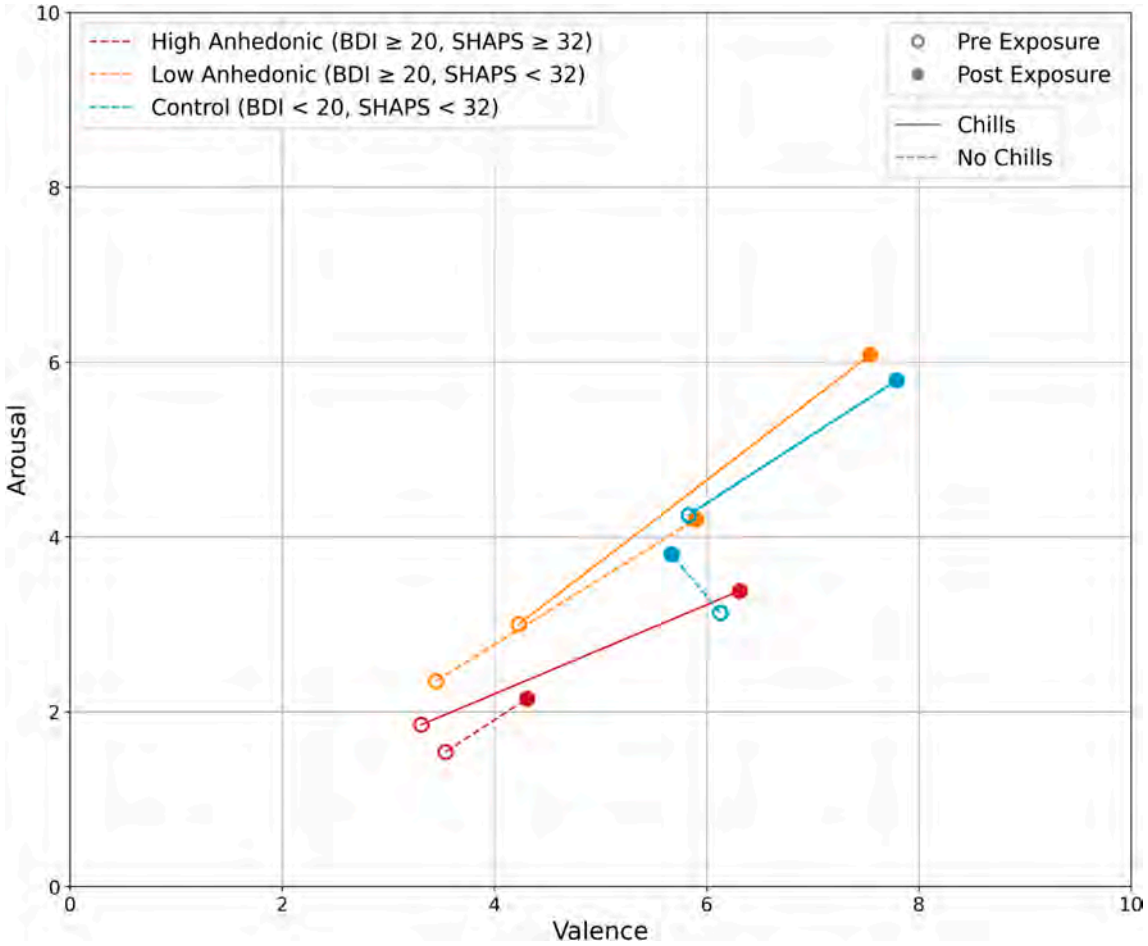

Fig. 6. Participants who experienced chills reported a larger shift in mean arousal and valence scores from pre to post assessment across all groups (HA, LA, and Control) compared to those who did not. Interestingly, the endpoint arousal and valence scores for the high anhedonia (HA) group after chills exposure were almost equivalent to the scores for the low anhedonia (LA) group without chills exposure. The endpoint scores for the LA no chills group (and therefore also the HA chills group) aligned with the starting scores for the control group. Additionally, the endpoint scores for the LA chills group matched the endpoint scores for the control group. This suggests that chills exposure in patients with high anhedonia can increase arousal and valence to levels comparable to people with low anhedonia who have not had chills exposure.

4. Discussion

We tested whether experiencing aesthetic chills could improve reward learning in individuals with elevated depressive symptoms, specifically anhedonia. The results suggest that exposure to chills had a significant impact on reward learning in anhedonic individuals but not in non-anhedonic patients. This effect suggests that chills exposure might temporarily affect and mitigate anhedonia in depressed populations, offering a potential avenue for reliable positive affect exposure in this population. These results are coherent with previous evidence supporting the role of chills in engaging dopaminergic release in reward and salience regions (Blood and Zatorre, 2001) and mitigating depressogenic cognitions (Jain et al., 2022; Schoeller et al., 2022). Indeed, dopamine dysregulation is a significant factor in the pathophysiology of depression (Yadid and Friedman, 2008) and interventions targeting dopamine have shown therapeutic efficacy (Dunlop and Nemeroff, 2007; Hori and Kunugi, 2012).

These results are also consistent with prior findings that depressed participants demonstrate deficits in reward-based decision-making (Kunisato et al., 2012) and reduced striatal activation during reward feedback (Brooks 3rd et al., 2009; Pizzagalli et al., 2009). Striatal dysfunction in major depression has been directly associated with deficits in the reward process (Pizzagalli et al., 2009), where extensive preclinical studies have shown that anhedonic traits in animal studies—typically induced by chronic exposure to stressors—correlate with altered DA transmission in specific brain regions (REF). Associated models emphasize the importance of a balanced DA interaction among the VTA, striatum, and PFC in maintaining normal hedonic behaviors (Pizzagalli et al., 2019), precisely the neurobiological circuit of the chills phenomenon (Blood and Zatorre, 2001; Salimpoor et al., 2009, 2011). Building on this understanding of DA transmission and the neurophysiology of chills, it's compelling to explore how such mechanisms overlap, and may coincide with DA striatal release (Salimpoor et al., 2009, 2011).

One way to conceptualize this interaction is to think of chills as the climax of the consummatory phase of reward processing (Berridge et al., 2009; Schoeller, 2015a; Schoeller and Perlovsky, 2016; Schoeller et al., 2024a, 2024b, 2024c), potentially affecting the rest of the reward cycle (Fig. 7), akin to cocaine intake and craving, as discussed in Blood and Zatorre (2001). The surge of dopamine at the chills episode might trigger the anticipation and reward bias observed in the anhedonic participants in this study. Chills have been previously associated to the pinnacle of the "consummatory" phase of the reward cycle (Schoeller, 2015a; Schoeller and Perlovsky, 2016; Schoeller et al., 2018), this is most evident in films where chills typically occur in the last third of the plot, where the story comes to a resolution, a.k.a., the film climax (Schoeller and Perlovsky, 2016) (Fig. 7). Chills have been theorized to correspond to a satiation of curiosity, i.e., the biological drive to reduce uncertainty, often associated to humans motivation to engage with film, music, and other epistemic activities (Schoeller, 2015b; Schoeller, 2016; Biederman and Vessel, 2006; Kenett et al., 2023; Sarasso et al., 2020). The intense bodily response serves as an interoceptive signal (i.e., somatic marker) (Carvalho and Damasio, 2021; Craig, 2008; Seth, 2013), and the phase transition to the subsequent phase known as the "satiatory", or Learning phase (Berridge et al., 2009).

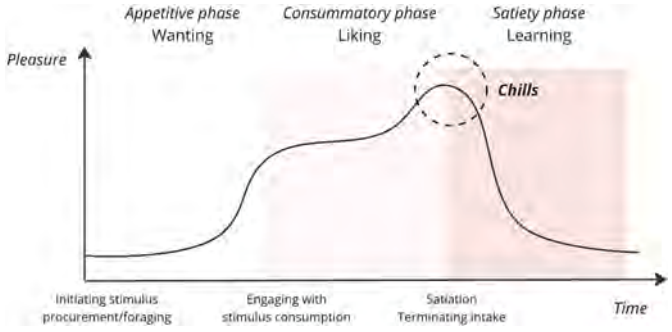

Fig. 7. Chills correspond to a significant surge in consummatory pleasure, exemplified by moments of intense emotional engagement during film consumption, marking the transition from the second "consummatory" phase to the third "satiety" phase, see further discussion in ("Schoeller (2015a) Knowledge, Curiosity, and Aesthetic Chills," n.d.; Schoeller and Perlovsky, 2016). Figure adapted from (Ellingsen et al., 2015; Schoeller and Perlovsky, 2016).

While this study is promising in hinting towards a non-pharmacological intervention for depressed populations and their anhedonic subsets, several limitations should be taken into consideration when interpreting the results. First, despite the large recruitment pool, the sample size of subjects with high anhedonia in this study was relatively small due to difficulties in recruiting these participants. A larger sample size of subjects would enhance the generalizability of the findings and provide more robust conclusions. Second, future research should control more closely for potential confounding variables such as medication, as some may influence hedonic tone (e.g., SSRIs, NDRIs and SNRIs) and, in turn, the observed responses. Third, it will be crucial for future studies to include more diverse samples to examine the cross-cultural validity of these findings. Furthermore, as our study utilized the BDI-IA, an older metric, future work should consider more current tools like the BDI-II or PHQ-9 to ensure relevance and accuracy in measuring depressive symptoms. Lastly, it would be valuable to explore the effects of different stimuli and modalities (e.g., auditory only) to ensure the findings are not specific to this particular set of two audio-visual stimuli (Grewe et al., 2011). While this study concerned positive, rewarding chills, the topic of negative, aversive chills, and their potential occurrence and consequences in depression is yet to be explored in future studies. Overall, this warrants further studies to address these factors and enhance our understanding of positive affect exposure in depressed populations.

5. Conclusion

Despite being the primary treatment for depression, SSRIs have limitations and can exacerbate anhedonia, a core symptom and predictor of depression. Current interventions mainly focus on reducing negative affect, leaving a significant gap in the development of reliable methods to induce and enhance positive affect in depressed individuals. The present exploratory findings suggest that chills exposure has a significant effect on reward learning in individuals with high anhedonia, aligning with the known neurobiology of the phenomenon. Exposure to chills resulted in an increase in reward learning from pre-exposure to post-exposure, indicating a temporary mitigation of blunted reward learning in these populations. These results highlight the potential of aesthetic chills as a novel approach to elicit and enhance positive affect in depressed populations. By targeting the consummatory phase of reward processing, chills exposure could offer a promising avenue for interventions aimed at improving hedonic tone and alleviating symptoms in anhedonic depression. Further research is warranted to explore the underlying mechanisms and long-term effects of chills exposure in depression, ultimately leading to the development of clinically valid and widely accessible treatment options.

CRediT authorship contribution statement

Abhinandan Jain: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Felix Schoeller:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Shiba Esfand:** Writing – original draft, Software, Methodology. **Jessica Duda:** Software, Resources. **Kaylee Null:** Software, Resources. **Nicco Reggente:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Diego A. Pizzagalli:** Writing – review & editing, Writing – original draft, Supervision, Software, Methodology,

Conceptualization. **Pattie Maes:** Writing – review & editing, Supervision, Investigation, Conceptualization.

Declaration of competing interest

Dr. Schoeller is the co-founder of BeSound SAS and Nested Minds LTD, holds ownership shares and has received compensation from both companies. Over the past 3 years, Dr. Pizzagalli has received consulting fees from Boehringer Ingelheim, Compass Pathways, Engrail Therapeutics, Neumora Therapeutics (formerly BlackThorn Therapeutics), Neurocrine Biosciences, Neuroscience Software, Otsuka, Sunovion, Sage Therapeutics, Sama Therapeutics, and Takeda; he has received honoraria from the American Psychological Association, Psychonomic Society and Springer (for editorial work) and from Alkermes; he has received research funding from the Brain and Behavior Research Foundation, BIRD Foundation, the Dana Foundation, DARPA, Millennium Pharmaceuticals, NIMH, and Wellcome Leap MCPsych; he has received stock options from Compass Pathways, Engrail Therapeutics, Neumora Therapeutics, and Neuroscience Software; he has a financial interest in Neumora Therapeutics, which has licensed the copyright to the probabilistic reward task through Harvard University. Dr. Pizzagalli's interests were reviewed and are managed by McLean Hospital and Partners HealthCare in accordance with their conflict of interest policies. No funding from these entities was used to support the current work, and all views expressed are solely those of the authors. All other authors have no conflicts of interest or relevant disclosures.

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AJ and FS conceived the study and set up the experiment with SE assistance. DAP, PM, and NR supervised the experiment providing guidance for the analysis. All authors contributed to the manuscript. This work was partially funded by a Joy Ventures Research Grant. FS and NR were also supported by funding from Tiny Blue Dot Foundation and Yosef Charitable Fund.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2024.10.038.

Data availability

All data are available at the following FigShare:

Schoeller, Felix; Jain, Abhinandan (2023). Aesthetic Chills Modulate Reward Learning in Anhedonic Depression. figshare. Dataset. doi: https://doi.org/10.6084/m9.figshare.24030213.v1

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