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No joy - why bother? Higher anhedonia relates to reduced pleasure from and motivation for threat avoidance

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ABSTRACT

Anhedonia impairs various components of the pleasure cycle, including wanting, liking, and the learning of pleasure-related associations. While successfully controlling threats might be inherently pleasurable, it remains unclear whether anhedonia affects this form of pleasure as well. With aversive pictures as threats, we conducted an online study ($N = 200$) to investigate the role of anhedonia during active avoidance learning process. Participants first learned cue-threat associations for different cues (threat vs. safety cues). In a subsequent avoidance learning phase, these cues signaled either avoidable, unavoidable, or no threat; participants could perform avoidance responses to prevent the upcoming threats during those cue presentations. Subjective relief pleasantness was measured after each threat omission. We found that higher trait anticipatory and consummatory anhedonia were both associated with lower relief pleasantness. Higher trait anticipatory anhedonia was also associated with fewer avoidance attempts. Since reduced threat-controlling behavior is reminiscent of a learned-helplessness state, the current results contribute to a better understanding of the connections between anhedonia and learned helplessness that have mostly been studied separately in the context of mood disturbance.

1. Introduction

Anhedonia, or the lack of motivation or ability to experience pleasure, causes people to refrain from previously enjoyed activities (American Psychiatric Association, 2013). As a transdiagnostic symptom to many psychiatric disorders (Husain & Roiser, 2018), anhedonia impairs various components of the pleasure cycle, including wanting (the appetitive phase that motivates the pursuit of pleasure), liking (the consummatory phase upon experiencing pleasure), and learning (the acquisition of pleasure-related associations; for more details, see Borsini, Wallis, Zunszain, Pariante, & Kempton, 2020; Rømer Thomsen, Whybrow, & Kringelbach, 2015). Recent evidence has shown that anhedonia is associated with sustained threat-related neural activations in response to the threat cue during threat extinction learning, where a former signal for threat is repeatedly presented without being accompanied by threat (Young et al., 2021). But how would anhedonia impact threat extinction learning?

One possibility is that omissions of threat are typically experienced as pleasurable events that involve reward processing (Gerlicher, Tüscher, & Kalisch, 2018; Lange et al., 2020; Leknes, Lee, Berna, Andersson, & Tracey, 2011; Luo et al., 2018; Raczka et al., 2011; Salinas-Hernández et al., 2018; Thiele, Yuen, Gerlicher, & Kalisch, 2021), which drive safety learning during threat extinction process. If anhedonia were to impair the pleasure derived from omissions of threat, it might hamper this safety learning. Similar to the threat omissions during threat extinction learning, there are reasons to believe that successfully controlling threats (i.e., active threat omissions), through behaviors that stop a stressful state and provide safety (escape/avoidance), is inherently pleasurable. However, it remains unclear whether anhedonia affects this form of pleasure as well. If so, we might expect that elevated levels of anhedonia would undermine the motivation to engage in threat-controlling behaviors (wanting), the experienced pleasure derived from successful threat avoidance or escape (liking), and the acquisition of behavior-safety associations (learning). To test these hypotheses, we set up an online experimental study to examine the relationship between anhedonia, controllability, and threat-omission-induced relief.

In the laboratory, active avoidance tasks provide a way to study controllability as avoidance behaviors are aimed at controlling threatening events (Krypotos, Vervliet, & Engelhard, 2018). In the

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signaled-avoidance learning task, one neutral stimulus (conditional stimulus, CS+; e.g., a picture) reliably signals an aversive stimulus (unconditional stimulus, US; e.g., an electrical stimulation), while a designated response (active avoidance; e.g., button pressing) during the CS+ cancels the occurrence of the impending US. Over the course of learning, correct active avoidance responses typically increase over consecutive trials until a full sense of control over the aversive US is formed. Hence, laboratory-based active avoidance is often regarded as an adaptive problem-solving behavior in the context of real threats (Krypotos et al., 2018; LeDoux, Moscarello, Sears, & Campese, 2017). Extremes in active avoidance rates are believed to reflect maladaptive coping styles and indicate underlying psychopathology: excessive active avoidance often interferes with daily life activities and valued life goals (Krypotos, Effting, Kindt, & Beckers, 2015; LeDoux et al., 2017), while insufficient active avoidance learning leaves aversive events relatively uncontrollable, a feature that is known to induce a state of learned helplessness (Maier & Seligman, 2016; Overmier & Molet, 2017).

It is not completely clear how active avoidance behaviors are learned and maintained (Krypotos et al., 2015), but some recent work highlights a role of relief in the reinforcement of active avoidance (Papalini, Ashoori, et al., 2021; Papalini, Beckers, et al., 2021; Papalini, Neefs, et al., 2021; San Martín, Jacobs, & Vervliet, 2020; Vervliet, Lange, & Milad, 2017). Specifically, successful omissions of an expected US are thought to elicit a pleasant feeling of relief, which positively reinforces the foregoing active avoidance response. Relief, induced by a discrepancy between an expected aversive event and its actual omission (e.g., a better-than-expected outcome) indeed meets the criteria of reward prediction error (Schultz, 2016), which can support avoidance learning. In fact, by definition, relief is a positive emotion triggered by the absence of an expected threat or the termination of an ongoing threat (Deutsch, Smith, Kordts-Freudinger, & Reichardt, 2015). When an expected threat is suddenly omitted, participants report non-neutral levels of relief pleasantness (Leknes et al., 2011; Vervliet et al., 2017) with higher threat expectancies resulting in higher pleasantness levels of relief (Papalini, Ashoori, et al., 2021; Papalini, Beckers, et al., 2021; San Martín et al., 2020; Willems & Vervliet, 2021). If experiencing threat-omission-induced relief is indeed pleasurable, we expect that both trait anticipatory anhedonia (deficits in reward wanting) and consummatory anhedonia (deficits in reward liking) would impair this form of relief. While consummatory anhedonia directly undermines the hedonic value of relief, anticipatory anhedonia reduces the motivation to pursue relief. As a result, the experienced pleasantness derived from not-so-much-desired relief would inevitably be weaker (the blue-colored path in Fig. 1).

The tenet that relief reinforces the avoidance response is the core assumption of the avoidance-relief theory. In a large sample of healthy subjects, those who scored lower on a distress tolerance questionnaire (i.e., anxious individuals) experienced generally stronger relief at the time of threat omissions and executed more avoidance responses in an active avoidance learning task (San Martín et al., 2020), confirming that an exaggerated feeling of relief might be an underlying mechanism of the excessive avoidance behavior typically seen in anxiety disorders (Krypotos et al., 2015; LeDoux et al., 2017; Schlund et al., 2020). However,

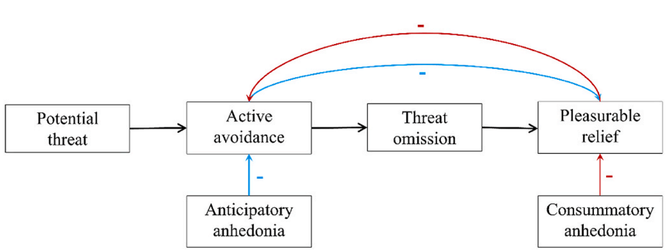

Fig. 1. The hypothesized influence of trait anticipatory and consummatory anhedonia on both avoidance and relief.

while excessive active avoidance has been the research focus in the context of anxiety disorders, it remains largely unknown how insufficient active avoidance could develop. We propose that pathological avoidance is characterized by an impaired ability to assess the emotional valence of a potential outcome, i.e., how pleasant or aversive it may be (Haskell, Britton, & Servatius, 2020). If this is the case, excessive avoidance could be driven by overestimating the aversiveness of the potential outcome, as we often observe in anxiety-related disorders (Pittig, Treanor, LeBeau, & Craske, 2018). In contrast, insufficient avoidance might be driven by underestimating the pleasantness of its outcome (i.e., relief). Following this reasoning, we argue that anhedonia, to the extent that it is accompanied by decreased relief pleasantness, could result in active avoidance deficits as well. If both anticipatory and consummatory anhedonia indeed reduces the relief pleasantness experienced upon US omissions, the reinforcement of active avoidance responses would be weakened, resulting in lower behavioral engagement in future avoidance (the red-colored path in Fig. 1). In addition, anticipatory anhedonia might directly undermine the relief wanting (i.e., the motivation to obtain the threat-omission-induced relief). In sum, we expect that the presence of anhedonia would cause a reduction in active avoidance responses.

Learned helplessness refers to a diminished perception of control over aversive events, leading to fatalistic acceptance and reduced engagement in problem-solving behaviors (Maier & Seligman, 2016; Overmier & Molet, 2017). Together with anhedonia, these two motivational deficits have been well studied, but mostly in separate strands of research. However, they may be more closely connected than previously thought. We propose that actively controlling aversive events may be inherently rewarding and that anhedonia could affect this form of reward. This might result in weaker reinforcement of active avoidance behaviors aimed at controlling aversive events, and thus reduced avoidance learning, leading to unnecessary confrontations with aversive events. This lowered control over aversive events is reminiscent of a learned helplessness state, which could further decrease motivation toward adaptive threat avoidance behaviors, allowing for even fewer occasions for relief feelings to occur. Thus, the anhedonia and learned helplessness may jointly contribute to maladaptive threat coping behaviors. Therefore, studying anhedonia in the context of controllability may help to better understand the connections between two phenomena (anhedonia and learned helplessness) that have mostly been studied separately in the context of mood disturbance.

Taken together, the current study aimed to test, in a community sample, whether trait anhedonia (both trait anticipatory anhedonia and consummatory anhedonia) would reduce the pleasantness of relief experienced during threat omissions (*Hypothesis 1*) and decrease the engagement in active avoidance behaviors (*Hypothesis 2*). Exploratorily, we also evaluated two underlying hypotheses of the avoidance-relief theory. Firstly, we examined whether omissions of an aversive event result in higher levels of relief pleasantness the less they are expected. Secondly, the relationship between relief pleasantness and active avoidance responses was examined to evaluate the reinforcing effect of relief on avoidance. Additionally, to maximize our chance of detecting anhedonia-related effects during active avoidance learning, we extended the learning process and reversed the avoidance-US omission contingency halfway through. We expected a similar anhedonia-related effect before and after the contingency reversal. Since depressive individuals are often less flexible in their coping (Sheppes, Suri, & Gross, 2015) and less efficient in adapting to environmental demands (Stange, Alloy, & Fresco, 2017), it is possible that they are less able to identify when their coping strategies are no longer effective for a changing environment. Therefore, depressive symptoms were also measured to exploratorily evaluate their effects on instrumental reversal learning in the current design. To increase the focus of the current manuscript, analyses and results regarding this hypothesis are reported in the supplementary materials.

2. Methods

2.1. Participants

A total of 251 participants (166 males; $M_{age} = 26.08$, $SD_{age} = 7.19$, range = 18–50 years) were recruited from Prolific (www.prolific.co, Palan & Schitter, 2018). Sufficient information regarding the current study was given on Prolific and all participants were asked to give informed consent before they could proceed with the study. 16 participants were excluded due to technical issues resulting in incomplete or no data being recorded. These participants were paid £ 2.5 while the remaining participants were paid £ 5 for their participation. Based on the pre-registered exclusion criteria (See Data management and analyses for more details), another 35 participants were excluded as non-learners during the computer task. All the following analyses were performed with the pre-registered sample size of 200 (130 males, $M_{age} = 25.82$, $SD_{age} = 6.77$, range = 18–47 years). The study protocol was approved by the Social and Societal Ethics Committee of KU Leuven (SMEC Reference Number: G-2020-2790). The study design and analysis methods were pre-registered at https://osf.io/5da6b.

2.2. Stimuli and measures

2.2.1. Stimuli

The conditional stimuli (CSs) were pictures of an office room with a desktop lamp that could light up in the color red, blue, or yellow (adapted from Milad, Orr, Pitman, & Rauch, 2005), presented against a black background at the middle of the computer screen. Eight moderately aversive pictures from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2008) were selected to serve as unconditional stimuli (USs, see Fig. S1 in the supplementary materials). All trials started with a 1-s presentation of the office room with the lamp switched off, after which the lamp lit up in one of the three colors. During the avoidance learning phase and the reversal learning phase, a red button (avoidance cue) was presented at the upper left corner of the CS picture, 1 s after the lamp color onset, for a duration of 2 s. Short inter-trial intervals (2, 3, or 4 s, randomly selected for each trial) were used since no physiological indices were measured.

2.2.2. US expectancy

During each CS presentation, participants were asked to rate their expectancy of a US in response to the question "*To what extent do you expect an aversive picture now?*". Participants registered their response by mouse-clicking on a scale presented below the CS that ranged from 0 ("*certainly no aversive picture*") to 10 ("*certainly an aversive picture*").

2.2.3. US unpleasantness

US unpleasantness was assessed at the end of each trial on which a US was presented by presenting the question "*How unpleasant was the picture that you just saw?*" in a red-colored font. Participants registered their response by mouse-clicking on a computerized Visual Analogue Scale (VAS) ranging from "*neutral*" to "*very unpleasant*".

2.2.4. Relief pleasantness

Relief pleasantness was assessed at the end of each trial on which a US was omitted by presenting the question "*How pleasant was the relief that you just felt?*" in a green-colored font. Participants registered their response by mouse-clicking on a computerized VAS ranging from "*neutral*" to "*very pleasant*".

2.2.5. CS valence and arousal

The valence ("*How pleasant do you find this figure?*") and arousal ("*How stimulating do you find this figure?*") of each lighted lamp picture were measured on computerized VASs ranging from "*very pleasant*" to "*very unpleasant*" for valence and from "*passive/calm*" to "*active/stimulating*" for arousal throughout the task.

2.2.6. Post-experimental questions

At the end of the experiment, participants were asked about their general avoidance intention (Avoidance Intention), the general pleasantness of US-omission-induced relief (General Relief), and the general unpleasantness of the USs (General US-unpleasantness). Specifically, we asked: (1) "*During the task, how much did you want to avoid seeing the aversive pictures?*". Responses were registered on a computerized VAS ranging from "*not at all*" to "*very much*"; (2) "*If you successfully avoided an aversive picture, how pleasant did you feel about the relief?*". Responses were registered on a computerized VAS ranging from "*neutral*" to "*very pleasant*"; (3) "*In general, how unpleasant did you feel when you saw the aversive pictures?*". Responses were registered on a computerized VAS ranging from "*neutral*" to "*very unpleasant*".

2.2.7. Anhedonia

The Temporal Experience of Pleasure Scale (TEPS, Gard, Gard, Kring, & John, 2006) allows measuring separate components of anhedonia (anticipatory and consummatory). It consists of 18 items using a six-point Likert scale ranging from 1 ("*very false for me*") to 6 ("*very true for me*"). In the original scale, one item is to be reverse-coded so that higher total scores represent a lower level of trait anhedonia. For ease of interpretation, we instead reverse-coded all other items so that higher total scores indicated higher levels of anhedonia. The internal consistency for both anticipatory and consummatory subscales of the TEPS was satisfactory in the current sample, as indicated by Cronbach's alpha coefficients (Cronbach, 1951) of 0.77 and 0.69, respectively.

2.2.8. Depressive symptoms

The Quick Inventory of Depressive Symptomatology-Self Report (QIDS-SR16) is a reliable and valid self-report measure of depressive symptoms (Rush et al., 2003). It has 16 items, and scores range from 0 to 27, with higher scores indicating greater severity of depressive symptoms. The scale showed excellent internal consistency in the current study, as indicated by Cronbach's alpha of 0.80.

2.2.9. Anxiety-related traits

Considering that anxiety-related traits have been found to correlate with active avoidance learning, trait anxiety, intolerance of uncertainty, and distress tolerance were also measured in the current study to control for their effects while testing the main hypotheses. The State and Trait Anxiety Inventory - Trait Version (STAI-T; Spielberger, Gorsuch, Lushene, Vagg, & Jacob, 1977) was used to assess trait anxiety. It consists of 20 items rated for frequency of occurrence using a four-point Likert scale ranging from 1 ("*almost never*") to 4 ("*almost always*"). The Intolerance of Uncertainty Scale (IUS; Freeston, Rhéaume, Letarte, Dugas, & Ladouceur, 1994) was used to measure how individuals react to uncertainty. It includes 27 items rated on a five-point Likert scale ranging from 1 ("*strongly disagree*") to 5 ("*strongly agree*"). The Distress Tolerance Scale (DTS) was used to measure the perceived ability to tolerate emotional distress. It includes questions related to tolerance, appraisal, absorption, and regulation (Simons & Gaher, 2005), and consists of 15 items rated on a five-point Likert scale ranging from 1 ("*totally agree*") to 5 ("*disagree completely*"). These scales all showed excellent internal consistency in the current sample as indicated by Cronbach's alpha (STAI-T: 0.93; IUS: 0.94; DTS: 0.93).

2.3. Procedure

Participants were recruited from Prolific (www.prolific.co) and directed to Qualtrics where they were asked to give their informed consent for participating in the current study. Following the completion of the informed consent process, participants were asked to fill in a few demographic questions (gender, age, education level, and whether they have current or past mental complaints) and complete the questionnaires. Afterwards, participants were automatically directed to Pavlovia (pavlovia.org) to perform the computer task.

The computer task consisted of three phases: a threat acquisition phase, an avoidance learning phase, and a reversal learning phase. A schematic presentation of the experimental design and two example trial flows during the avoidance learning phase can be found in Fig. 2. Each color lamp was presented once to collect valence and arousal ratings before the threat acquisition phase started, where the three lamp colors were randomly selected to serve as CS+1, CS+2, and CS-. While both the CS+1 and CS+2 were always paired with a US, the CS- was never paired with a US. This phase consisted of two blocks (first block: 4 CS+1, 4 CS-; second block: 4 CS+2, 4 CS-; the order of the two blocks was counterbalanced among participants). The first and the last trial in each block was always a CS + trial in order to facilitate threat acquisition (Lonsdorf et al., 2017). The rest of the trials were randomized with no more than two identical trials presented in a row. Participants were told that '*In this task, you will first see a picture of one office room. Then the lamp on the desk will light up in different colors for a few seconds. Following the lighted lamp picture, you may or may not see an aversive picture. If you see an aversive picture, try to find out if there is a pattern*'. After the threat acquisition phase, each color lamp was presented again to collect valence and arousal ratings.

Afterwards, the active avoidance learning phase started, where participants were told that '*In the following phase, you will perform a similar task again. But now a red button will appear for 2 s after the lamp lights up. During the presentation of this red button, you can press the spacebar on your keyboard. Pressing the spacebar may or may not prevent the aversive picture afterwards, and this may be different for each lamp color*'. In reality, both the CS+1 and the CS+2 were followed by a US if there was no avoidance response (the spacebar press). Pressing the spacebar prevented the US after the CS+1 (CS + signaling avoidable US, CS + av) but not the CS+2 (CS + signaling unavoidable US, CS + unav). Without any indication, the reversal learning phase then started, where the contingency between the avoidance response and US omission was reversed. Pressing the spacebar now canceled the US following the CS+2 (now CS+av) but not the CS+1 (now the CS+unav). During both avoidance learning phases, the CS- was never followed by a US, regardless of the avoidance response. Both active avoidance learning phases consisted of 8 blocks with one CS+av, one CS+unav, and one CS- in each block and the order of trials within each block was randomized so that there were no more than two identical trials presented in a row. Note that CS+1 and CS+2 were randomly chosen to be CS+av and CS+unav during the avoidance learning phase, and their roles were switched accordingly during the reversal learning phase.

Throughout the experiment, the rating scale for US expectancy was presented at the bottom of the screen during every trial from the time of the CS onset (during the threat acquisition phase) or from the time of the avoidance cue offset (during the two avoidance learning phases). Participants were asked to rate their expectancy of US occurrence using the scale presented at the bottom of the screen. 500 ms after the rating was given, a US was presented for 3 s if the current trial was to contain a US (CS+unav trials or CS+av trials without avoidance response), after which the rating scale for US unpleasantness was presented at US offset. Otherwise, the screen stayed blank for 3 s and the rating scale for relief pleasantness was presented on the screen afterwards. Both the rating scales for US unpleasantness and the relief pleasantness were presented until a rating was given. At the end of the task, the post-experimental questions were asked using computerized VAS scales.

2.4. Data management and analyses

2.4.1. Deviations from pre-registration

Due to the operant feature of avoidance responses, participants had a variable amount of ratings for relief pleasantness, which the repeated-measure analysis of variance (our pre-registered analysis method) was unable to handle. In view also of the multilevel structure of the data (i.e.,

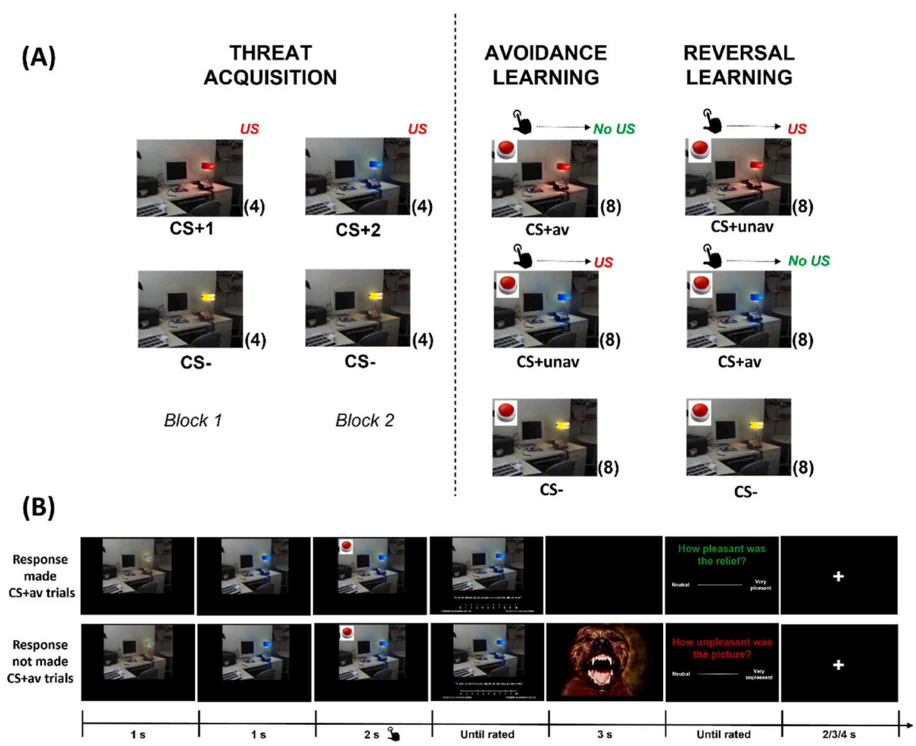

Fig. 2. Experimental design. (A) The task consisted of three phases, a threat acquisition phase, an avoidance learning phase, and a reversal learning phase. Two color lamps were paired with aversive pictures during the threat acquisition phase. One of these became the CS+ signalling avoidable US (CS+av) while the other became the CS+ signaling unavoidable US (CS+unav) during the following avoidance learning phase. During the reversal learning phase, the previous CS+av signaled unavoidable US (now CS+unav) while the previous CS+unav signaled avoidable US (now CS+av). Pressing the spacebar during the presentation of the red button could cancel the aversive pictures paired with the CS+av but not the CS+unav. Pressing the spacebar was unnecessary to the CS- since it was never paired with an aversive picture during any phases. (B) Overview of the timeline of a successful avoidance trial and a non-avoidance trial. All trials started with 1 s context presentation, followed by the lamp color onset. The red button appeared 1 s after the lamp color onset for 2 s. The scale for US expectancy was presented at the time of the red button offset. Once the US expectancy was given, the screen turned blank for 3 s if it was a successful avoidance trial or a CS- trial and a scale for relief pleasantness was presented afterwards until a rating was given. Otherwise, an aversive picture was presented for 3 s if it was a non-avoidance trial or an unavoidable trial and a scale for US unpleasantness was presented afterwards until a rating was given. CS+av = the CS+ signaling avoidable US; CS+unav = the CS+ signaling unavoidable US. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

multiple observations per participant), we switched to the framework of linear mixed-effects models (LMM) to test the main hypotheses.

2.4.2. Data processing and statistical analyses

Raw data were first preprocessed and further analyzed in R using RStudio (RStudio Team, 2020). The entire anonymized data and R scripts used in the current study have been made publicly available at https://osf.io/5da6b. There was no missing data for the outcome measures as the task only proceeded after a rating was given. Successful threat acquisition was required in order for a participant's data to be included in further analyses for hypothesis testing. This was operationalized as either higher US-expectancy ratings towards both the CS+1 and the CS+2 compared to the CS- across each block or higher US-expectancy ratings towards the last CS+1 and the last CS+2 compared to the last CS- in each block. Participants were excluded only if they failed both criteria.

All the models were built using the ***lme4*** package (Bates et al., 2018) and significance was calculated using the ***lmerTest*** package (Kuznetsova, Brockhoff, & Christensen, 2017), following the relevant model specification and reporting guidelines (Bates, Kliegl, Vasishth, & Baayen, 2018; Brown, 2021; W. Luo et al., 2021). Unrestricted maximum likelihood (ML) was used for all models to control the optimization procedure for the parameter estimates. All categorical predictors (e.g., Phase, CS type) were coded using sum to zero contrasts while continuous predictors (e.g., Trial) were grand-mean centered to make interpretations easier and to reduce multicollinearity when an interaction term was included (Bickel, 2007). A random intercept over all participants was included in all models to account for the repeated-measures nature of the data. Random slopes were tested and kept if they significantly improved model fit and achieved model convergence. The model with the best goodness-of-fit was selected based on the likelihood-ratio test. Once the best model was selected, the significance of fixed effects was evaluated by the likelihood-ratio test. The parameters of interest were then tested using the summary outputs, applying Satterthwaite approximations to estimate degrees of freedom and obtain two-tailed p values. The marginal means were estimated and post-hoc comparisons were conducted for fixed effects using ***emmeans*** and ***emtrends*** packages with Bonferroni correction and the Satterthwaite approximation (Russell, 2021). The nature of any significant interaction effect was additionally inspected with the interaction plot. The fixed effects of other covariates of no interest (age, gender, US unpleasantness, QIDS, STAI-T, IUS, DTS) were added into the final models (both separately and simultaneously) to check the robustness of our findings. Predictors with variance inflation factor (VIF) bigger than 5 were removed from the model (Daoud, 2017). Except for Bonferroni-corrected estimates, the significance threshold was set at $p = .05$. Summaries for all final models can be found in supplementary materials.

2.4.3. Threat acquisition

The prerequisite to evaluate avoidance learning was successful initial threat acquisition. To assess whether participants acquire differential conditioned threat across different CS types as indicated by subjective US-expectancy ratings, the ratings for the CS- were merged by trial numbers into four datapoints (i.e., trials 1–2; trials 3–4; trials 5–6; trials 7–8), resulting in 4 data points for the CS-, which corresponded to the data points of the two CS+ (four CS+1 trials in the first block, four CS+2 trials in the second block). *CS* and *Trial* were included as fixed effects and this model was compared with a model in which their interaction was additionally included as a fixed effect. Successful threat acquisition was additionally examined with CS-valence and CS-arousal ratings measured before and after the threat acquisition phase using 3 (*CS*: CS+1, CS+2, CS-) * 2 (*Time*: before, after) Repeated Measure Analysis of Variance (RM-ANOVA). Greenhouse-Geisser corrections were applied where Mauchly's test of sphericity was not met. Bonferroni correction was applied to all post-hoc tests to protect against inflated type I errors. Effect sizes are reported as partial eta-squared and the alpha level was set to $\alpha = 0.05$.

2.4.4. Task effects

Before turning to hypothesis testing, we first inspected the task effects indicated by the main effects of *Phase* (Avoidance learning/ Reversal learning), *CS* (CS+av, CS+unav, CS-), and *Trial* on different trial-wise outcomes (avoidance response, US expectancy, relief pleasantness). Generalized Linear Mixed Model (GLMM) was used for the avoidance response data due to its binary nature. With avoidance response, US expectancy, and relief pleasantness as separate dependent variables, *Phase*, *CS*, and *Trial* were always included as fixed effects and this model was compared to other models in which their interactions were additionally included as fixed effects. For US expectancy, we additionally included whether the subjects pressed the red button during each trial (variable *Avoided* with the value 1 for a correct avoidance response, i.e., *Response made*; or 0 for no or incorrect avoidance response, i.e., *Response not made*) as a predictor (Papalini et al., 2021b). The above model-fitting process resulted in three best-fitting models (the simple models), one for each outcome measure.

2.4.5. Hypothesis 1: higher trait anhedonia is associated with less relief pleasantness

Anticipatory and consummatory anhedonia scores were each added separately as additional fixed effects into the task model for relief pleasantness, interacting with the other fixed effects in the model. The relation between trait anhedonia (both anticipatory and consummatory) and the relief pleasantness measured at the end of the task was also investigated using the Spearman correlation method.

2.4.6. Hypothesis 2: higher trait anhedonia is associated with less active avoidance

Anticipatory anhedonia and consummatory anhedonia scores were each added separately as additional fixed effects into the task model for avoidance responses, interacting with the other fixed effects in the model.

2.4.7. Exploratory analyses

More unexpected US omission relates to higher relief pleasantness. It has been suggested that relief pleasantness depends on the violation of a negative expectation, i.e., more unexpected omission of an aversive event should result in higher level of relief pleasantness. Since US expectancy in the current study was measured after the opportunity for avoidance and before the omission or presentation of the US, we reasoned that US omissions would be more unexpected when the US-expectancy ratings were higher. Therefore, we expected a positive relationship between the US-expectancy and relief-pleasantness ratings. During the task, the US-expectancy ratings and the relief-pleasantness ratings were measured on a trial-by-trial basis, resulting in multiple observations per participant. To account for non-independence among multiple observations from each participant and only capture the common intra-individual association, we used repeated-measures correlation (***rmcorr***, Bakdash & Marusich, 2017) to estimate the correlation coefficient between US-expectancy and relief-pleasantness ratings.

More relief pleasantness is associated with more active avoidance. To evaluate the reinforcing effect of relief on avoidance, the relationship between trial-by-trial relief-pleasantness ratings and active avoidance responses during both the avoidance learning phase and the reversal learning phase was examined. Due to unequal data points (there could be a relief-pleasantness rating without an avoidance response executed, e.g., a non-avoided CS- trial, and there was not always a relief-pleasantness rating after an avoidance response, e.g., an avoided CS+unav trial), this relationship was evaluated with overall avoidance proportion as the outcome variable and averaged relief-pleasantness ratings as the predictor interacting with the variable *Phase* via LMM.

3. Results

3.1. Self-reports and correlations

The mean, standard deviation, and range of the questionnaires and the post-experimental questions (Avoidance Intention, General Relief, General US unpleasantness) are summarized in Table 1. Spearman correlation was used since most of the variables failed to conform to a normal distribution. The distribution of anticipatory and consummatory anhedonia as well as their relationship can be found in Fig. 3. Similar scatter plots for other variables can be found in supplementary materials. For the post-experimental questions, participants who experienced a higher level of US unpleasantness had higher intention to avoid and also experienced a higher level of relief pleasantness ($ps < .001$). Notably, participants with a higher level of trait distress tolerance had lower intention to avoid ($r_s = -0.23$, $p < .05$).

3.2. Threat acquisition and task effects

More detailed results for this section can be found in the supplementary materials. On average, the US-expectancy ratings for the CS+1 and the CS+2 were not discernably different, and both higher than the ratings for the CS-. While they increased for the CS+1 and CS+2 comparably over trials, they decreased for the CS- (see Fig. 4A). Valence and arousal for all CSs were comparable before the threat acquisition phase. After the threat acquisition phase, compared to the CS-, both the CS+1 and the CS+2 were rated as more unpleasant as well as more arousing (see Fig. 4B and C). These results collectively suggest a successful and comparable differential threat acquisition for the CS+1 and the CS+2 relative to the CS-.

The effects of the active avoidance learning paradigm are in line with previous work (Papalini et al., 2021a; Papalini, Beckers, Claes, & Vervliet, 2021ab; San Martín et al., 2020). Over training, participants gradually acquired the different contingencies between the avoidance response and its associated outcome, resulting in increased effective avoidance (avoidance towards the CS+av) and decreased ineffective (avoidance towards the CS+unav) and unnecessary avoidance (avoidance towards the CS-, see Fig. 5A). Participants experienced stronger relief pleasantness towards the CS + av compared to the CS- and this relief pleasantness decreased as learning developed and US omissions was increasingly expected (Fig. 5B).

3.3. Hypothesis 1: higher trait anhedonia is associated with less relief pleasantness

When anticipatory anhedonia scores were added into the task model for relief pleasantness, all the main effects were significant (Phase: χ^2 (1) = 14.56, $p < .001$, CS: χ^2 (1) = 86.16, $p < .001$; Trial: χ^2 (1) = 77.14, $p < .001$, Anticipatory anhedonia: χ^2 (1) = 4.98, $p < .05$) as was the four-way interaction (Phase * CS * Trial * Anticipatory anhedonia, χ^2 (1) = 5.95, $p < .05$). On average, higher anticipatory anhedonia was associated with lower relief-pleasantness ratings ($\beta = -0.64$, $SE = 0.29$, $t(198.19) = -2.24$, $p < .05$). To follow up the four-way interaction effect, LMM was used for each CS in each phase separately with Trial, Anticipatory anhedonia scores, and their interaction term as fixed effects. Results showed that the fixed effect of anticipatory anhedonia was only significant for the CS- during the reversal learning phase, where higher anticipatory anhedonia was linked with lower relief pleasantness ($\beta = -0.75$, $SE = 0.33$, $t(200) = -2.26$, $p < .05$, see Fig. 6B). Based on visual inspection, the fixed effect of anticipatory anhedonia seemed to have a larger impact on relief pleasantness during early trials compared to later trials in the avoidance learning phase for CS + av. However, this trend was not statistically significant (Trial * Anticipatory anhedonia: $\beta = 0.12$, $SE = 0.06$, $t(159.47) = 1.93$, $p = .056$).

When consummatory anhedonia scores were added into the task model for relief pleasantness, all the main effects were significant (Phase: χ^2 (1) = 12.37, $p < .001$, CS: χ^2 (1) = 85.57, $p < .001$; Trial: χ^2 (1) = 322.55, $p < .001$, Consummatory anhedonia: χ^2 (1) = 4.40, $p < .05$) as was the four-way interaction (Phase * CS * Trial * Consummatory anhedonia, χ^2 (1) = 7.53, $p < .01$). On average, higher consummatory anhedonia was associated with lower relief-pleasantness ratings ($\beta = -0.89$, $SE = 0.42$, $t(199.21) = -2.11$, $p < .05$). To follow up the four-way interaction effect, LMM was used for each CS in each phase separately, with Trial, Consummatory anhedonia scores, and their interaction term as fixed effects. Results showed that the fixed effect of consummatory anhedonia was only significant for CS + av during the avoidance learning phase, with higher consummatory anhedonia linked to lower relief pleasantness ($\beta = -1.15$, $SE = 0.47$, $t(185.23) = -2.45$, $p < .05$, see Fig. 6C). Based on visual inspection, this fixed effect of consummatory anhedonia seemed to have a larger impact on relief

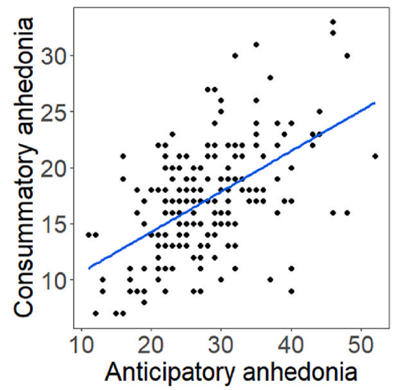

Fig. 3. Relationship between consummatory and anticipatory anhedonia. Dots represents raw data from each participant; Solid-blue line represents linear least squares regression fits to data points. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Means, standard deviations, ranges, and correlations between measures.

	M (*SD*)	Range	1	2	3	4	5	6	7	8
1. TEPS_anti	27.73 (7.56)	11–52	—							
2. TEPS_cons	17.05 (5.11)	7–33	0.50***	—						
3. QIDS	7.96 (4.95)	0–24	0.37***	0.31***	—					
4. STAI-T	47.38 (12.09)	20–77	0.48***	0.37***	0.74***	—				
5. IUS	79.60 (19.52)	32–126	0.24*	0.23*	0.50***	0.71***	—			
6. DTS	3.11 (0.82)	1.07–5.00	−0.2	−0.13	−0.53***	−0.63***	−0.69***	—		
7. AI	65.26 (32.51)	0–100	−0.1	−0.14	0.08	0.13	0.16	−0.23*	—	
8. GR	62.98 (34.31)	0–100	−0.16	−0.12	0.07	0.07	0.06	−0.21	0.71***	—
9. GUS	62.62 (32.26)	0–100	−0.10	−0.17	0.03	0.06	0.13	−0.15	0.74***	0.71***

Note. TEPS_anti = anticipatory anhedonia; TEPS_cons = consummatory anhedonia; QIDS = Quick Inventory of Depressive Symptoms; STAI-T = The State and Trait Anxiety Inventory - Trait Version; IUS = Intolerance of Uncertainty Scale; DTS = Distress Tolerance Scale; AI = avoidance intention; GR = general relief pleasantness; GUS = general US unpleasantness. Type-I error inflation was countered through Bonferroni correction. *$p < .05$, **$p < .01$, ***$p < .001$.

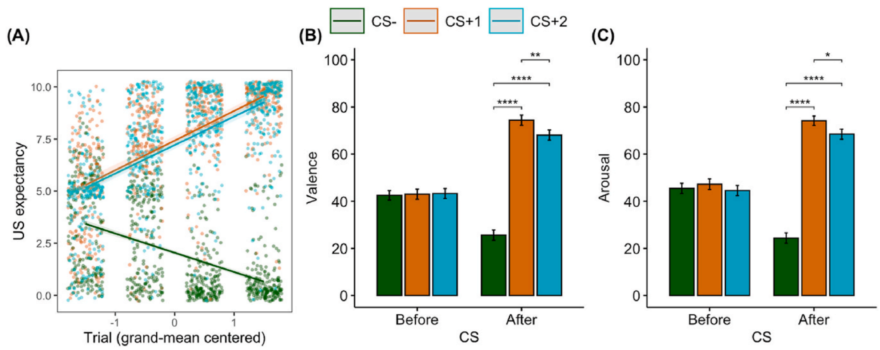

Fig. 4. Successful threat acquisition indicated by different measures. (A) US-expectancy ratings ranged from 0 to 10, where 0 represented "certainly no aversive picture" and 10 represented "certainly an aversive picture"; (B) Valence ratings ranged from 0 to 100, where 0 represented "very pleasant" and 100 represented "very unpleasant"; (C) Arousal ratings ranged from 0 to 100, where 0 represented "passive/calm" and 100 represented "active/stimulating". CS+1 = the CS+ in the first block; CS+2 = the CS+ in the second block. The variable *Trial* was mean-centered with larger negative values representing earlier trials while larger positive values representing later trials. Dots represent raw data from each participant. Error bars represent mean ± standard error. *p < .05, ****p < .0001.

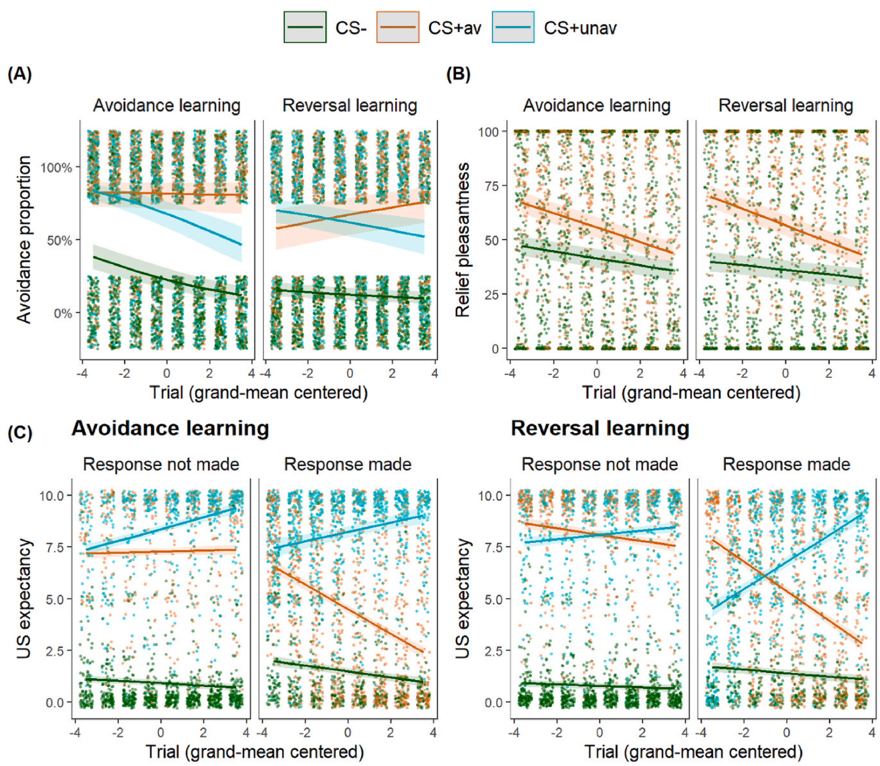

Fig. 5. Task effects. (A) the proportion of avoided trials; (B) relief-pleasantness ratings; (C) *Response made* and *Response not made* US-expectancy ratings. CS+av = the CS+ signaling avoidable US; CS+unav = the CS+ signaling unavoidable US. The variable *Trial* was mean-centered with larger negative values representing earlier trials while larger positive values representing later trials. Dots represent raw data from each participant; smooth lines represent the best model fit to the data; colored bands around the lines represent 95% confidence level.

pleasantness during early trials compared to later trials in the avoidance learning phase for CS + av. However, this trend was again not statistically significant (Trial * Consummatory anhedonia: $\beta = 0.17$, $SE = 0.10$, $t(164.30) = 1.74$, $p = .084$).

When covariates of no interests (age, gender, US unpleasantness, QIDS, STAI-T, IUS, DTS) were added into the models separately or simultaneously, the four-way interaction always remained significant in all the models ($ps < .05$). However, the main effect of trait anticipatory and consummatory anhedonia disappeared either when US pleasantness was added into the model or all covariates were added together. Notably, only the main effects of US unpleasantness were significant in either model, with higher US unpleasantness associated with higher relief pleasantness ($ps < .001$). Visual inspection for the four-way interaction remained similar to Fig. 6, although following up the four-way interaction in the model including all the covariates with LMMs, none of the anhedonia-related effect was significant. Bonferroni-corrected Spearman correlation analyses failed to reveal any association between anhedonia traits and the relief-pleasantness ratings measured at the end of the task.

To sum up, the first hypothesis was partially supported, in that higher trait anticipatory anhedonia was mainly associated with lower relief pleasantness on CS- trials during the reversal learning phase, whereas higher trait consummatory anhedonia was mainly associated with relief pleasantness on CS+av trials during the initial avoidance learning phase.

3.4. *Hypothesis 2: higher trait anhedonia is associated with less active avoidance*

When adding anticipatory anhedonia into the task model for avoidance responses, none of its interaction terms was significant. Therefore, the final model only included its main effect, which was significant ($\chi^2(1) = 3.99$, $p < .05$). Further testing the coefficient showed that higher anticipatory anhedonia was associated with lower probability of avoidance ($\beta = -0.04$, $SE = 0.02$, $t = -2.09$, $p < .05$). However, the significant main effect of anticipatory anhedonia disappeared after controlling for either US pleasantness or trait anxiety alone or all covariates at the same time. Instead, higher US unpleasantness significantly predicted higher probability of avoidance ($ps < .05$). No significant effect was found for consummatory anhedonia before nor after

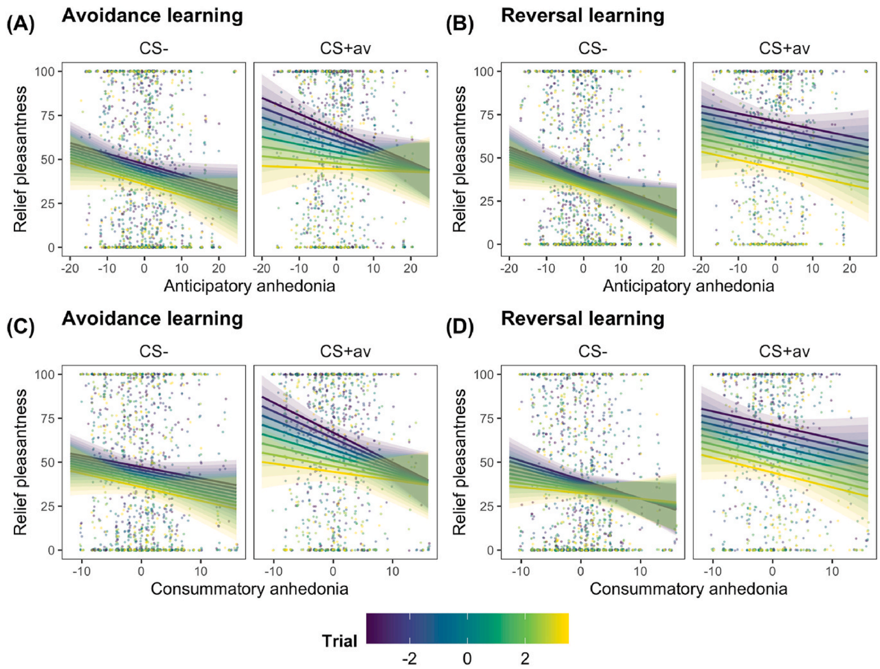

Fig. 6. Higher trait anhedonia is associated with less relief pleasantness. (A) the effect of anticipatory anhedonia during avoidance learning; (B) the effect of anticipatory anhedonia during reversal learning; (C) the effect of consummatory anhedonia during avoidance learning; (B) the effect of consummatory anhedonia during reversal learning. CS+av = the CS+ signaling avoidable US. The variable *Trial* was mean-centered with larger negative values representing earlier trials while larger positive values representing later trials. Dots represent raw data from each participant; smooth lines represent the best model fit to the data; colored bands around the lines represent 95% confidence level.

controlling for other covariates.

3.5. Exploratory analyses

More unexpected US omission relates to higher relief pleasantness. The ***rmcorr*** results showed that US-expectancy ratings were positively correlated with relief-pleasantness ratings with all trials included, r_{rm} (5148) = 0.44, 95% CI [0.41, 0.46], $p < .001$, with the CS+av trials only, r_{rm} (1964) = 0.43, 95% CI [0.39, 0.46], $p < .001$, and with the CS- trials only, r_{rm} (2999) = 0.20, 95% CI [0.17, 0.23], $p < .001$, see Fig. 7. These results provide evidence that the relief-pleasantness level depended on the surprisingness of US occurrence. According to the avoidance-relief theory, relief pleasantness is directly driven by unexpected omission of an aversive event. Therefore, as a sensitivity analysis, trial-by-trial US-expectancy ratings were grand-mean centered and added separately as another main effect into the previous models where the effect of different types of trait anhedonia on relief pleasantness were tested. Results showed that the main effects of anticipatory and consummatory anhedonia each remained significant (anticipatory: $\beta = -0.60$, $SE = 0.27$, $t(195.90) = -2.21$, $p < .05$; consummatory: $\beta = -0.98$, $SE = 0.40$, $t(197.20) = -2.45$, $p < .05$), with the effect of US expectancy also being significant (in the model for anticipatory anhedonia: $\beta = 2.70$, $SE = 0.15$, $t(4834.73) = 18.27$, $p < .001$; in the model for consummatory anhedonia: $\beta = 2.70$, $SE = 0.15$, $t(4826.25) = 18.28$, $p < .001$). These results confirm the robustness of the link between both anticipatory and consummatory anhedonia effects and relief pleasantness.

More relief pleasantness is associated with more active avoidance. With overall avoidance proportion as the outcome variable, and average relief pleasantness, Phase and their interaction term as the predictors, the LMM results showed a significant effect of Phase: χ^2 (1) = 30.72, $p < .001$, average relief pleasantness: χ^2 (1) = 6.52, $p < .05$, but not their interaction effect: χ^2 (1) = 3.77, $p = .052$. Further testing of coefficients showed that on average, there was a higher probability of avoidance during the avoidance learning phase compared to the reversal learning phase ($\beta = 0.03$, SE = 0.01, $t(207.27) = 5.76$, $p < .001$), and higher average relief pleasantness significantly predicted higher probability of avoidance ($\beta = 0.001$, SE = 0.001, $t(396.83) = 2.56$, $p < .05$). Notably, the effect of relief pleasantness disappeared when controlling for either US pleasantness alone or all covariates together (age, gender, US unpleasantness, QIDS, STAI-T, IUS, DTS). Instead, higher US unpleasantness significantly predicted higher probability of avoidance (*ps* < .05).

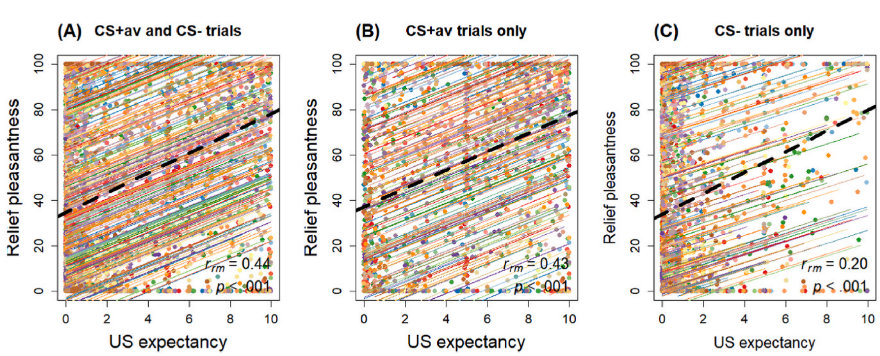

Fig. 7. Repeated-measures correlations between US expectancy and relief pleasantness. The relief-pleasantness ratings were plotted against US-expectancy ratings. (A) the CS+av and the CS- trials pooled together; (B) results including the CS+av trials only; (C) results including the CS- trials only. Dots represent raw data from each measurement and are grouped by participants with each color summarizing one participant; the solid-colored parallel lines were the best linear fit to the data from each participant after statistically adjusted for inter-individual variability; black-dashed lines represent the corresponding regression plot for the same data averaged across participants; repeated-measures correlation coefficients (r_{rm}) and corresponding p values are indicated. CS+av = the CS+ signaling avoidable US. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

The main goal of the current study was to test, in healthy participants, whether trait anhedonia (both anticipatory and consummatory anhedonia) would be associated with a reduced experience of relief pleasantness upon threat omissions and with decreased threat avoidance. We used an online active avoidance learning task and observed similar task effects as reported in previous laboratory-based studies (Papalini et al., 2021a; Papalini et al., 2021ab; San Martín et al., 2020). Most importantly for the present purposes, we found that participants with a higher level of trait anticipatory or trait consummatory anhedonia experienced lower relief pleasantness at the time of threat omissions, and participants with a higher level of anticipatory anhedonia, but not consummatory anhedonia, avoided less in general. These results partially confirmed our hypotheses with some unexpected observations, which we discuss below.

If threat-omission-induced relief is indeed pleasurable by nature, such relief experiences would be blunted by the presence of anhedonia, which was exactly what we found in the current study. The relief pleasantness was significantly reduced in the case of either high trait anticipatory anhedonia or high trait consummatory anhedonia. This remained true even after the avoidance-US omission contingency was reversed. Notably, trait anticipatory anhedonia was mainly related to relief pleasantness on CS- trials during the reversal learning phase, while trait consummatory anhedonia was mainly related to relief pleasantness on CS+av trials during the initial avoidance learning phase. These results suggest that the impairing effect of trait anhedonia on relief varies dependent on specific factors (e.g., specific cues, specific learning stages) that generate different levels of relief pleasantness. Future studies may consider further manipulating relief magnitudes over a larger range to better understand the boundary conditions for observable anhedonia effects on relief pleasantness. Although not statistically significant, there seemed to be a trend for both trait anticipatory and trait consummatory anhedonia to be associated with larger effects during early CS+av trials compared to later trials. Since the relief pleasantness at the time of threat omissions following the CS+av trials was higher in the early trials compared to the later trials, it seems sensible that the most potent anhedonia effect should be observed in those situations that would normally induce the highest relief pleasantness.

As expected, we found that participants with a higher level of trait anticipatory anhedonia executed significantly fewer avoidance responses during the task. However, no effect of trait consummatory anhedonia on avoidance responses was found even though we expected it to have an indirect impact through a reduction in relief pleasantness, which should result in weaker reinforcement of avoidance responses (the red-colored path in Fig. 1). This null finding may be due to a smaller difference between the CS+av avoidance and the CS+unav avoidance in the current study (see below). Although an effect of anhedonia on avoidance to the CS- was not found in the current study, trait anhedonia was found to be associated with reduced relief pleasantness to CS- offset. Theoretically, this could reduce the unnecessary avoidance to the CS-. This potentially beneficial role of trait anhedonia requires future investigation.

In exploratory analyses, we found that the US-expectancy ratings were positively correlated with relief-pleasantness ratings, which confirms that the level of relief pleasantness depends on the discrepancy between expectation and outcome (i.e., expectancy violation), consistent with what was found in a previous study (Willems & Vervliet, 2021). The average relief pleasantness was found to predict the overall avoidance responses only during the reversal learning phase, but not during the initial avoidance learning phase. The lack of predictive effect of the averaged relief pleasantness may be due to the fact that the difference in avoidance proportion between the CS+av and the CS+unav was smaller in the current study compared to previous studies (Papalini et al., 2021a; Papalini, Neefs, et al., 2021c; San Martín et al., 2020). We noticed that in the later stage of the avoidance learning phase in the current study, the avoidance proportion for the CS+ v (around 0.70) was lower and the avoidance proportion for the CS+unav (around 0.50) was higher compared to those in those previous studies (around 1.0 for the CS+av and around 0.4 for the CS+unav, Papalini et al., 2021a; Papalini, Neefs, et al., 2021c; San Martín et al., 2020), where electrical stimuli were used as the unconditional stimulus. Our participants did not avoid as many CS+av trials as in the previous studies, maybe because the moderately aversive pictures used in the current study were not as aversive as electrical stimuli. Additionally, conducting an experiment online makes it challenging to ascertain participants concentrate on the task the whole time despite some evidence showed they did (see supplementary materials for further discussion). In particular, some of our participants may have occasionally looked away from the screen when the aversive pictures were presented. As a result, they might not have gone through the intended level of aversive experiences and the relief pleasantness derived from the US omissions would be lower in those participants, resulting in weaker reinforcement of avoidance responses and, therefore, fewer avoidance responses towards the CS+av trials. In addition, there was no cost attached to the avoidance responses, which might contribute to an elevated rate of avoidance responses towards the CS+unav trials. The smaller differentiation of avoidance proportion between the CS+av and the CS+unav may have made it difficult to observe a clear reinforcing effect of relief pleasantness on the avoidance responses during the avoidance learning phase. Future optimizations of the current design could use a more aversive unconditional stimulus, introduce costs to the avoidance actions, or shorten the avoidance response window to make it more challenging to perform the task so that participants might be more inclined to stay focused on the task.

There were some unexpected findings regarding the main hypotheses. First of all, no correlation was found between trait anhedonia and the overall relief pleasantness measured at the end of the task. In fact, this retrospective measure of the US-omission-induced relief might be biased as it was significantly higher compared to the averaged relief pleasantness measured during the task (paired *t*-test, $t(199) = 8.85$, $p < .001$). This overestimation of relief might be due to the fact that the long experiment was finally over when the retrospective relief was measured, and participants were experiencing more relief compared to in the middle of the task. Secondly, in all sensitivity analyses, US unpleasantness measured at the end of the experiment seemed to be the strongest predictor for both relief pleasantness and avoidance responses during the task. A higher level of US unpleasantness significantly predicted a higher level of relief pleasantness while the main effects of anticipatory and consummatory anhedonia were no longer present. This indicates that the relief pleasantness of the US omissions was mainly determined by how unpleasant the US was perceived in the current study. Similarly, US unpleasantness overshadowed the effect of trait anticipatory anhedonia on avoidance responses. A higher level of US unpleasantness predicted more avoidance responses while the effect of anticipatory anhedonia was no longer significant. Similar to the measure of retrospective relief, it is possible that the US unpleasantness measured at the end of the experiment would be biased. It could be either overestimated due to its retrospective nature or underestimated because of habituation to the US over the course of the task. However, a closer examination of the US unpleasantness measured during the task did not show any pattern of US habituation (see Fig. S9 in the supplementary materials). When comparing the US unpleasantness measured at the end of the task to the average US unpleasantness measured during the whole task, no significant difference was found. Therefore, the US unpleasantness as measured at the end of the experiment is assumed to be valid. The fact that US unpleasantness seems to be the main driver for both relief pleasantness and avoidance responses may in fact not be surprising, given that threat-omission-induced relief is found to be a function of US expectancy and intensity, with higher expectancy of the US as well as higher US intensity leading to higher relief pleasantness (Willems & Vervliet, 2021).

In the current study, threat-omission-induced relief is a conditional state, given that an active avoidance response was incentivized by how aversive the threat was perceived as well as by how pleasant the avoidance outcome (i.e., relief) was valued (Fig. 8). Relief is derived from the initial perceived threat aversiveness, while anticipatory anhedonia could impair the valuation of relief and consummatory anhedonia could impair the capacity of experiencing relief. All these factors (dashed lines in Fig. 8) jointly contribute to the dynamic development of relief pleasantness during the avoidance learning process. In other words, the positive affective state of relief is a result of both threat and reward processing systems. Of note, anhedonia was previously found to be associated with increased responsiveness in threat-related neural circuitry in response to extinguished threat (Young et al., 2021). Therefore, even though no correlation was found in the current study between self-reported US unpleasantness and trait anhedonia, we cannot rule out the possibility that the presence of anhedonia might influence threat responding and complicate its influence on relief pleasantness.

Instead of restoring positive affect, most psychological interventions so far aim to attenuate negative affect and are largely ineffective for reducing anhedonia (Craske, Meuret, Ritz, Treanor, & Dour, 2016). Nowadays, targeting anhedonia is not only a goal specifically for depression (Khazanov, Forbes, Dunn, & Thase, 2022) or anxiety treatments (Taylor, Hoffman, & Khan, 2022), but also transdiagnostic treatments (Nagy et al., 2020). Studying the positive affect process during maladaptive threat learning is crucial to improve treatment efficacy for these affective disorders since accumulating evidence has shown that anhedonia might perpetuate threat responding (Taylor et al., 2022; Young et al., 2021). The effect of US unpleasantness in the current study again demonstrated the potential interaction between threat and reward processes during maladaptive avoidance behaviors. Given the high comorbidity rate of anxiety-related disorders and depression, such an interaction process deserves further investigation to understand how maladaptive avoidance behaviors are learned and maintained.

One limitation of the current online study is the exclusive reliance on self-report measures. It has been shown that unconscious liking can develop without subjective awareness and further influence goal-directed behaviors (Berridge & Winkielman, 2003; Pessiglione et al., 2008; Winkielman, Berridge, & Wilbarger, 2005). Adding extra measurement levels that could capture implicit reactions (e.g., physiological and neural responses) would contribute to a more complete picture of the processing of threat-omission-induced relief and its potential impairments. Additionally, the anhedonia scale used in the current study, like many other self-report measures of hedonic capacity, requires participants to recollect memories about pleasure experiences from specific rewards and evaluate them consciously. These processes might be influenced by a variety of cognitive biases or working memory impairments, resulting in an inaccurate measure of trait anhedonia (Kieslich, Valton, & Roiser, 2022).

Secondly, we assumed that while consummatory anhedonia might reduce experienced relief pleasantness directly, anticipatory anhedonia should impair the motivation to seek relief, resulting in lower pleasantness when this less-wanted relief is experienced (the blue-colored path in Fig. 1). However, in the absence of a direct measure of the '*wanting*' of relief in the current study, this assumption should be treated with caution.

Thirdly, in the current study, we proposed that early anhedonia symptoms can eventually lead to learned helplessness by reducing the pleasure derived from controlling threats, thereby resulting in deficits in adaptive avoidance. However, we did not directly measure learned helplessness, which requires a test in a **new** situation (Overmier & Seligman, 1967). Future studies could include an additional test phase in either a similar or different context compared to the initial avoidance acquisition phase to test whether the behavioral deficits fail to transfer in both situations.

As a last limitation, although the current study found an impairing effect of anhedonia on threat-omission-induced relief, the disappearance of this effect when taking into account US unpleasantness makes it difficult to draw a definite conclusion as to whether this form of relief is indeed rewarding by nature. Decisive evidence would require comparing the processing of threat-omission-induced relief directly to the processing of reward.

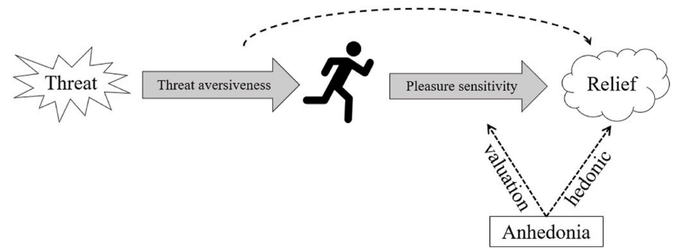

Fig. 8. The generation of threat-omission-induced relief.

To conclude, we found that both trait anticipatory and trait consummatory anhedonia impaired the pleasurable relief derived from active threat omissions, but only anticipatory anhedonia was associated with reduced threat avoidance. These results suggest the potential interaction between the threat and reward processing during maladaptive threat avoidance behaviors.

CRediT authorship contribution statement

Lu Leng: Conceptualization, Methodology, Software, Investigation, Project administration, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. **Tom Beckers:** Conceptualization, Methodology, Investigation, Supervision, Writing – review & editing. **Bram Vervliet:** Conceptualization, Methodology, Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

All data and code used in the current study have been made publicly available via the Open Science Framework at https://osf.io/5da6b.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2022.104227.

References

American Psychiatric Association, A. P. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.
Bakdash, J. Z., & Marusich, L. R. (2017). Repeated measures correlation. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00456
Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2018). *Parsimonious mixed models. Arxiv: 1506.04967[Stat.ME]* http://arxiv.org/abs/1506.04967.
Berridge, K., & Winkielman, P. (2003). What is an unconscious emotion?(The case for unconscious "liking"). *Cognition & Emotion, 17*(2), 181–211. https://doi.org/10.1080/02699930302289
Bickel, R. (2007). *Multilevel analysis for applied research: It's just regression*. Guilford Press.
Borsini, A., Wallis, A. S. J., Zunszain, P., Pariante, C. M., & Kempton, M. J. (2020). Characterizing anhedonia: A systematic review of neuroimaging across the subtypes

of reward processing deficits in depression. *Cognitive, Affective, & Behavioral Neuroscience, 20*(4), 816–841. https://doi.org/10.3758/s13415-020-00804-6

Brown, V. A. (2021). *An introduction to linear mixed-effects modeling in R: Advances in Methods and Practices in psychological science*. https://doi.org/10.1177/2515245920960351

Craske, M. G., Meuret, A. E., Ritz, T., Treanor, M., & Dour, H. J. (2016). Treatment for anhedonia: A neuroscience driven approach. *Depression and Anxiety, 33*(10), 927–938. https://doi.org/10.1002/da.22490

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*(3), 297–334. https://doi.org/10.1007/BF02310555

Daoud, J. I. (2017). Multicollinearity and regression analysis. *Journal of Physics: Conference Series, 949*, Article 012009. https://doi.org/10.1088/1742-6596/949/1/012009

Deutsch, R., Smith, K. J. M., Kordts-Freudinger, R., & Reichardt, R. (2015). How absent negativity relates to affect and motivation: An integrative relief model. *Frontiers in Psychology, 6*. https://doi.org/10.3389/fpsyg.2015.00152

Freeston, M. H., Rhéaume, J., Letarte, H., Dugas, M. J., & Ladouceur, R. (1994). Why do people worry? *Personality and Individual Differences, 17*(6), 791–802. https://doi.org/10.1016/0191-8869(94)90048-5

Gard, D. E., Gard, M. G., Kring, A. M., & John, O. P. (2006). Anticipatory and consummatory components of the experience of pleasure: A scale development study. *Journal of Research in Personality, 40*(6), 1086–1102. https://doi.org/10.1016/j.jrp.2005.11.001

Gerlicher, A. M. V., Tüscher, O., & Kalisch, R. (2018). Dopamine-dependent prefrontal reactivations explain long-term benefit of fear extinction. *Nature Communications, 9*(1), 4294. https://doi.org/10.1038/s41467-018-06785-y

Haskell, A. M., Britton, P. C., & Servatius, R. J. (2020). Toward an assessment of escape/avoidance coping in depression. *Behavioural Brain Research, 381*, Article 112363. https://doi.org/10.1016/j.bbr.2019.112363

Husain, M., & Roiser, J. P. (2018). Neuroscience of apathy and anhedonia: A transdiagnostic approach. *Nature Reviews Neuroscience, 19*(8), 470–484. https://doi.org/10.1038/s41583-018-0029-9

Khazanov, G. K., Forbes, C. N., Dunn, B. D., & Thase, M. E. (2022). Addressing anhedonia to increase depression treatment engagement. *British Journal of Clinical Psychology, 61*(2), 255–280. https://doi.org/10.1111/bjc.12335

Kieslich, K., Valton, V., & Roiser, J. P. (2022). Pleasure, reward value, prediction error and anhedonia. *Current Topics in Behavioral Neurosciences*. https://doi.org/10.1007/7854_2021_295

Krypotos, A.-M., Effting, M., Kindt, M., & Beckers, T. (2015). Avoidance learning: A review of theoretical models and recent developments. *Frontiers in Behavioral Neuroscience, 9*. https://doi.org/10.3389/fnbeh.2015.00189

Krypotos, A.-M., Vervliet, B., & Engelhard, I. M. (2018). The validity of human avoidance paradigms. *Behaviour Research and Therapy, 111*, 99–105. https://doi.org/10.1016/j.brat.2018.10.011

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*(1), 1–26. https://doi.org/10.18637/jss.v082.i13

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2008). *International affective picture system (IAPS): Affective ratings of pictures and instruction manual*. Gainesville, FL: University of Florida. *Technical Report A-8*.

Lange, I., Goossens, L., Michielse, S., Bakker, J., Vervliet, B., Marcelis, M., et al. (2020). Neural responses during extinction learning predict exposure therapy outcome in phobia: Results from a randomized-controlled trial. *Neuropsychopharmacology, 45*(3), 534–541. https://doi.org/10.1038/s41386-019-0467-8

LeDoux, J. E., Moscarello, J., Sears, R., & Campese, V. (2017). The birth, death and resurrection of avoidance: A reconceptualization of a troubled paradigm. *Molecular Psychiatry, 22*(1), 24–36. https://doi.org/10.1038/mp.2016.166

Leknes, S., Lee, M., Berna, C., Andersson, J., & Tracey, I. (2011). Relief as a reward: Hedonic and neural responses to safety from pain. *PLoS One, 6*(4). https://doi.org/10.1371/journal.pone.0017870

Lonsdorf, T. B., Menz, M. M., Andreatta, M., Fullana, M. A., Golkar, A., Haaker, J., et al. (2017). Don't fear 'fear conditioning': Methodological considerations for the design and analysis of studies on human fear acquisition, extinction, and return of fear. *Neuroscience & Biobehavioral Reviews, 77*, 247–285. https://doi.org/10.1016/j.neubiorev.2017.02.026

Luo, W., Li, H., Baek, E., Chen, S., Lam, K. H., & Semma, B. (2021). *Reporting practice in multilevel modeling: A revisit after 10 Years: Review of educational research*. https://doi.org/10.3102/0034654321991229

Luo, R., Uematsu, A., Weitemier, A., Aquili, L., Koivumaa, J., McHugh, T. J., et al. (2018). A dopaminergic switch for fear to safety transitions. *Nature Communications, 9*(1), 1–11. https://doi.org/10.1038/s41467-018-04784-7

Maier, S. F., & Seligman, M. E. P. (2016). Learned helplessness at fifty: Insights from neuroscience. *Psychological Review, 123*(4), 349–367. https://doi.org/10.1037/rev0000033

Milad, M. R., Orr, S. P., Pitman, R. K., & Rauch, S. L. (2005). Context modulation of memory for fear extinction in humans. *Psychophysiology, 42*(4), 456–464. https://doi.org/10.1111/j.1469-8986.2005.00302.x

Nagy, G. A., Cernasov, P., Pisoni, A., Walsh, E., Dichter, G. S., & Smoski, M. J. (2020). Reward network modulation as a mechanism of change in behavioral activation. *Behavior Modification, 44*(2), 186–213. https://doi.org/10.1177/0145445518805682

Overmier, J. B., & Molet, M. (2017). Learned helplessness. *Encyclopedia of Animal Cognition and Behavior, 1–5*. https://doi.org/10.1007/978-3-319-47829-6_1041-1

Overmier, J. B., & Seligman, M. E. (1967). Effects of inescapable shock upon subsequent escape and avoidance responding. *Journal of Comparative & Physiological Psychology, 63*(1), 28–33. https://doi.org/10.1037/h0024166

Palan, S., & Schitter, C. (2018). Prolific.ac—a subject pool for online experiments. *Journal of Behavioral and Experimental Finance, 17*, 22–27. https://doi.org/10.1016/j.jbef.2017.12.004

Papalini, S., Ashoori, M., Zaman, J., Beckers, T., & Vervliet, B. (2021a). The role of context in persistent avoidance and the predictive value of relief. *Behaviour Research and Therapy, 138*, Article 103816. https://doi.org/10.1016/j.brat.2021.103816.

Papalini, S., Beckers, T., Claes, L., & Vervliet, B. (2021b). The drive for thinness: Towards a mechanistic understanding of avoidance behaviors in a non-clinical population. *Behaviour Research and Therapy, 142*, Article 103868. https://doi.org/10.1016/j.brat.2021.103868.

Papalini, S., Neefs, L., Beckers, T., van Oudenhove, L., & Vervliet, B. (2021c). Overnight fasting affects avoidance learning and relief. *Biological Psychiatry, 89*(9, Supplement), S302–S303. https://doi.org/10.1016/j.biopsych.2021.02.754.

Pessiglione, M., Petrovic, P., Daunizeau, J., Palminteri, S., Dolan, R. J., & Frith, C. D. (2008). Subliminal instrumental conditioning demonstrated in the human brain. *Neuron, 59*(4), 561–567. https://doi.org/10.1016/j.neuron.2008.07.005

Pittig, A., Treanor, M., LeBeau, R. T., & Craske, M. G. (2018). The role of associative fear and avoidance learning in anxiety disorders: Gaps and directions for future research. *Neuroscience & Biobehavioral Reviews, 88*, 117–140. https://doi.org/10.1016/j.neubiorev.2018.03.015

Raczka, K. A., Mechias, M.-L., Gartmann, N., Reif, A., Deckert, J., Pessiglione, M., et al. (2011). Empirical support for an involvement of the mesostriatal dopamine system in human fear extinction. *Translational Psychiatry, 1*(6). https://doi.org/10.1038/tp.2011.10. e12–e12.

Rømer Thomsen, K., Whybrow, P. C., & Kringelbach, M. L. (2015). Reconceptualizing anhedonia: Novel perspectives on balancing the pleasure networks in the human brain. *Frontiers in Behavioral Neuroscience, 9*. https://doi.org/10.3389/fnbeh.2015.00049

RStudio Team. (2020). *RStudio: Integrated Development for R. RStudio, PBC*. http://www.rstudio.com/.

Rush, A. J., Trivedi, M. H., Ibrahim, H. M., Carmody, T. J., Arnow, B., Klein, D. N., et al. (2003). The 16-item quick inventory of depressive symptomatology (QIDS), clinician rating (QIDS-C), and self-report (QIDS-SR): A psychometric evaluation in patients with chronic major depression. *Biological Psychiatry, 54*(5), 573–583. https://doi.org/10.1016/S0006-3223(02)01866-8

Russell, V. L. (2021). *Emmeans: Estimated marginal means, aka least-squares means. R package version 1.6.1* https://CRAN.R-project.org/package=emmeans.

Salinas-Hernández, X. I., Vogel, P., Betz, S., Kalisch, R., Sigurdsson, T., & Duvarci, S. (2018). Dopamine neurons drive fear extinction learning by signaling the omission of expected aversive outcomes. *Elife, 7*, Article e38818. https://doi.org/10.7554/eLife.38818

San Martín, C., Jacobs, B., & Vervliet, B. (2020). Further characterization of relief dynamics in the conditioning and generalization of avoidance: Effects of distress tolerance and intolerance of uncertainty. *Behaviour Research and Therapy, 124*, Article 103526. https://doi.org/10.1016/j.brat.2019.103526

Schlund, M. W., Ludlum, M., Magee, S. K., Tone, E. B., Brewer, A., Richman, D. M., et al. (2020). Renewal of fear and avoidance in humans to escalating threat: Implications for translational research on anxiety disorders. *Journal of the Experimental Analysis of Behavior, 113*(1), 153–171. https://doi.org/10.1002/jeab.565

Schultz, W. (2016). Dopamine reward prediction-error signalling: A two-component response. *Nature Reviews Neuroscience, 17*(3), 183–195. https://doi.org/10.1038/nrn.2015.26

Sheppes, G., Suri, G., & Gross, J. J. (2015). Emotion regulation and psychopathology. *Annual Review of Clinical Psychology, 11*(1), 379–405. https://doi.org/10.1146/annurev-clinpsy-032814-112739

Simons, J. S., & Gaher, R. M. (2005). The distress tolerance scale: Development and validation of a self-report measure. *Motivation and Emotion, 29*(2), 83–102. https://doi.org/10.1007/s11031-005-7955-3

Spielberger, C. D., Gorsuch, R., Lushene, R., Vagg, P., & Jacob, G. (1977). *Manual for the state-trait anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press. https://doi.org/10.1037/t06496-000

Stange, J. P., Alloy, L. B., & Fresco, D. M. (2017). Inflexibility as a vulnerability to depression: A systematic qualitative review. *Clinical Psychology: Science and Practice, 24*(3), 245–276. https://doi.org/10.1111/cpsp.12201

Taylor, C. T., Hoffman, S. N., & Khan, A. J. (2022). *Anhedonia in anxiety disorders*. Springer Berlin Heidelberg. https://doi.org/10.1007/7854_2022_319

Thiele, M., Yuen, K. S. L., Gerlicher, A. V. M., & Kalisch, R. (2021). A ventral striatal prediction error signal in human fear extinction learning. *NeuroImage*. , Article 117709. https://doi.org/10.1016/j.neuroimage.2020.117709

Vervliet, B., Lange, I., & Milad, M. R. (2017). Temporal dynamics of relief in avoidance conditioning and fear extinction: Experimental validation and clinical relevance. *Behaviour Research and Therapy, 96*, 66–78. https://doi.org/10.1016/j.brat.2017.04.011

Willems, A. L., & Vervliet, B. (2021). When nothing matters: Assessing markers of expectancy violation during omissions of threat. *Behaviour Research and Therapy, 136*, Article 103764. https://doi.org/10.1016/j.brat.2020.103764

Winkielman, P., Berridge, K. C., & Wilbarger, J. L. (2005). Unconscious affective reactions to masked happy versus angry faces influence consumption behavior and judgments of value. *Personality and Social Psychology Bulletin, 31*(1), 121–135. https://doi.org/10.1177/0146167204271309

Young, K. S., Bookheimer, S. Y., Nusslock, R., Zinbarg, R. E., Damme, K. S. F., Chat, I. K.-Y., et al. (2021). Dysregulation of threat neurociruitry during fear extinction: The role of anhedonia. *Neuropsychopharmacology, 1–8*. https://doi.org/10.1038/s41386-021-01003-8