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Increase in avoidance of learnt fear via unconditioned stimulus revaluation

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A R T I C L E I N F O

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A B S T R A C T

Not all individuals develop anxiety-related disorders by direct exposure to trauma. Other pathways, such as retrospectively revaluating neutral past events as more aversive than they were, could also lead to the development of fear. This process has been modelled in the laboratory by pairing a neutral conditioned stimulus (CS) with a low intensity unconditioned stimulus (US). The intensity of the US is later increased and hence revaluated as aversive, leading to the development of conditioned fear to the CS. The present study (n = 66) examined whether avoidance of learnt fear, a feature of anxiety-related disorders, could develop via this retrospective revaluation process. In a sensory preconditioning protocol, two neutral preconditioning stimuli (PSs) were paired with two neutral CSs. Each of these CSs were then associated with a distinct low intensity US. In the following manipulation phase, one US increased in intensity for one group (the Revaluation group) while the same US remained at the same intensity for another group (the Control group). In test, the Revaluation group showed stronger avoidance responses to the PS associated with the revaluated CS compared to the Control group. However, there was no evidence of conditioned fear developing to the revaluated CS, nor did anxiety-related risk factors appear to influence the rate of avoidance of learnt fear. These findings suggest that avoidance of learnt fear can be increased via US revaluation, even after a seemingly benign experience, and highlight potential therapeutic interventions aimed at reducing avoidance of learnt fear.

1. Introduction

Fear conditioning is a paradigm that validly models the etiology of anxiety-related disorders (Lissek et al., 2005). In this paradigm, a neutral conditioned stimulus (CS) is repeatedly paired with a biologically aversive unconditioned stimulus (US), eventually leading to the CS alone capable of evoking conditioned fear (Beckers et al., 2013; Lonsdorf et al., 2017). Despite acquiring conditioned fear to a threat-predicting CS is adaptive, as it promotes self-preservation, this learning may become pathological when fear persists to a CS even in the absence of a US, or when it generalizes to non-threatening stimuli (Beckers et al., 2023; Dymond et al., 2015; Zinbarg et al., 2022).

While CS – US pairings are thought to model the etiology of anxiety-related disorders, not all individuals with these disorders have experienced direct traumatic events (Zinbarg et al., 2022). Davey (1989, 1992) proposed that clinical anxiety may also develop via other indirect pathways, such as by revaluating a neutral US as more aversive. For example, after a neutral dental experience (a neutral US), an individual may revaluate this experience as more aversive than it was in hindsight when hearing that a friend lost a tooth due to a faulty dental procedure. This could lead to the onset of dental fear and potentially result in the development of full-blown dental phobia. Supporting this notion, laboratory studies have shown that revaluating a US as more aversive increases conditioned fear to the CS (e.g., Hosoba et al., 2001; White & Davey, 1989). In these studies, participants initially showed limited to no conditioned fear to a CS that was paired with a low intensity US. However, after directly experiencing a gradual increase in US aversiveness, participants exhibited a significant increase in conditioned fear to the CS, despite the lack of direct association between the CS and the now aversive US. Therefore, these findings suggest that conditioned fear can be acquired even when a CS is initially paired with a nonaversive US, provided that the US is later revaluated as threatening.

Previous studies have found that avoidance behaviours are sensitive to changes in US value. For example, Declercq and De Houwer (2008) examined safety behaviors, a behavior performed during CS presentation that can effectively prevent US onset, in humans. They observed that after revaluating an initially negative US into a positive US, participants showed a decrease in their safety behaviors to the revalued CS

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when compared to a non-revalued CS. Other studies (Flores et al., 2018; Gillan et al., 2014) showed that US devaluation led to less safety behaviors, but this pattern was weaker in patients with obsessive-compulsive disorder or in a subclinical example. These studies indicate that revaluating US aversiveness can affect the magnitude of safety behaviors.

Despite preliminary evidence suggesting that clinical fear and safety behaviors can be acquired or diminished via US revaluation (Declercq & De Houwer, 2008; Gillan et al., 2014; Hosoba et al., 2001; White & Davey, 1989), it remains unclear whether avoidance of learnt fear, a maladaptive feature in anxiety-related disorders, is acquired in similar ways. Avoidance of learnt fear refers to behavioral responses that reduce the likelihood of encountering feared stimulus. For example, individuals with phobias avoid places or stimuli where phobic-related objects might be presented (Katz, 1974; Kleinknecht & Lenz, 1989; Sawchuk et al., 2000; Walz, Mühlberger, & Pauli, 2016a). Clinical studies have shown that avoidance of learnt fear imposes impairments to daily life functioning (Corrigan et al., 2007; Walz et al., 2016a).

In a fear conditioning model, avoidance of learnt fear can be modelled by designated responses that reduce the chance of CS (feared stimulus) occurrence. Using a sensory preconditioning procedure (Wong and Pittig, 2022a, 2022b, 2023; Wong et al., 2024), two preconditioning stimuli (PSs) were first paired with two neutral CSs. One CS was then paired with an aversive US whereas another CS was paired with the absence of an US. Participants showed greater avoidance responses to the PS that signalled the threat-predicting CS compared to the PS that signalled the safety-predicting CS, modelling the avoidance to stimuli/situations that predict the onset of a feared stimulus in anxiety-related disorders. It is thought that the PSs activate the representation of the CSs: the PS activates the representation of the threat-related CS, which in turn activates the US representation (Gewirtz & Davis, 2000). Therefore, even though the PS has no direct association with the US, it can still evoke anticipatory responses of the US, thus evoking avoidance responses (e.g., Boddez et al., 2020; Mitchell et al., 2009).

According to the Expectancy model (Lovibond, 2006), avoidance responses are primarily driven by the expectation of a threat and the belief that avoidance responses can reduce the likelihood of threat occurrence. Building on this model, it is proposed that a key factor driving avoidance of learnt fear is to ultimately prevent US occurrence, i.e., avoidance of learnt fear reduces the likelihood of CS occurrence, and hence the US that follows (Wong et al., 2022). Therefore, when the CS predicts a neutral US, limited avoidance of learnt fear to this CS is expected since the US is not perceived as threatening. However, if the same US is later reevaluated as aversive, an increase in avoidance of learnt fear is expected, as the US is now viewed as a threat.

Preliminary evidence also found that certain risk factors for anxiety-related disorders are associated with persistent avoidance of learnt fear (e.g., Pittig et al., 2014; Rinck et al., 2016; Wong & Pittig, 2023). For instance, laboratory studies suggested that trait anxiety, a risk factor characterized by a strong tendency to perceive a variety of situations as threatening and respond negatively to these situations in general (Watson & Clark, 1984), is associated with persistent avoidance of learnt fear (Wong et al., 2024; Wong & Pittig, 2023) or enhances the link between conditioned fear and avoidance of learnt fear (Pittig et al., 2014). Intolerance of uncertainty, another risk factor characterized by a tendency to sustain negative emotional responses to a lack of information of the situation (Freeston et al., 1994), was also preliminarily found to associated with persistent avoidance of learnt fear (Wong et al., under review). In addition, recent evidence has shown that distress tolerance, a protective factor against anxiety-related disorders featured by a heightened ability to tolerate distress (Simons & Gaher, 2005), is associated with a decrease in unnecessary avoidance in general (e.g., San Martin et al., 2020; Vervliet et al., 2017). Considering these early evidence, the current study explored whether these risk factors or protective factors were associated with an increase or decrease in avoidance of learnt fear.

Taken together, the current study examined whether avoidance of learnt fear could be increased via US revaluation in a sensory preconditioning protocol. We first paired two PSs with two neutral CS, respectively. The CSs were then paired with two different low intensity USs. In a following crucial manipulation, one group (Revaluation group) experienced an increase in aversiveness of one US, whereas the same US remained low in aversiveness in another group (Control group). The PSs were then presented and avoidance responses were assessed. We also assessed whether conditioned fear was acquired to the CS that predicted the revalued US. The following hypotheses were proposed.

(1) The Revaluation group would show stronger avoidance of learnt fear to the PS associated with a revalued CS-US association when compared to the Control group.
(2) The Revaluation group would show stronger fear (as indexed by skin conductance) to the revaluated CS compared to the Control group after US revaluation. We also explored whether risk factors such as trait anxiety and intolerance of uncertainty, or protective factors such as distress tolerance, played a role in avoidance of learnt fear.

2. Method

2.1. Participants

Psychology undergraduates from Erasmus University Rotterdam and the general community in Rotterdam were recruited as participants. Psychology undergraduates were compensated with partial course credits. The exclusion criteria consisted of dyslexia, visual or hearing impairment, colour blindness, pregnancy, psychoactive medication, and current diagnosis of any psychiatric diagnosis. We used the 'Summary-statistics-based power analysis" shiny app by Murayama et al. (2022), which uses summary statistics (e.g., t-values) of the effect of interest from prior work to obtain an estimate of statistical power for the current study. We used the summary statistics based on the increase in safety behaviors to a CS + after US revaluation, which estimates that at least 62 participants (31 in each group) is required to detect the increase in avoidance responses after US revaluation that has a similar effect size of Declercq and De Houwer (2008) with a targeted power of 0.95. Considering potential attrition rates due to dropouts and technical

Table 1
Descriptive statistics for the sample. DTS = Distress tolerance scale; IUS = Intolerance of uncertainty scale; DASS21 = Depression Anxiety Stress scale −21. Numeric values for gender indicate the number of women, men, and other in each group. Bold p-values indicate significant group differences.

	Revaluation group (n = 31)	Control group (n = 35)	Group comparisons p-values	Cronbach's α
	Mean (SD)	Mean (SD)		
Gender (Women/Men/Other)	29/2/0	27/7/1	0.164	NA
Age	19.94 (1.63)	20.40 (3.08)	0.455	NA
DTS (1–5)	2.52 (0.61)	2.63 (0.66)	0.495	0.86
IUS (27–135)	64.81 (19.30)	66.34 (16.10)	0.726	0.93
DASS21-Anxiety (0–42)	12.26 (7.79)	15.37 (8.41)	0.125	0.78
DASS21-Depression (0–42)	10.32 (7.97)	11.03 (8.71)	0.733	0.85
DASS21-Stress (0–42)	12.71 (6.84)	17.37 (7.97)	**.014**	0.77

difficulties, a total of 72 participants were recruited. See Table 1 for the descriptive statistics of the final sample. Noted that while the Control group showed significantly higher stress level than the Revaluation group, none of the other demographic data differed between groups.

2.2. Apparatus and materials

Two standardized black-and-white images of a shoe and a wrench (Snodgrass & Vanderwart, 1980) were used as the preconditioned stimuli (PSs). An orange triangle and a purple hexagon were used as the conditioned stimuli (CSs). These stimuli were individually presented at the centre of a white screen. A headphone (Audio-Technica ATH-M40x) connected to an amplifier (Beyerdynamic A-20) was used to administer the two noise unconditioned stimuli (USs). One noise US was directed to the right ear (right noise US) while the other noise US (left noise US) was directed to the left ear. Each noise US was presented for 1000ms and at a frequency of 44100 Hz. Stimuli associated to the right noise US are referred to with a 'r' subscript while stimuli associated to the left noise US are indicated using a 'l' subscript. A pair of Ag/AgCl electrodes were attached to the hypothenar muscles of participants' non-dominant hand to measure skin conductance responses (SCRs). The SCR data was recorded at 1000 Hz via a Biopac MP150 system equipped with a EDA100 amplifier.

Three visual analogue scales (VASs) were used in this study. CS expectancy ratings and US expectancy ratings were measured via bidirectional visual analogue scales (VAS) displayed on the bottom of the screen with their corresponding stimuli: CS expectancy VAS was presented during PS presentations. The right end of the CS expectancy VAS displayed 100 % expectancy of CSr and the left end indicated 100 % expectancy of CSl. The middle of the VAS indicated 0 % expectancy of neither CS. The CS expectancy VAS was presented along with a question 'How likely do you expect the following outcomes? Left click to indicate your ratings". The US expectancy VAS was presented during CS presentations. The right end of this VAS displayed 100 % expectancy of a right noise US and the left end indicated 100 % expectancy of a left noise US. The middle of the US expectancy VAS indicated 0 % expectancy of neither US. The US expectancy VAS was presented along with a question 'How likely do you expect the following outcomes? Left click to indicate your ratings'. The avoidance response VAS ranged from 0 % (certain NOT avoid) to 100 % (certain avoid). This VAS was presented along with a question 'Indicate the extent of your avoidance to prevent the outcome that follows'. All three VAS had intervals of 1 %. A computer equipped with Presentation software (Neurobehavioral Systems Inc., Berkeley, CA, Version 20.1) displayed all visual stimuli and VASs and recorded all self-reported ratings and avoidance responses.

Depression Anxiety Stress Scale-21 (DASS-21; Lovibond & Lovibond, 1995; Lovibond, 1998), Intolerance of Uncertainty Scale (IUS; Buhr & Dugas, 2002), and Distress Tolerance Scale (DTS; Simons & Gaher, 2005) questionnaires were included. We used the trait version of DASS-21 (Lovibond, 1998) that assesses trait anxiety and discriminates it from depression and stress (Antony et al., 1998; Lovibond, 1998). Scores of trait anxiety were calculated by multiplying the sum of scores of the anxiety subscales by two, allowing them to be comparable to the original 42-item DASS. The IUS measures an individual's emotional, cognitive, and behavioral responses to ambiguous situations, consequences of being uncertain, and efforts to control the future (Buhr & Dugas, 2002). Finally, the DTS measures emotional distress tolerance (i.e. ability to experience and withstand negative psychological states) via a 15 item self-report questionnaire (Simons & Gaher, 2005). Levels of distress tolerance are determined by sum of scores of DTS.

2.3. Procedure

Once written informed consent was obtained, skin conductance electrodes with isotonic gel were fixed to the hypothenar muscles on the palm of participants' non-dominant hand. After donning the headphones, a noise US familiarization procedure was administered. This procedure consisted of a series of noise blasts that gradually increased in intensity from 30 dB to 100 dB. Aversiveness ratings, from 0 (not at all uncomfortable) to 10 (extremely uncomfortable), were assessed for each intensity. If the participant found the final noise blast too aversive, they were given the option to reduce the volume to 95 dB or continue with 100 dB.

After noise US familiarization, a reward-matching procedure was implemented. This procedure involved a set of questions asking "Are you willing to tolerate the noise blast for €_?". Reward amounts ranged from odd numbers between 5 and 31 cents and were presented in a random order. Each question prompted participants to respond either 'Yes' or 'No' verbally. The competing incentive was then determined by the amount of reward between the highest 'No' and the lowest 'Yes'. Such as, if the participant agreed to tolerate the US from 21 cents onwards but not when offered 5 to 19 cents, the midpoint (20 cents) would be selected as the maximum competing reward per trial (see Wong & Pittig, 2022b).

Participants were then asked to complete the DASS-21, IUS, and DTS questionnaires. The conditioning task that followed constituted of six stages: Preconditioning, Baseline costly avoidance, CS-US contingency learning, Revaluation manipulation, Post-revaluation avoidance test, and Fear retention test (see Fig. 1).

Preconditioning. This stage consisted of a total of 16 trials divided into four blocks: each block comprised of two PSr trials and two PSl trials. Hence, each PS type was displayed eight times, in which PSr (e.g., a shoe) was 100 % reinforced by CSr whereas PSl (e.g., a wrench) was 100 % reinforced by CSl. On each PS trial, participants were prompted to indicate their CS expectancy. Once CS expectancy rating was indicated, the CS expectancy VAS disappeared while the PS remained on screen for 8 s. Immediately after PS offset, the corresponding CS was showed for 4 s, followed by a 4 s intertrial intervals. The PSs and CSs were counterbalanced across all participants. Presentation order of trials was pseudorandomized so that the same trial type would not appear more than twice in a row, which was implemented in all following stages.

Baseline costly avoidance. This stage consisted of 2 blocks, with each block comprising of 2 PSr and 2 PSl trials, amounting to a total of 8 trials in total. Participants could avoid the CSs following the PSs by indicating their avoidance on the avoidance VAS. The avoidance responses were negatively proportional to the likelihood of CS presentation. For example, indicating 70 % avoidance would mean a 70 % chance of omitting CS onset. Furthermore, a hypothetical monetary reward could be granted for each trial, with the amount being inversely proportional to the avoidance made. For example, an avoidance response of 70 % would forfeit 70 % of the maximum reward for that trial. Participants were informed that all earned rewards throughout the experiment were hypothetical.

On each trial, the PS was presented along with the avoidance VAS. After participants had indicated their avoidance responses, the avoidance VAS disappeared while the PS remained on screen for 8 s. Immediately after PS offset, either the corresponding CS appeared or a blank screen appeared for 4 s depending on the avoidance responses. The reward feedback was subsequently displayed for 2s. Moreover, ITI was randomized between 11 and 15s. This randomization was administered for all succeeding stages.

CS-US contingency learning. Participants were instructed to learn the CS – US relationship in this stage. This stage consisted of 4 blocks, with each block comprising 2 CSr and 2 CSl trials, amounting to 16 trials. The CSr was 100 % reinforced by a low intensity right noise US of 30 dB, while CSl was 100 % reinforced by a low intensity left noise US of 30 dB. The CS was presented on screen with the US expectancy VAS. Once participants had indicated their US expectancy ratings, the US expectancy VAS disappeared while the CS remained on screen for 8 s. Immediately after CS offset, the corresponding US was presented.

Revaluation Manipulation. This was the only stage that the groups received different manipulations. In the Revaluation group, each

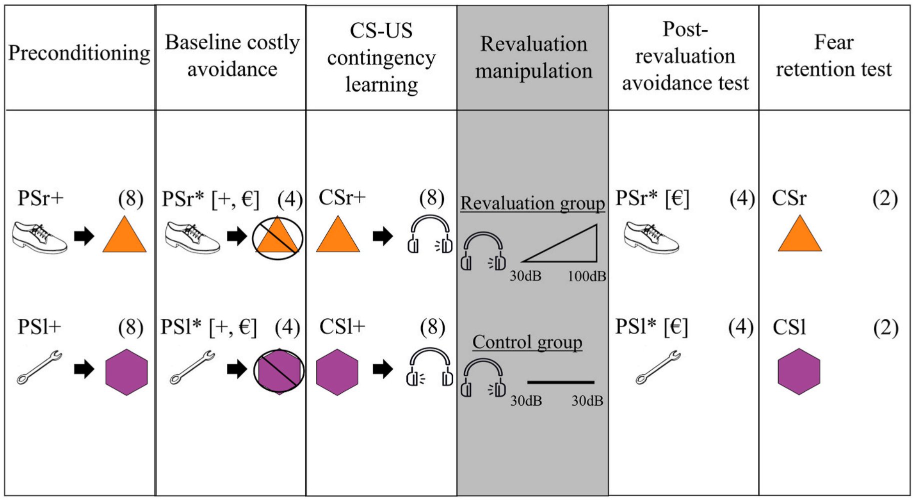

Fig. 1. Experimental design. PS indicates preconditioning stimuli; CS indicates conditioned stimuli. + indicates the reinforcement of CS or US presentations for PS or CS presentations, respectively; * indicates avoidance responses availability; + and € in brackets indicate reinforcement and a competing reward, depending on the avoidance responses. Revaluation manipulation (the shaded part) was the only phase where group manipulation took place.

participant is presented with a right noise US which increased in intensity (30 dB→54 dB→78 dB→100 dB→100 dB→100 dB) across 6 trials. Whereas the Control group receives a right noise US with the same intensity (30 dB) over all 6 trials. During each trial, a black fixation cross was presented. Two seconds before the right noise US was administered, the fixation cross turned red. An aversiveness rating VAS was immediately displayed at the bottom of the screen after a right noise US was administered.

Post-revaluation avoidance test. Similar to Baseline costly avoidance, the potential outcomes following the PSs could once again be avoided by participants. This stage consisted of 2 blocks, in which each block comprised 2 PSr trials and 2 PSl trials, amounting to 8 trials in total. Participants were reminded that hypothetical rewards were inversely proportional to the magnitude of reward received for each trial. The procedure was the same as described in Baseline costly avoidance, with the exception that neither PS was reinforced. Namely, a blank white screen would always appear for 4s following PS offset regardless of participants' avoidance responses.

Fear retention test. This stage consisted of 2 CSr trials and 2 CSl trials. Participants were informed that avoidance was unavailable, and they were prompted to indicate their US expectancy ratings for each trial. Unbeknownst to participants, none of the CSs were reinforced by a US.

2.4. Scoring and analysis

Only skin conductance measured during CS presentations during the Fear retention test was analyzed (i.e., the 8 s window when participants were asked to provide US expectancy ratings). The SCR data were analyzed using BrainVision Analyzer. We applied a 1 Hz low-pass filter to remove high frequency noises and a 50 Hz notch filter to the SCR data. We calculated the SCRs by locating the peak responding and its corresponding trough 1 s after CS onset till CS offset. The SCR data were then square-root transformed to reduce skewness (Boucsein et al., 2012).

All analyses were carried out with linear mixed models; all models had participants as the only random effect. The linear mixed models were carried out using R with lmer package (Bates et al., 2015). The degree of significance was reported with Satterthwaite approximation for degrees of freedom (Satterthwaite, 1941). In addition to the frequentist analyses, we also calculated Bayes factors (BF10) with BayesFactor package using default JZS priors (Jarosz & Wiley, 2014). According to Lee and Wagenmakers (2014), Bayes factors larger than 10 indicate strong evidence for an effect whereas Bayes factors smaller than 0.10 indicate strong evidence for the null hypothesis. The analyses were categorized into three parts: Manipulation check, Main hypotheses, and Exploratory analyses. All analyses were pre-registered on the Open Science Framework (https://osf.io/vgbfq).

2.5. Manipulation check

Preconditioning. We first checked whether participants acquired the PS – CS associations (PSr predicted CSr; PSl predicted CSl), and whether there were pre-existing group biases in acquiring this association. To this end, CS expectancy ratings served as dependent variable, whereas PS type (PSr and PSl), Block (Block 1 to Block 4), Group (Revaluation group and Control group), and their interactions served as fixed effects.

Baseline costly avoidance. We expected no differences in avoidance between PSs and between groups during Baseline avoidance. To this end, avoidance served as dependent variable, whereas PS type, Block, Group, and their interactions served as fixed effects. CS-US contingency learning. We checked whether participants acquired the CS-US associations (CSr predicted a right noise US, CSl predicted a left noise US). Therefore, US expectancy ratings served as dependent variable, whereas CS type (CSr and CSl), Block, Group, and their interactions served as fixed effects.

Revaluation manipulation. We check whether the increase in right noise US intensity in the Revaluation group would lead to an increase in US aversiveness ratings in the Revaluation group, but not in the Control group. To this end, we compared the aversiveness ratings between the first and last trials of US presentation. Thus, aversiveness ratings served as dependent variable, whereas Trial and Group served as fixed effects.

2.6. Main hypotheses

Our primary hypothesis was to examine whether the Revaluation group would show an increase in avoidance of learnt fear after US revaluation. To this end, we first analyzed whether the Revaluation group exhibited greater avoidance to PSr compared to PSl (i.e., differential avoidance) during Post-revaluation Avoidance test compared to the Control group. To this end, avoidance responses served as dependent variable, whereas PS type, Block, Group, and their interactions served as fixed effects. In addition, we carried out a cross-phase analysis, in which we compared avoidance responses on the last block of Baseline costly avoidance with avoidance responses on the first block of Post-revaluation avoidance test. This cross-phase analysis served two purposes. First, by only including the first test block, it reduced confounding extinction learning as none of the PSs were reinforced during Post-revaluation Avoidance test. Second, this comparison allowed us to directly examine whether avoidance responses to PSr increased from Baseline costly avoidance to Post-revaluation avoidance test, and whether this pattern was greater in the Revaluation group compared to the Control group (i.e., this pattern reflects the increase in avoidance of learnt fear).

We also examined whether the Revaluation group acquired conditioned fear to CSr after US revaluation. To this end, US expectancy ratings or SCRs measured during Fear retention test served as dependent variable, whereas CS type, Group, and their interaction served as fixed effects. Noted that we expected different patterns between US expectancy ratings and SCRs. We expected no group differences in differential US expectancy ratings, given that this measure would not be affected by US aversiveness (e.g., a right noise US was expected regardless of its aversiveness). In contrast, we expected a stronger differential responding in SCRs in the Revaluation group compared to the Control group, as SCRs are typically measured to reflect conditioned fear.

2.7. Exploratory analyses

We explored the effect of trait anxiety, intolerance of uncertainty, or distress tolerance on avoidance responses during Post-revaluation avoidance test. We also examined whether these trait risk factors had any effect on the increase in avoidance responses (especially in the Revaluation group) before and after US revaluation manipulation.

3. Results

We restricted analyses to participants who had 1) acquired the correct PS–CS associations and 2) acquired the correct CS-US associations. The first criterion was defined by a >0 difference in CS expectancy ratings in the last block of Preconditioning (i.e., indicating CSr expectancy for PSr and CSl expectancy for PSl). Likewise, the second criterion was defined by a >0 difference in US expectancy ratings in the last block of CS-US contingency acquisition (i.e., indicating right noise US for CSr and left noise US for CSl). A total of four participants (3 in the Revaluation group, 1 in the Control group) were excluded from analyses due to these two criteria. In addition, two participants from the Revaluation group were excluded as their data were not recorded properly due to technical issues, leading to a final sample size of 66 participants (n = 31 in the Revaluation group, n = 35 in the Control group). Of note, SCR data from 8 participants (3 in the Revaluation group, 5 in the Control group) were not measured due to technical issues. However, behavioral data from these participants were retained for analyses. To summarize, 66 participants were included for the analyses of behavioral data, whereas 58 participants were included for the analyses of SCR data. The data could be found via https://osf.io/yta8h/files/osfstorage.

3.1. Manipulation check

Preconditioning. Fig. 2A shows the CS expectancy ratings during

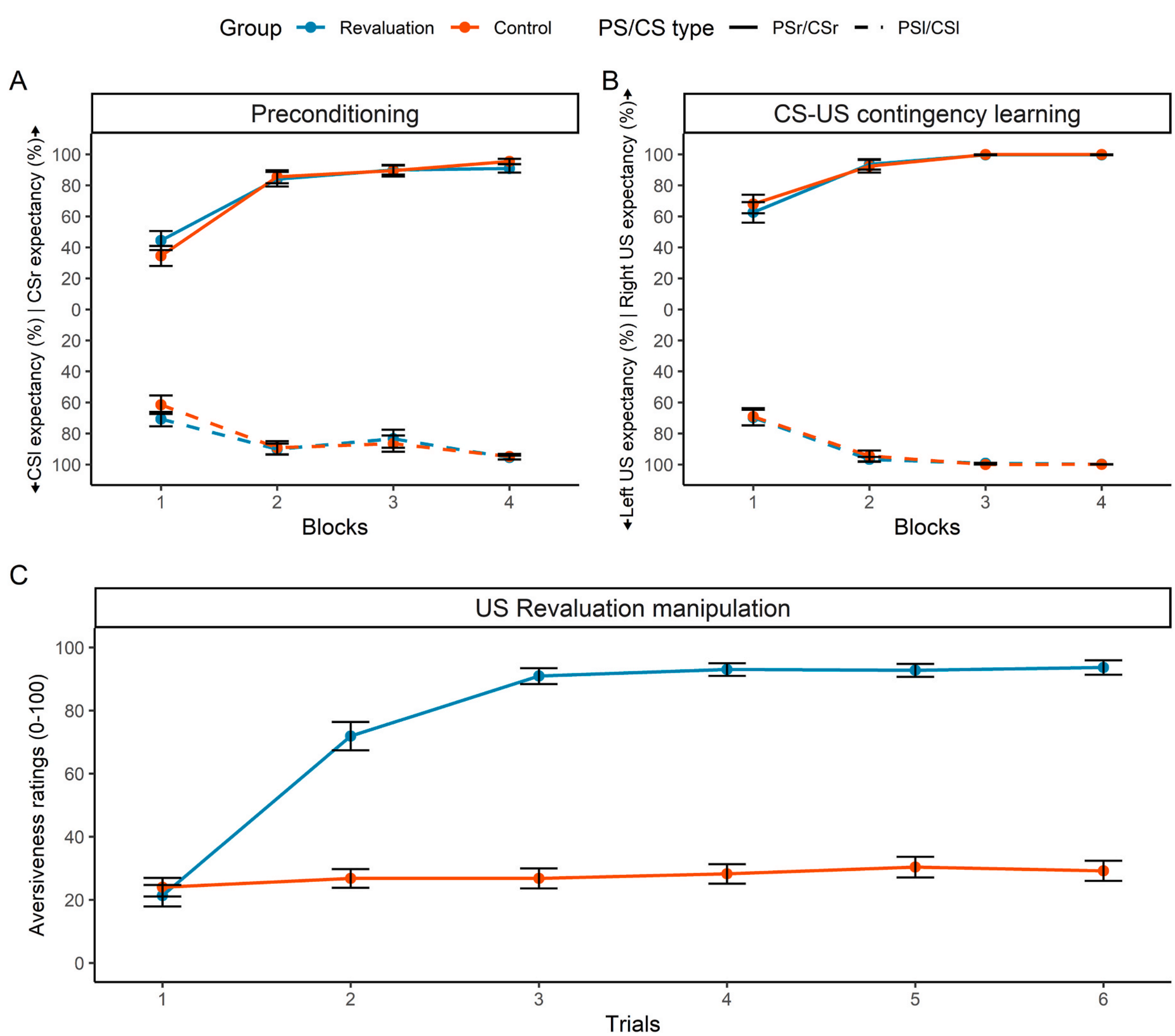

Fig. 2. (A) CS expectancy ratings during Preconditioning, (B) US expectancy ratings during CS-US contingency learning, and (C) aversiveness ratings during US revaluation manipulation. Error bars indicate standard error of the mean.

Preconditioning. Participants developed the correct differential CS expectancy ratings to the PSs across blocks (i.e., strong CSr expectancy to PSr and strong CSl expectancy to PSl). This pattern was supported by a significant interaction between PS type and Block, F (3, 1056) = 73.47, $p < .001$, $BF_{10} > 1000$. Follow-up pairwise comparisons suggested that the correct differential CS expectancy ratings were observed in all blocks (all Bonferroni-corrected $ps < 0.001$, all $BFs_{10} > 1000$). No effects involving Group reached significance (all $ps \geq 0.201$, all $BFs_{10} \leq 0.122$).

Baseline costly avoidance. Participants used limited avoidance responses to the PSs during Baseline costly avoidance (Fig. 3A). Averaged across PS type and Group, participants showed a decrease in avoidance responses across blocks, F (1, 462) = 8.14, p = .005, BF_{10} = 4.93. Importantly, no effects involving PS type nor Group reached significance (all $ps \geq 0.185$, all $BFs_{10} \leq 0.354$).

CS-US contingency acquisition. Fig. 2B shows the US expectancy ratings during Participants developed the correct differential US expectancy ratings to the CSs across blocks (i.e., strong right noise US expectancy to CSr and strong left noise US expectancy to CSl). This pattern was supported by a significant interaction between CStype and Block, F (3, 1056) = 85.37, $p < .001$, $BF_{10} > 1000$. Follow-up pairwise comparisons indicated that participants showed the correct differential US expectancy ratings in all blocks (all Bonferroni-corrected $ps < 0.001$, all $BFs_{10} > 1000$). No effects involving Group reached significance (all $ps \geq 0.624$, all $BFs_{10} \leq 0.097$).

US revaluation. Both groups showed low levels of aversiveness ratings to the right noise US on the first trial of Revaluation manipulation (Fig. 2C). However, on the last trial, the Revaluation group showed higher aversiveness ratings to the right noise US than the Control group. This pattern was supported by a significant interaction between Group and Trial, F (1, 66) = 255.12, $p < .001$, $BF_{10} > 1000$. Follow-up pairwise comparisons showed that no group differences in aversiveness ratings to the right noise US on the first trial, t (109) = 0.63, p = .530, BF_{10} = 0.29; however, on the last trial, the Revaluation group showed significantly higher aversiveness ratings to the US compared to the Control group, t (109) = 15.16, $p < .001$, $BF_{10} > 1000$.

In sum, participants acquired the correct PS-CS associations and CS-US associations, and limited baseline avoidance to the PSs without any group differences. The US revaluation manipulation was also successful as the increase in US intensity in the Revaluation group led to a greater perceived aversiveness ratings than the Control group.

3.2. Main hypotheses

Post-revaluation avoidance test. Averaged across blocks, the Revaluation group showed stronger avoidance responses to PSr than to PSl compared to the Control group (Fig. 3A). This pattern was supported by a significant interaction between PS type and Group, F (1, 462) = 4.77, p = .029, BF_{10} = 18.48. Follow-up pairwise comparisons indicated that

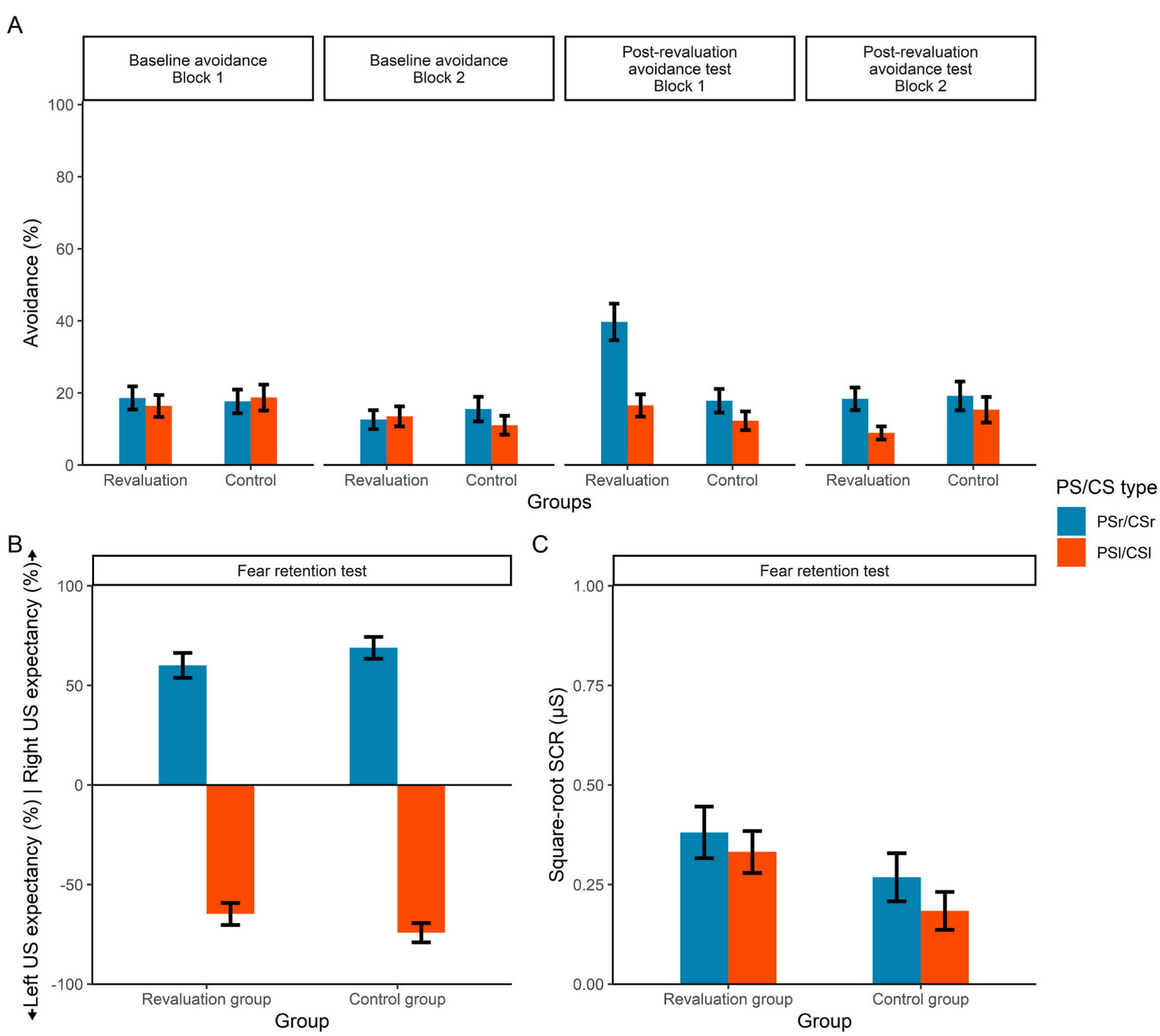

Fig. 3. Avoidance responses during Baseline avoidance and Post-revaluation avoidance test (A). US expectancy ratings (B) and skin conductance responses (C) during Fear retention test. Error bars indicate standard error of the mean.

the Revaluation group exhibited stronger avoidance responses to PSr than to PSl, t (464) = 6.29, Bonferroni-corrected $p < .001$, $BF_{10} > 1000$, while there was limited evidence that the Control group showed a similar pattern, t (464) = 1.91, Bonferroni-corrected $p = .056$, $BF_{10} = 0.33$. However, the group differences in avoidance responses specific to PSr averaged across test blocks did not reach significance, t (87.8) = 1.963, $p = .053$, $BF_{10} = 3.47$. This apparent null group difference was presumably due to the decrease in avoidance responses to PSr the second test block, especially in the Revaluation group. In contrast to this idea, the three-way interaction involving PS type, Group, and Block did not reach significance, F (1, 462) = 2.87, $p = .091$, $BF_{10} = 0.61$, suggesting no evidence that the group differences in differential avoidance responses differed between blocks. Despite this non-significant interaction, we further examined the simple effects given we hypothesized group differences in responding to PSr. The greater avoidance responses to PSr in the Revaluation group compared to the Control group was only observed in the first test block, F (1,66) = 8.17, $p = .006$, $BF_{10} = 6.77$, but not in the second test block, F (1,66) = 0.014, $p = .906$, $BF_{10} = 0.38$.

Cross-phase analysis. We carried out a cross-phase analysis comparing the group differences in differential avoidance to the PSs on the last block of Baseline costly avoidance and the first block of Post-revaluation avoidance test. The Revaluation group showed stronger avoidance responses to PSr than to PSl compared to the Control group in the first block of Post-revaluation avoidance test; however, this difference was relatively limited in the last block of Baseline costly avoidance. This pattern was supported by a significant 3-way interaction involving PS type, Group, and Block, F (1, 462) = 9.91, $p = .002$, $BF_{10} = 16.04$. Follow-up pairwise comparisons indicated that both groups showed no differential avoidance responses to the PS in the last block of Baseline avoidance (all Bonferroni-corrected $ps = 1.00$, all $BFs_{10} \leq 0.30$), while only the Revaluation group showed significantly stronger avoidance to PSr than to PSl in Post-revaluation avoidance test, t (468) = 6.12, Bonferroni-corrected $p < .001$, $BF_{10} = 146.20$, but not the Control group, t (468) = 1.56, Bonferroni corrected $p = .724$, $BF_{10} = 0.40$. Further analyses were carried out to examine the group differences in avoidance responses to PSr in each block. In the last block of Baseline avoidance, there was no evidence for any group differences in avoidance responses to PSr, t (118) = 0.484, $p = .629$, $BF_{10} = 0.23$. In contrast, on the first block of Post-revaluation avoidance test, the Revaluation group showed significantly stronger avoidance responses to PSr compared to the Control group, t (118) = 3.63, $p < .001$, $BF_{10} = 76.17$.

Fear retention test. We examined whether participants retained any differential US expectancy ratings to the CSs, and more importantly, if the Revaluation group would exhibit conditioned fear to CSr, as indexed by SCRs. For the US expectancy data (Fig. 3B), averaged across groups, participants showed differential US expectancies to the CSs, F (1, 264) = 596.77, $p < .001$, $BF_{10} > 1000$. As expected, no interaction effects involving Group reached significance (all $ps \geq 0.098$, all $BFs_{10} < 0.67$). For the SCR data (Fig. 3C), contradicted to our expectation, there was no group differences in differential responding to the CSs, as the interaction between CS type and Group did not reach significance, F (1, 174) = 0.11, $p = .743$, $BF_{10} = 0.21$. There was no evidence for a CS type main effect, F (1, 174) = 1.58, $p = .211$, $BF_{10} = 0.309$. Interestingly, when averaged across CS type, the Revaluation group showed stronger SCRs than the Control group, F (1, 58) = 4.23, $p = .044$, however, the Bayesian analysis suggested there was limited evidence for this pattern, $BF_{10} = 0.86$.

3.3. Exploratory analyses

We found no evidence that any trait risk factors (trait anxiety, intolerance of uncertainty, and distress tolerance) had any effect on avoidance responses during Postrevaluation avoidance test (all $ps \geq 0.104$, all $BFs_{10} \leq 0.25$). Likewise, when comparing avoidance responses in the last block of Baseline costly avoidance and in the first block of Post-revaluation avoidance test, we found no evidence that any trait risk factors had any effect on the increase in avoidance of learnt fear before and after US revaluation (all $ps \geq 0.094$, all $BFs_{10} \leq 0.37$).

Unexpectedly, the Control group showed significantly higher stress level compared to the Revaluation group. Thus, we also examined whether stress played a significant role in the increase in avoidance of learnt fear and whether it confounds with the current findings. The detailed analysis involving stress can be found in the Supplementary materials. In short, there is no concrete evidence that our main findings were confounded with stress.

3.4. Sensitization?

The increase in avoidance responses in the Revaluation group observed in Post-revaluation avoidance test could be alternatively driven by sensitization, a non-associative process that increases general responding to all stimuli due to repeated exposure to an aversive US (Groves & Thompson, 1970). If this is the case, one would expect that Revaluation group would also show stronger avoidance responses to PSl compared to the Control group in Post-revaluation avoidance test. There was no evidence for this pattern, t (87.8) = 0.203, $p = .840$, $BF_{10} = 0.145$. Furthermore, if sensitization plays a major role in driving the observed avoidance responses, one would expect that the Revaluation group would show a greater increase in avoidance responses to the neutral PSl after US revaluation in comparison to the Control group. However, the cross-phase analysis revealed no evidence for any group differences in avoidance responses before and after US revaluation, F (1, 198) = 0.259, $p = .611$, $BF_{10} = 0.20$. In sum, the increase in avoidance responses to PSr after US revaluation in the Revaluation group was unlikely due to sensitization.

4. Discussion

This study aimed to examine whether avoidance of learnt fear and conditioned fear could be increased via US revaluation in a sensory preconditioning protocol. We expected that after US revaluation, participants would show strong avoidance responses to the PS that signalled the revaluated CS. Likewise, participants would develop conditioned fear to a revalued CS. We also explored whether individual risk factors such as trait anxiety, intolerance of uncertainty, and individual protective factor such as distress tolerance had an effect on the magnitude of avoidance of learnt fear.

Results showed that manipulation of US revaluation in this study was successful, as the Revaluation group showed significantly higher aversiveness rating to the revalued US compared to the Control group. A key finding was that avoidance of learnt fear was increased only after US revaluation, as reflected by two patterns: First, the Revaluation group showed stronger avoidance responses to the revalued PSr (the PS that signalled CSr – the CS that signalled the revalued, high intensity US) compared to the non-revalued PSl (the PS that signalled CSl – the CS that signalled the low intensity US), while this differential avoidance responses were limited in the Control group. Second, before US revaluation, no group differences were observed in the differential avoidance responses to the two PSs. However, after US revaluation, only the Revaluation group showed an increase in differential avoidance responses to the PSs. These two patterns jointly suggest the increase in avoidance of learnt fear to PSr after US revaluation. The current finding is generally in line with the Expectancy model (Lovibond, 2006). This model proposes that avoidance is motivated by a high expectation of threat and a belief that such avoidance can minimize threat occurrence. The observed increase in avoidance responses toward the revalued PSr following US revaluation suggests that the US was reinterpreted as aversive; participants thus engaged in stronger avoidance of learnt fear to reduce the occurrence of the now threatening outcome. While the Control group showed limited avoidance responses given that the USs were perceived as non-threatening. These patterns jointly support the model's premise that avoidance is generally motivated by an expected threat.

On the other hand, no group differences were found in differential conditioned fear to the CSs. This suggests that the Revaluation group did not exhibit conditioned fear to the CSr, the CS that signalled a revalued US, inconsistent with the literature (Hosoba et al., 2001; White & Davey, 1989). Alternatively, there was some evidence that the Revaluation group showed stronger SCRs than the Control group when averaged across CSs, suggesting sensitization due to repeated exposure to a high intensity US (Groves & Thompson, 1970). The lack of differential SCRs to the CSs in the Revaluation group could be due to sensitization – the general increase in responding to both CSs might have washed out any observable differential responding to the CSs, assuming that the increase in responding to CSl was larger than to CSr. One may argue that the increase in avoidance of learnt fear in the Revaluation group could be due to sensitization rather than US revaluation. However, if this is the case, the Revaluation group should also showed increase in avoidance of learnt fear to PSl compared to the Control group, which there was no evidence for this pattern. Therefore, the current findings favor the interpretation that the increase in avoidance of learnt fear was due to US revaluation rather than sensitization.

Counter to our expectations, none of the individual factors had any effect on the increase in avoidance of learnt fear. One potential reason for these null findings is that these individual factors are more likely to manifest their effects under certain conditions, for example, under conditions of high threat ambiguity (Beckers et al., 2013; Lissek et al., 2006; Morriss et al., 2021). The condition for the current study was perhaps low in threat ambiguity, as the stimuli contingencies (PS-CS, CS-US) and response contingencies (avoidance – PS) were quite straightforward and predictable (see Morriss et al., 2021). Another potential reason is that we did not have sufficient power to detect any individual differences in avoidance of learnt fear (see Wong et al., 2023).

4.1. Clinical implications and future directions

The current findings suggest how individuals with anxiety-related disorders may develop avoidance of learnt fear even after encountering a benign CS – US pairing, provided that the US is later revaluated as threatening. For instance, after being gently nibbled by a dog, an individual may revaluated this experience as worse than it was, leading to avoidance of learnt fear (e.g., avoiding parks with dogs). However, the current study modelled US revaluation as directly experiencing the increase in US aversiveness, which is unlikely in real life. Future studies can perhaps examine a more ecological US revaluating process. For instance, individuals may ruminate about the US experience and later revaluate it as aversive. This process could be modelled by mental imagery, in which participants could imagine for instance, imagining the increase in US aversiveness (Mertens et al., 2020; Woelk, Krans, Raes, Vervliet, & Hagenaars, 2022). The current findings suggest that the US plays an important role in driving avoidance of learnt fear. Combined with preliminary findings that extinguishing the CS – US association reduces avoidance of learnt fear (Wong & Pittig, 2023), the current findings suggest that exposure-based treatments may effectively reduce maladaptive fear avoidance.

A recent theoretical model (Honey & Dwyer, 2022) suggests that the strength of responding to a PS depends on whether the CS memory trace activated by PS presentation matches the perceived salience of the CS during CS-US pairings. Specifically, the stronger the match between the CS memory trace intensity and CS-US pairing intensity, the stronger the response to the PS. Post-traumatic stress disorders are characterized by intrusive and vivid memories of traumatic reminders (Brewin, 2011; Perl et al., 2023), which resemble a strong retrieval of a CS memory trace upon PS presentation (e.g., an intersection triggers memory of a traumatic vehicle accident). Given that traumatic events typically involve high salience, it is plausible that the intensity of the CS memory trace matches that of the traumatic event. This alignment may trigger a very strong response to the PS, such as heightened avoidance of learnt fear. Future studies can explore whether this speculative mechanism contributes to strong avoidance of learnt fear in clinical anxiety and whether US revaluation plays a role in this.

4.2. Strengths and limitations

One strength of this study is the use of a sensory preconditioning protocol. This protocol enables us to first examine baseline avoidance of learnt fear, and the different processes that lead to an increase in avoidance of learnt fear. This parallels to how avoidance of learnt fear develops after the CS has acquired threat value. Another strength is the incorporation of cost in avoidance responses, which parallels to avoidance responses that cause impairments in clinical anxiety (Pittig et al., 2020).

Despite our strengths, one limitation of this study was the lack of evidence for the acquisition of conditioned fear to the CS after US revaluation, which was inconsistent with the literature (e.g., Hosoba et al., 2001; White & Davey, 1989). Future studies can also include other measures to measure fear, such as self-reported fear ratings. Another limitation was that the Control group showed higher stress levels than the Revaluation group. However, while preliminary evidence suggests that stress may increase avoidance (Vogel & Schwabe, 2019), this was not likely to confound the observed increase in avoidance responses in the Revaluation group after US revaluation. If anything, if stress is linked to heightened avoidance, it would likely reduce the observed group difference following US revaluation. Another limitation was the lack of control for sensitization. Although the current findings favor the interpretation of US revaluation rather than sensitization, future studies should control for sensitization.

5. Conclusion

This study found supportive evidence for an increase in avoidance of learnt fear through US revaluation. The findings provide a laboratory model of how avoidance of learnt fear develops after a benign experience, provided that part of the experience is later on revaluated as threatening. Future studies can further examine whether other types of US revaluation, for example, imagery rescripting of the US, can also lead to the development of avoidance of learnt fear.

CRediT authorship contribution statement

Larissa M. Chang: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Matthias J. Wieser:** Writing – review & editing, Resources, Methodology, Conceptualization. **Alex H.K. Wong:** Writing – review & editing, Visualization, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that there were no conflicts of interest with respect to the authorship or the publication of this article.

Preregistration

This study was preregistered on the Open Science Framework (https://osf.io/vgbfq).

Data availability statement

The datasets generated and analyzed during the current study are available in the Open Science Framework repository https://osf.io/yta8h/files/osfstorage.

Reporting

We reported how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Ethical approval

This study was approved by the Ethics Committee of the Erasmus School of Social and Behavioral Sciences (ETH2324-0380) in accordance to the Declaration of Helsinki.

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Declaration of competing interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from h.k.wong@essb.eur.nl.

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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.2025.104813.

Data availability

I have shared the link to my data (https://osf.io/yta8h/?view_only=20f03b49955c48cf86e2e02fedc06a6d)

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