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The role of relief in persistent avoidance of learnt fear

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ABSTRACT

Avoiding an imminent threat evokes a feeling of relief, a pleasant feeling that is believed to positively reinforce behavioral avoidance. Preliminary evidence suggests that a strong level of relief is associated with persistent behavioral avoidance, even when there is no realistic threat. The present study examined whether this association extends to avoidance of learnt fear, a behavioral response that avoids a threat-predicting signal. Using a sensory preconditioning procedure, two neutral preconditioning stimuli (PSs) were first paired with two neutral to-be conditioned stimuli (CSs). One CS (CS+) was then paired with an aversive outcome, whereas another CS (CS-) was paired with the absence of the aversive outcome (i.e., safety). In test, participants showed stronger avoidance of learnt fear to the threat-related PS that was associated with the CS+ compared to the safety-related PS that was associated with the CS-. Participants showed higher subjective relief ratings to the threat-related PS than the safety-related PS, presumably due to the omission of the CS+ and the aversive outcome. Of note, participants who reported higher relief ratings also showed more persistent avoidance of learnt fear. Exploratory analyses showed that anxiety severity and intolerance of uncertainty were associated with persistent avoidance of learnt fear, however, these risk factors were not associated with relief. In sum, stronger relief ratings are associated with persistent avoidance of learnt fear.

1. Introduction

Fear avoidance refers to behavioral responses that reduce the probability of the onset of a feared or threatening stimulus. Fear avoidance can be classified as safety behaviors and avoidance of learnt fear. Safety behaviors are a type of fear avoidance performed when confronting a feared stimulus to reduce the probability of the onset of an expected threat (Krypotos et al., 2018; De Houwer & Hughes, 2020), for instance, an individual with dog phobia may slowly back away when encountering a dog (feared stimulus) to reduce the chances of getting attacked (expected threat). Avoidance of learnt fear is performed to reduce the probability of the onset of a feared stimulus (and hence the expected threat that follows; Wong et al., 2022). For instance, the aforementioned individual may take a detour to avoid places where dogs are likely to be encountered and thus prevent the expected dog attack. Both safety behaviors and avoidance of learnt fear become maladaptive in clinical anxiety as they are often performed excessively, even in the absence of realistic threat and cause severe impairments to daily life (Krypotos et al., 2018; Pittig et al., 2020). Despite the clinical importance of furthering our understanding of both types of avoidance, the literature largely focuses on safety behaviors but not avoidance of learnt fear (Krypotos et al., 2018; Wong, Aslanidou, et al., 2023).

The current study aimed to examine whether relief plays a role in persistent (maladaptive) avoidance of learnt fear. Relief is an appetitive response evoked by the termination of aversive events or the omission of an expected threat (e.g., extinction learning; Andreatta et al., 2010; Andreatta, Fendt, et al., 2012; Andreatta et al., 2013; Bouton et al., 2021; Kalisch et al., 2019; Willems & Vervliet, 2021). Recent studies suggest that avoidance is tightly linked to relief (e.g., Leng et al., 2022; Papalini et al., 2021; Vervliet et al., 2017). Although these studies largely focused on safety behaviors, reviewing these studies is of relevance to understanding whether relief plays a similar role in avoidance of learnt fear. These studies examined safety behaviors in a fear and avoidance conditioning framework. In this framework, a conditioned stimulus (CS+) is repeatedly paired with an aversive unconditioned stimulus (US). Safety behaviors are modelled by executing a designated response (e.g., button press) *during CS+ presentation* that reduces the probability of the onset of the expected US. The aforementioned studies

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showed that US omission due to safety behaviors evoked relief responses, as indicated by an increase in self-reported relief ratings and skin conductance responses (SCRs) after CS+ offset (e.g., Leng et al., 2022; Vervliet et al., 2017). In these studies, relief responses were strong on early acquisition trials but declined steadily across trials. This pattern aligned with the notion that relief works similarly to positive prediction error (Maia, 2010; Moutoussis et al., 2008). On early trials, participants were still learning about the safety behaviors – US omission relation, thus US omission evokes a large 'pleasant surprise'. Over trials of safety behaviors acquisition, relief decreased as US omission was less surprising (i.e., participants had acquired the safety behaviors – US omission contingency).

Considering that relief is an appetitive response that works similarly as positive prediction error, Vervliet et al. (2017) proposed relief can positively reinforce safety behaviors. If relief persists (i.e., a lack of decrease in positive prediction error over trials), it continuously reinforces safety behaviors, leading to persistent safety behaviors even when the CS+ no longer signals threat (i.e., the US). This notion is supported by evidence that persistent relief was associated with stronger safety behaviors (Papalini et al., 2021; San Martin et al., 2020). Preliminary evidence suggests that risk factors for clinical anxiety are linked to persistent relief and excessive safety behaviors (San Martin et al., 2020; Vervliet et al., 2017). For instance, intolerance of uncertainty, a personality trait characterized by an incapacity to tolerate negative emotions evoked by a lack of information about the situation (Freeston et al., 1994), and (low) distress tolerance, a risk factor characterized by an inability to tolerate negative emotions (Simons & Gaher, 2005), are associated with persistent relief and excessive safety behaviors (San Martin et al., 2020; Vervliet et al., 2017). These studies suggest that persistent relief may play a role in maintaining maladaptive, excessive safety behaviors in subclinical yet healthy samples.

Despite growing evidence that persistent relief maintains maladaptive safety behaviors, there are no studies examining whether relief plays a similar role in avoidance of learnt fear. One paradigm to study avoidance of learnt fear is higher-order conditioning, in which a higher-order CS predicts the onset of a threat-predicting CS (Wong et al., 2022). Preliminary studies have shown greater avoidance responses to a higher-order CS that signals a threat-predicting CS compared to another higher-order CS that signals a safety-predicting CS (Klein et al., 2021; Wong & Pittig, 2022, 2023), indicating the acquisition of avoidance of learnt fear. It remains unclear what factors motivate more pronounced avoidance of learnt fear. Some studies suggest that avoidance of learnt fear is motivated by US prevention (Wong & Pittig, 2020, 2022). In contrast, other evidence suggests avoidance of learnt fear persists even when threat expectancy is low (Klein et al., 2021), suggesting that this avoidance response might be independent of US expectations and factors other than threat prevention might also play a role. For instance, it is thought that negative valence per se can drive avoidance (Chen & Bargh, 1999; Hans Phaf et al., 2014). As the threat-predicting CS (and the higher-order CS that predicts this CS) gain negative valence given their associations with the aversive US, it is speculated that negative valence plays a role in avoidance of learnt fear (see Wong et al., 2022).

Given that relief is linked to persistent safety behaviors, the current study aimed to examine whether this association extends to avoidance of learnt fear via a sensory preconditioning paradigm, a specific form of higher-order conditioning in which the pairing of the higher-order CS and CS takes place before CS – US pairings. That is, whether 1) the omission of the CS due to successful avoidance of learnt fear can evoke relief, and in turn 2) whether higher level of relief is linked to persistent avoidance of learnt fear under extinction test. We measured relief via subjective ratings and skin conductance (see Papalini et al., 2023; Vervliet et al., 2017), in addition to measuring electromyography (EMG) in the *corrugator supercilia* muscle, the so-called "frowning muscle". EMG activity in the corrugator supercilia muscle is typically potentiated to unpleasant stimuli while inhibited to pleasant stimuli (e.g., Lang et al., 1993; Larsen et al., 2003). Therefore, we explored whether relief could be reflected by an inhibition in the EMG activity of this muscle. Furthermore, given that clinical anxiety (De Kleine et al., 2023) and risk factors for clinical anxiety such as intolerance of uncertainty and (low) distress tolerance, are associated with persistent relief and excessive safety behaviors (San Martin et al., 2020; Vervliet et al., 2017), we further explored whether these personality traits were associated with excessive relief and persistent avoidance of learnt fear. In addition, previous work suggested that trait anxiety, another risk factor characterized by a strong tendency to experience psychological distress and physiological arousal across situations, and heightened threat sensitivity (Watson & Clark, 1984), was associated with persistent avoidance in general (Hulsman et al., 2021; Pittig et al., 2014; Wong & Pittig, 2023). Recent evidence (Leng et al., 2022, 2024) also found that anhedonia, a construct characterized by a lack of motivation to pursue pleasure or an incapability to experience pleasure, was associated with decreased safety behaviors. Notably, individuals high in anhedonia engaged in less safety behaviors even to the CS+, despite such response could effectively prevent US onset (Leng et al., 2024). This pattern was presumably due to anhedonia, which was associated with weaker relief, as relief was experienced as a "pleasant event", which in turn reduced the reinforcement of safety behaviors. In light of this recent evidence, we also explored whether anxiety severity and depression severity, in which the latter refers to a construct beyond anhedonia characterized by an incapability to experience pleasure, and persistent feelings of hopelessness and sadness, was associated with persistent or insufficient avoidance of learnt fear, respectively.

In sum, the aims of this study were twofold. First, we examined whether avoidance of learnt fear evoked relief, and whether stronger relief predicted persistent avoidance of learnt fear. Second, we explored whether risk factors for anxiety-related disorders such as intolerance of uncertainty, (low) distress tolerance, anxiety and depressive severities, were associated with stronger relief and persistent avoidance of learnt fear.

2. Method

This study was preregistered on Open Science Framework (https://osf.io/cmsa3).

2.1. Participants

Undergraduates at Erasmus University Rotterdam were recruited as participants. We performed a data-based power stimulation (Kumle et al., 2021) based on a previous study that examined whether relief predicts the persistence of low-cost safety behaviors (Papalini et al., 2021). The power estimation was based on the association between self-reported relief ratings to the CS+ during the last block of *Avoidance learning* and safety behaviors to the CS+ during *Test*. This yielded 88.3 % power to detect an expected effect size of b = 0.11 with a sample size of 100 participants. We recruited a total of 110 participants to account for attrition rates. The final sample for statistical analyses was 94 participants (see Results for the exclusion criteria). This study was approved by the Ethics Committee of the Erasmus School of Social and Behavioural Sciences (ETH2122-0451) in accordance with the Declaration of Helsinki.

2.2. Apparatus and materials

Two standardized 2D black and white drawings (Snodgrass & Vanderwart, 1980, p. 400px x 400px), a shoe and a wrench, served as the preconditioned stimuli (PSs), PS1 and PS2. An orange triangle and a purple hexagon (both with a size of 400 px x 400 px) served as the conditioned stimuli (CSs), CS1 and CS2. The PS and CS were counterbalanced across all participants.[1] Avoidance of learnt fear, US expectancy, and CS expectancy were measured throughout the experiment. The visual analogical scale (VAS) for avoidance of learnt fear was presented along with a question “How much do you want to avoid the outcome it signals?” and ranged from 0 % (certainly NOT avoid), 50 % (uncertain), to 100 % (certainly avoid) with 1 % steps. The VAS for US expectancy was presented along with a question “How likely do you expect an electric shock?”. The scale ranged from 0 % (Certain NO shock) to 100 % (CERTAIN shock) with 1 % steps. Similarly, the CS expectancy VAS was presented with the question “How likely do you expect the following outcomes?”. The VAS itself was bidirectional, with the right end of the scale indicating 100 % expectancy of an orange triangle (i.e., CS1 expectancy), whereas the left end of the scale indicating 100 % expectancy of a purple hexagon (i.e., CS2 expectancy), while the middle of the scale indicating 0 % of neither presentation of the CSs. The relief VAS was presented after PS offset, only in the last phase of the experiment (*Avoidance test*). It was presented along with a question “How relieved do you feel?”. The VAS ranged from 0 % (Neutral) to 50 % (Moderately relieved) to 100 % (Very relieved) with 1 % steps. We also measured valence ratings to the PSs and the CSs before and after the acquisition of CS – US associations. Valence ratings were assessed by a valence VAS presented along the PSs or the CSs with the question “How pleasant do you find this image?”, ranged from −50 (very unpleasant), 0 (neutral), to 50 (very pleasant) with 1 unit increment.

Skin conductance was assessed via a pair of disposable 8 mm Ag/AgCl electrodes attached to the hypothenar muscles of participants' non-dominant hand. Electromyographic (EMG) activities were measured on the left *corrugator supercilia* muscle via a pair of Ag/AgCl electrodes and a reference Ag/AgCl electrode located on the middle of participants' forehead. We used a dampened pad to clean these sites before attaching the Ag/AgCl electrodes. Both SCR and EMG were assessed at a 1000 Hz sampling rate by a Biopac MP150 system with an EDA100 amplifier and EMG100C amplifier. The US was a train of electric pulses of 50 Hz amounting to a total of 500 ms, generated by a DS7A Digitimer stimulator.

Three psychometric questionnaires were used. The short version of Intolerance of Uncertainty (IU-12) (Freeston et al., 1994) was used to measure intolerance of uncertainty. IU-12 consists of 12 items assessing one's negative beliefs and impaired function to ambiguity; each item assesses how much of a characteristic it is to a participant via a 5-point Likert scale. An example item in IU-12 is “Uncertainty makes me uneasy, anxious, or stressed”. IU-12 has great internal consistency with a Cronbach's alpha of 0.93 (Wilson et al., 2020). Distress tolerance scale (DTS) was used to measure distress tolerance, a predisposition construct that reflects the capacity to tolerate negative emotional states (Simons & Gaher, 2005). DTS consists of 15 items assessing general capability of tolerating distress and coping mechanisms, in which each statement can be assessed via a 5-point Likert scale. An example item in DTS is “Feeling distressed or upset is unbearable to me”. DTS has great internal consistency with a Cronbach's alpha of 0.84 (Brown et al., 2022). We used the anxiety sub-scale and the depression sub-scale of the short version of Depression Anxiety Stress scale (DASS-21)(Lovibond & Lovibond, 1995) to assess anxiety and depression severities, respectively. Anxiety is characterized by heightened vigilance and sensitivity to threat across a variety of situations, whereas depression is characterized by a low level of positive affect, persistent feelings of hopelessness, and loss of pleasure to reward (Clark & Watson, 1991). DASS-21 consists of 21 statements and participants had to answer on a 4-point Likert scale how much the statements apply to them. An example item for the anxiety subscale is “I felt I was close to panic” and an example item for the depression subscale is “I felt that life was meaningless”. Both anxiety and depression sub-scales have great internal consistency with a Cronbach's alpha of 0.95 and 0.93, respectively (Crawford & Henry, 2003).

[1] We, however, did not counterbalance the stimuli serve as PSs and CSs across participants (i.e., the black and white drawings always served as the PSs whereas the geometric shapes served as the CSs).

2.3. Procedure

After providing informed consent, participants filled in the DASS-21, IU-12, and DTS. Next, skin conductance and EMG electrodes filled with isotonic gel were attached to participants. US electrodes were attached to participants wrist of the non-dominant hand. A shock workup procedure was then performed, in which participants started with an intensity of 0.2 mA. We then carried out a stepwise US workup procedure until participants reached a level of US intensity perceived as “definitely unpleasant but not painful”. The PSs and the CSs were then presented once each with the valence VAS, prompting participants to rate their valence to the visual stimuli before the conditioning task. The conditioning task consisted of four phases: *Preconditioning, Baseline avoidance, Fear acquisition training,* and *Avoidance test* (see Table 1).

2.3.1. Preconditioning

PS1 and PS2 were presented eight times each. PS1 was always followed by CS1 while PS2 was always followed by CS2. The PS was presented on screen along with the CS expectancy scale for 8 s. Participants were prompted to indicate their CS expectancy ratings during PS presentation on each trial. Immediately after PS offset, the CS was presented in the center of the screen for 4 s. The presentation order of the PSs was pseudo-randomized in a way so that the same PS type would not appear more than twice in a row. The intertrial intervals (ITIs) were 4 s.

2.3.2. Baseline avoidance

At the beginning of this phase, participants were instructed that they could avoid the outcome that followed the PSs. Each PS was presented four times each with the avoidance scale. Participants could indicate their avoidance responses on the avoidance scale. The selected avoidance response was negatively proportional to the chance of CS presentation. For instance, a response of 70 % on this scale would probabilistically lead to a 70 % chance of CS omission. Immediately after an avoidance response was made, the PS remained on screen for 8 s. After PS offset, a CS or a blank screen was presented for 4 s depending on the avoidance response (see Fig. 1A for the trial structure). The ITIs were 4 s. Noted that avoidance of learnt fear was operationalized dimensionally as avoidance is not always dichotomous, but instead can be engaged to a certain extent (Krypotos et al., 2018; Wong & Pittig, 2022). For example, an individual with dog phobia may pass by a park where people walk their dogs (i.e., partial avoidance), or taking a completely different detour to avoid even passing by the park (i.e., full avoidance).

2.3.3. Fear acquisition training

Prior to this phase, participants were informed that avoidance responses were temporarily unavailable. The two CSs were presented eight times each. Each CS was presented along with the US expectancy scale

Table 1
PS indicates preconditioning stimuli; CS indicates conditioned stimuli; + indicates US presentation; - indicates US absence; * indicates avoidance of learnt fear availability; CSs in brackets indicate the presentation of a CS that depends on avoidance of learnt fear; Number in parentheses indicates the number of trials per trial type.

Preconditioning		Baseline avoidance		Fear acquisition training		Avoidance test	
PS1 → CS1	(8)	PS1* → [CS1]	(4)	CS1+	(6)	PS1*-	(8)
PS2 → CS2	(8)	PS2* → [CS2]	(4)	CS1-	(2)	PS2*-	(8)
				CS2-	(8)		

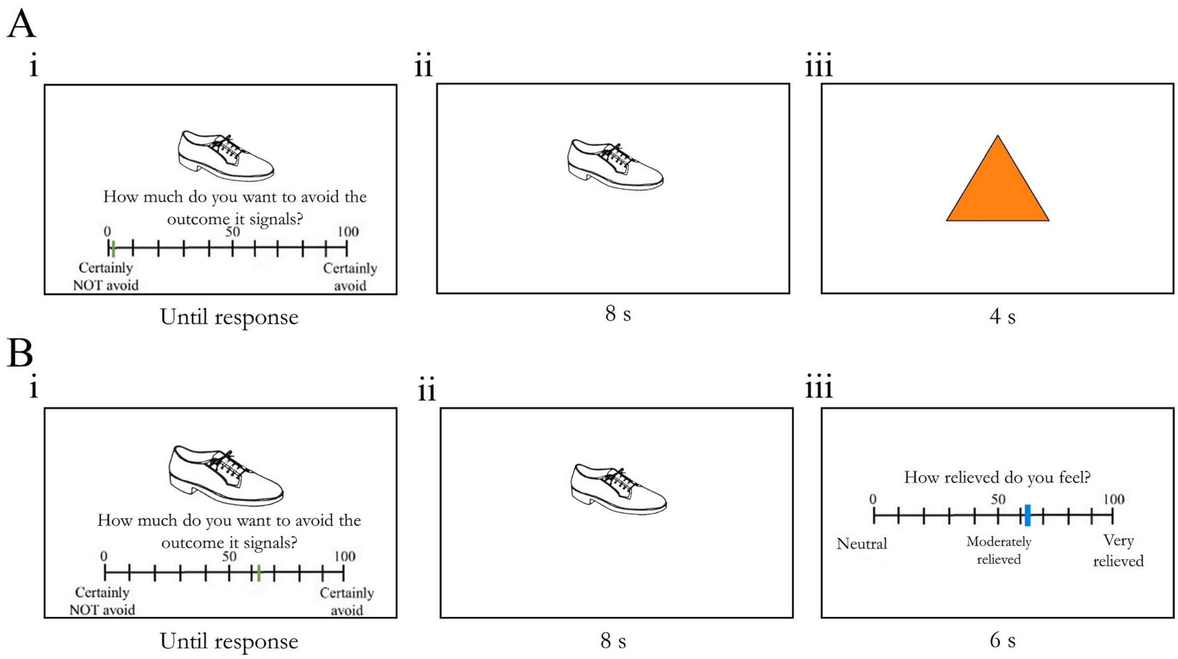

Fig. 1. A) Trial structure for *Baseline avoidance*. (i) Participants were prompted to indicate their avoidance responses. (ii) Immediately after an avoidance response was registered, the avoidance scale disappeared while the PS remained on screen for 8 s (iii) Immediately after PS offset, the corresponding CS or a white screen (depending on avoidance responses) was presented for 4 s. B) Trial structure for *Avoidance test*. (i) Participants were prompted to indicate their avoidance responses. (ii) Immediately after an avoidance response was indicated, the avoidance scale disappeared while the PS remained on screen for 8 s (iii) Immediately after PS offset, participants had to report how relieved they felt in 6 s.

for 8 s for each trial. Participants were prompted to indicate their US expectancy ratings during CS presentation. Immediately after CS1 offset, the US was presented in six out of eight trials. CS2 was never followed by an US. The presentation order of the CSs was pseudo-randomized in a way so that the same CS type would not appear more than twice in a row. The ITIs were randomized between 15 and 18 s. Immediately after *Fear acquisition training*, the PSs and CSs were presented with the valence VAS, prompting participants to rate their valence to these visual stimuli.

2.3.4. Avoidance test

Before this phase began, participants were informed that avoidance became available again, and they could avoid the outcomes that potentially followed the PSs. The PSs were presented eight times each. Similar to *Baseline avoidance*, the PSs were presented with the avoidance scale until a response was made, and then remained on screen for 8 s. However, none of the PSs were reinforced by a CS nor a US. Immediately after PS offset of all test trials, the relief scale was presented for 6 s (see Fig. 1B for the trial structure). Participants were prompted to indicate the degree of relief on the scale.

2.4. Scoring and analyses

We used BrainVision Analyzer to analyse the SCR and EMG data offline. For the SCR data, a 50 Hz notch filter and a 1 Hz low-pass filter were applied offline to the raw data. Conditioned fear indexed by SCR was obtained during the 8 s CS presentation during *Fear acquisition training*. Conditioned fear-related SCR was obtained by identifying the peak responding and its corresponding trough between 900 ms and 4000 ms after CS onset. Relief indexed by SCR was obtained 6 s immediately after PS offset during *Avoidance test*. We calculated relief-related SCR as suggested by prior studies (e.g., Papalini et al., 2021; Vervliet et al., 2017), by identifying the peak SCR during the 6 s post PS offset, baseline corrected by the average skin conductance level 2 s prior to PS offset on each trial. Responding smaller than 0.02 μS were scored as zeros. We then square root transformed all SCR data to reduce skewness.

For the EMG data, a 50 Hz notch filter and a 20 Hz low-pass filter were applied offline to the raw data. The data was then rectified and a moving average filter was applied. CS-elicited EMG responses were obtained during the 8 s CS presentation during *Fear acquisition training*. The EMG responses were divided into four bins, resulting in four windows of 2 s. These responses were baseline corrected by the average EMG activity 2 s prior to CS onset on each trial. Relief-related EMG responses were obtained during the 6 s immediately after PS offset during *Avoidance test*. Similarly, the EMG responses were divided into 2 s bins, resulting in 3 bins per trial. These responses were baseline corrected by the average EMG activity 2 s prior to PS offset on each trial. For all EMG data, the responses were averaged across bins per trial (see Morriss et al., 2021).

We analyzed all data with linear mixed models and robust regression models. Participants served as the only random effect for all linear mixed models. Keeping the models parsimonious is thought to balancing Type I error rate while maintaining sufficient power (Matuschek et al., 2017). The analyses were classified into three sections: *Manipulation check, Main hypotheses,* and *Exploratory analyses*. All non-exploratory analyses were pre-registered on Open Science Framework (https://osf.io/cmsa3).

2.4.1. Manipulation check

Preconditioning. We first checked whether participants acquired the correct PS – CS contingencies during *Preconditioning*. To this end, CS expectancy ratings served as dependent variable, whereas PS type and Trial (a linear trend repeated measures across trials) served as fixed effects.

Baseline avoidance. We compared baseline avoidance to the PSs. Avoidance of learnt fear served as dependent variable, whereas PS type and Trial served as fixed effects. Considering that we hypothesized no differences in avoidance of learnt fear between PS1 and PS2 during *Baseline avoidance*, we employed a Bayesian approach to support the absence of an effect (Kruschke, 2015). Therefore, we established a model that consisted of the 95 % highest density intervals (HDI) that contained the most credible values, analogous to the 95 % confidence intervals in frequentist analyses. We then obtained the posterior distribution via Markov Chain Monte Carlo that falls under the area around the null value, namely the Region Of Practical Equivalence (ROPE). The higher the percentage of HDIs that fell under the area of ROPE, the more likely it reflects the absence of an effect (Kruschke, 2015; Kruschke & Liddell, 2018).

Fear acquisition training. We checked whether participants acquired the CS – US contingencies as indexed by self-reported ratings and physiological measures. Therefore, US expectancy ratings, SCR, or EMG responses served as dependent variables in three separated models, whereas CS type and Trial served as fixed effects.

2.4.2. Main hypotheses

One of the main hypotheses was to establish (and replicate) avoidance of learnt fear during *Avoidance test*. To this end, avoidance of learnt fear served as dependent variable, whereas PS type and Trial served as fixed effects. Second, we hypothesized that participants showed stronger relief to PS1 compared to PS2. To this end, relief ratings, post-PS SCR, and post-PS EMG responses served as dependent variables, whereas PS type and Trial served as fixed effects. Third, we hypothesized that the degree of relief would be associated with more persistent avoidance of learnt fear; this effect was expected to be stronger to PS1 compared to PS2. To this end, we carried out robust regression models to assess whether relief measures (relief ratings, post-PS SCR, and post-PS EMG responses) of the first two trials of *Avoidance test* predicted the level of avoidance of learnt fear on the last six trials of the same phase. Fourth, we examined whether valence ratings became more negative to PS1 and CS1 after *Fear acquisition training*, whereas valence ratings became more positive to PS2 and CS2. We also examined whether the change in valence before and after *Fear acquisition training* was stronger to the CSs compared to the PSs. To this end, valence ratings served as dependent variable, whereas Threat type (PS1/CS1 vs PS2/CS2), Trial type (PSs vs CSs), Phase (before and after *Fear acquisition training*) served as fixed effects.

2.4.3. Exploratory analyses

We explored whether individual factors (intolerance of uncertainty, distress tolerance, anxiety severity or depression severity) were associated with persistent or insufficient avoidance of learnt fear and strong level of relief. In these analyses, the individual factors and PS type served as predictors, whereas avoidance of learnt fear on the last six trials of *Avoidance test* or relief ratings on the first two trials of *Avoidance test* served as the outcome. Noted that despite all three subscales of DASS-21 (anxiety, depression, and stress) were administered, only the anxiety and depression subscales were included for analyses.

We also explored whether any change in valence to the PSs or the CSs were associated with relief ratings on the first two trials of *Avoidance test*. In these analyses, relief ratings served as dependent variable, whereas PS/CS type and change in valence (to the PSs or to the CSs) served as fixed effects.

All statistical analyses were conducted in R (R core team, 2023), with *lmer* package for frequentist models (Bates et al., 2015), *rstanarm* package (Goodrich et al., 2020) and *bayetestR* package (Makowski et al., 2019) for Bayesian models, and *robustbase* package (Mächler et al., 2021) for robust regression analyses. The degree of significance was reported with Satterthwaite approximation for degrees of freedom (Satterthwaite, 1941). For the linear mixed models, all the main effects and higher-order interaction effects were analyzed in separate models (Hayes et al., 2012). Main effects were not reported if the higher-order interaction effects were significant.

3. Results

Only participants who 1) acquired differential CS expectancy ratings to the PSs and 2) acquired differential US expectancy ratings to the CSs were included in the analyses (see https://osf.io/cmsa3). The first criterion was defined as having higher CS1 expectancy ratings to PS1 compared to PS2 averaged across the last two trials of *Preconditioning*. The second criterion was defined as having higher US expectancy ratings to CS1 compared to CS2 averaged across the last two trials of *Fear acquisition training*. Ten participants were excluded based on these two criteria. In addition, one participant was excluded for requesting to decrease the US intensity during the experiment, whereas data for five participants were not recorded due to technical issues. In sum, the final sample consisted of 94 participants. The demographic data can be seen in Table 2.

3.1. Manipulation check

Preconditioning, Fig. 2B shows CS expectancy ratings to the PSs. Participants developed greater CS1 expectancies to PS1 and greater CS2 expectancies to PS2 across trials, supported by a significant interaction between PS type and Trial, $b_{PStype*Trial} = -1318.33$, SE = 81.17, $p < .001$. This pattern suggests that participants acquired the correct PS – CS contingency.

Baseline avoidance. Fig. 2A shows the avoidance of learnt fear to the PSs across the different phases in the experiment. Overall, participants showed similar levels of avoidance of learnt fear to the PSs during *Baseline avoidance*. There was no evidence that participants exhibited any differences in avoidance of learnt fear to the two PSs (all $ps \geq 0.325$). The Bayesian model provided further support that avoidance of learnt fear to PS1 did not differ to PS2, as 80.32 % of HDIs depicting the main effect of PS type fell under the area of ROPE. In sum, participants showed no differential avoidance of learnt fear to the PSs prior to *Fear acquisition training*.

Fear acquisition training. Fig. 2C and D shows the US expectancy ratings, and SCRs during *Fear acquisition training*. For the US expectancy data, participants developed higher US expectancy ratings to the threat-predicting CS1 compared to the safety-related CS2 across trials. This pattern was supported by a significant interaction between CS type and Trial, $b_{CStype*Trial} = -564.07$, SE = 43.98, $p < .001$. For the SCR data, participants exhibited greater responding to CS1 compared to CS2 averaged across trials, supported by a main effect of CS type, $b_{CStype} = 0.18$, SE = 0.02, $p < .001$. This effect did not interact with Trial, $b_{CStype*Trial} = -0.84$, SE = 0.87, $p = .335$. For the EMG data (see Fig. S1 in the supplementary materials), no effects reached significance (all $ps \geq 0.209$). In sum, participants acquired discriminative responding to the CSs in both US expectancy ratings and SCRs, but not in EMG responses.

3.2. Main hypothesis

Avoidance of learnt fear in Avoidance test. Participants showed stronger avoidance of learnt fear to PS1 compared to PS2, however, this differential avoidance of learnt fear to the PSs decreased across test trials (see Fig. 1A). This pattern was supported by a significant interaction between PS type and Trial, $b_{PStype*Trial} = -139.70$, SE = 54.49, $p = .011$. In addition, we compared avoidance of learnt fear to the PSs on the last trial of *Baseline avoidance* to the first trial of *Avoidance test*; this comparison examined the change in differential avoidance of learnt fear to

Table 2
Demographic data. IUS = Intolerance of Uncertainty Scale short version; DTS = Distress Tolerance Scale; DASS21 = Depression Anxiety Stress Scale 21.

	Mean (standard deviation)
Age	21.82 (3.56)
Sex – Female	62 (66 %)
US intensity (mA)	1.59 (0.90)
IUS - 12 (12–60)	28.01 (8.39)
DTS (1–5)	2.53 (0.71)
DASS21 – Depression (0-42)	14.21 (11.04)
DASS21 – Anxiety (0-42)	14.23 (10.18)
DASS21 – Stress (0-42)	18.45 (10.98)

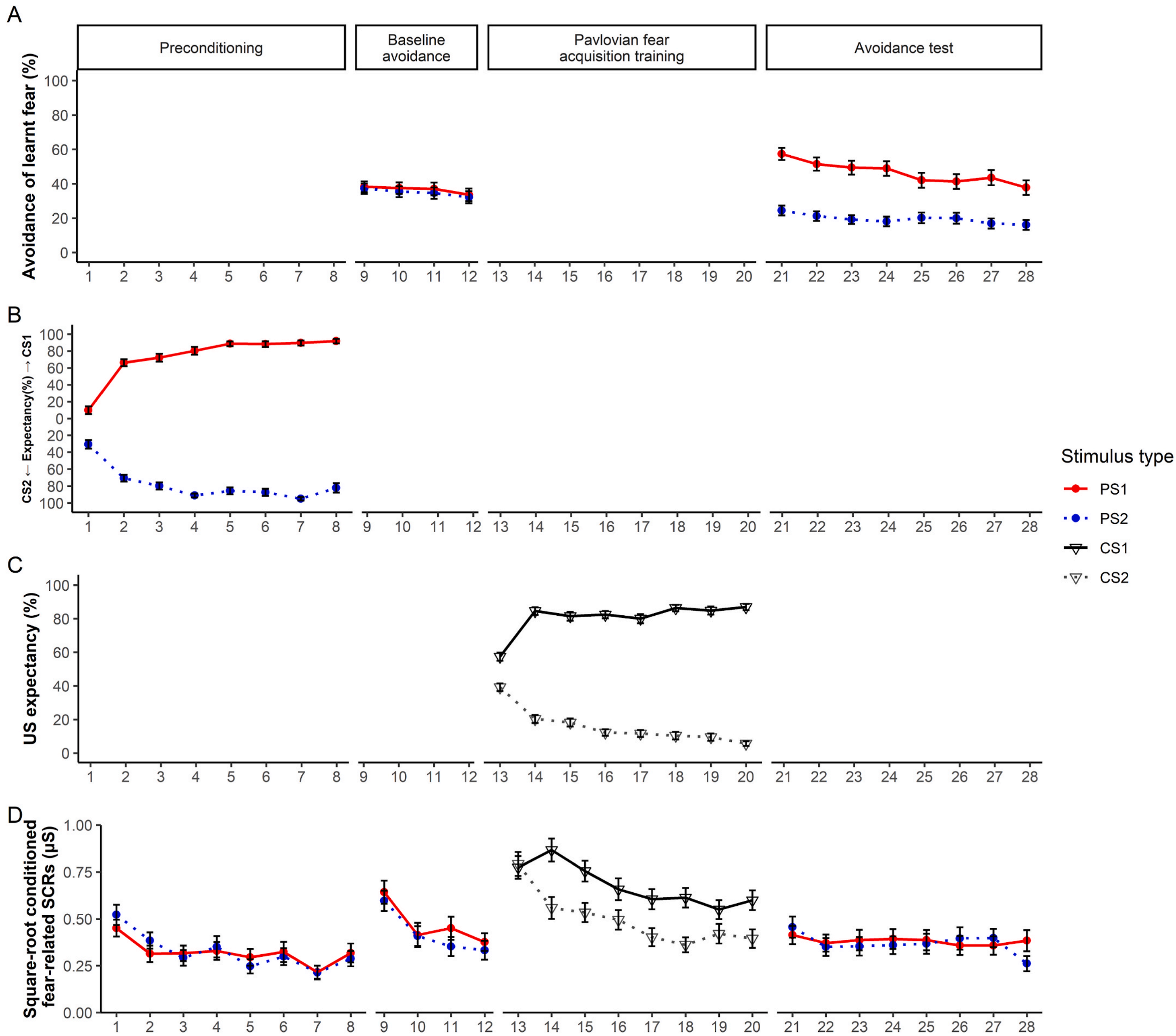

Fig. 2. (A) Avoidance of learnt fear, (B) CS expectancy ratings, (C) US expectancy ratings, & (D) square-root conditioned fear-related SCRs across all phases.

the PSs before and after CS1 was associated with threat. We observed a larger increase in avoidance of learnt fear to PS1 between the two phases compared to avoidance of learnt fear to PS2, $b_{PStype*Phase} = 31.46$, SE = 5.67, $p < .001$. Further analyses revealed that there was a significant increase in avoidance of learnt fear to PS1 between the two phases, $b_{Phase(PS1)} = 23.76$, SE = 4.00, $p < .001$, while avoidance of learnt fear to PS2 did not statistically differ between the two phases, $b_{Phase(PS2)} = -7.70$, SE = 4.00, $p = .056$. These patterns suggest that participants acquired differential avoidance of learnt fear to the PSs.

Relief to the PSs in Avoidance test. Relief was assessed after PS offset via self-reported relief ratings, SCRs, and EMG in all test trials (see Fig. 3A–C). For the self-reported relief ratings, participants showed higher relief ratings to PS1 compared to PS2, while these differential ratings decreased across trials. This pattern was supported by a significant interaction between PS type and Trial, $b_{PStype*Trial} = 136.54$, SE = 43.25, $p = .002$. For relief-related SCR data, no effects reached significance (all $ps \geq 0.475$). For relief-related EMG data, although responses were stronger after PS1 offset compared to PS2 offset averaged across test trials (e.g., stronger relief to PS2 compared to PS1), this difference did not reach significance, $b_{PStype} = 0.06$, SE = 0.03, $p = .051$. In sum, participants showed stronger self-reported relief to PS1 due to the omission of the threat-predicting CS1 (and the US) compared to PS2, however, this pattern was not observed in the SCR nor EMG data.

Association between relief and persistent avoidance of learnt fear. Fig. 3D to E shows whether relief on the first two test trials were associated with avoidance of learnt fear on the last six test trials for each PS type. Using a robust regression model, we found that the level of self-reported relief ratings had a larger positive association with avoidance of learnt fear to PS1 compared to PS2, $\beta_{PStype*Relief} = 0.50$, SE = 0.13, $p < .001$. Follow-up analyses revealed that relief ratings on the first two test trials were positively associated with persistent avoidance of learnt fear to PS1 on the last six test trials, $\beta_{Relief(PS1)} = 0.63$, SE = 0.091, $p < .001$, whereas there was no evidence that relief ratings to PS2 was associated with persistent avoidance of learnt fear to it, $\beta_{Relief(PS2)} = 0.13$, SE = 0.089, $p = .150$. There was no evidence for any associations between SCR nor EMG with persistent avoidance of learnt fear (all $ps \geq 0.265$). We also explored whether the relief ratings on the first two trials were positively associated with avoidance of learnt fear on the same trials. We found

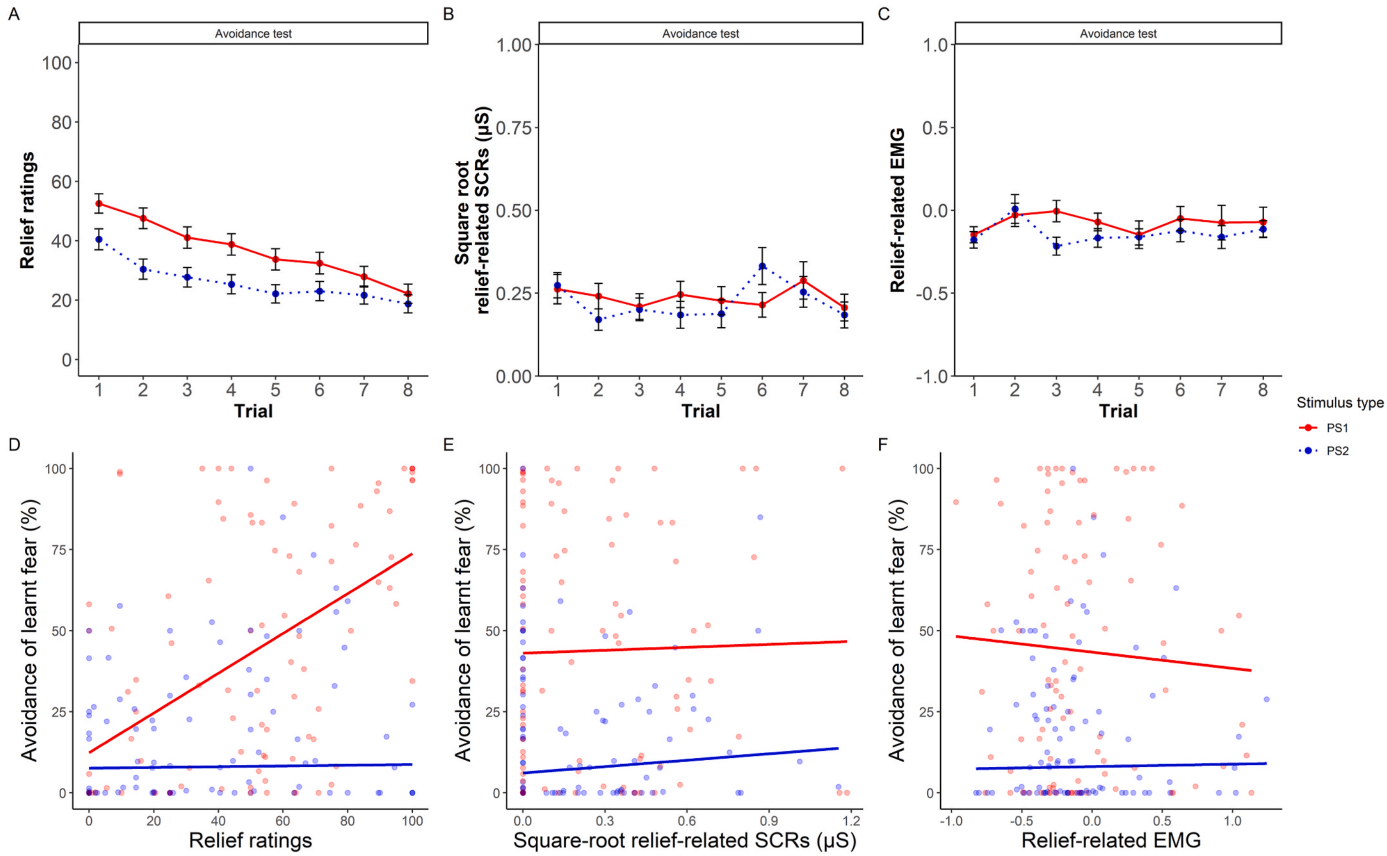

Fig. 3. Top panel. Relief rating (A), square-root relief-related SCRs (B), and relief-related EMG (C) measured during the 6s after PS offset during Avoidance test. Bottom panel. The association between relief ratings (D), square-root relief-related SCRs (D), and relief-related EMG (F) on the first two trials of Avoidance test and avoidance of learnt fear on the last six trials of Avoidance test.

that averaged across PS types, avoidance of learnt fear was positively associated with the magnitude of relief ratings, $\beta_{avoidance} = 0.53$, SE $= 0.05$, $p < .001$, however, this effect did not interact with PS type, $\beta_{avoidance*PStype} = 0.14$, SE $= 0.11$, $p = .191$. Despite the interaction not reaching significance, we found that avoidance of learnt fear was positively associated with relief to both PS1 and PS2 (all *ps* < 0.001), in which this association was stronger to PS1 ($\beta_{avoidance(PS1)} = 0.57$) compared to PS2 ($\beta_{avoidance(PS2)} = 0.43$). In sum, the magnitude of self-reported relief on early test trials was positively associated with stronger avoidance of learnt fear in later test trials, specifically to PS1 that signaled the threat-predicting CS1.

Valence ratings and avoidance of learnt fear. Fig. 4A shows the valence ratings to the PSs and CSs before the conditioning task and immediately after *Fear acquisition training*. The valence ratings to the threat-related stimuli decreased between the two phases, whereas valence ratings to the safety-related stimuli showed an increase; this change was stronger to the CSs compared to the PSs. This pattern was supported by a three-way interaction between Threat type, Trial type, and Phase, $b_{Threattype*Trialtype*Phase} = 21.73$, SE $= 4.81$, $p < .001$. Fig. 4B and C shows the association between the magnitude of avoidance of learnt fear and the change in valence to the PSs and the CSs, respectively. Despite valence ratings changed (before fear acquisition to after fear acquisition) more strongly to the CSs compared to the PSs, the regression model showed that a negative change in valence to the PSs was more strongly associated with an increase in avoidance of learnt fear compared to the change in valence to the CSs, $\beta_{Change\ in\ valence*Trial(PSs\ vs\ CSs)} = -0.20$, SE $= 0.098$, $p = .037$. Follow-up analyses revealed that a negative change in valence to both PSs and CSs was associated with an increase in avoidance of learnt fear (all *ps* < 0.001).

3.3. Exploratory analyses

We explored whether individual factors were associated with maladaptive patterns of avoidance of learnt fear or stronger level of relief (Fig. S2). To this end, individual factors and PS type served as predictors, whereas avoidance of learnt fear on the last six trials of *Avoidance test* or relief ratings on the first two trials of *Avoidance test* served as the outcome. To reduce multicollinearity issues for the interaction terms of interest, we mean-centered all four individual factor variables (Iacobucci et al., 2016). We provided a brief description of the findings here; the detailed analyses and figures can be found in the supplementary materials. Anxiety severity and intolerance of uncertainty, when controlling for the other risk factors respectively, were both specifically associated with an increase in avoidance of learnt fear to PS1 that signaled a threat-related CS (all *ps* ≤ 0.041). No other risk factors were significantly associated with avoidance of learnt fear (all *ps* ≥ 0.454) and none of the risk factors were significantly associated with relief ratings on early test trials (all *ps* ≥ 0.546).

We also explored whether the change in valence to the CSs or the PSs were associated with relief ratings on the first two trials of Avoidance test (Fig. S3). In these models, relief ratings served as dependent variable, whereas PS/CS type and change in valence (to the PSs or to the CSs) served as fixed effects. In brief, we found that a negative change in valence to CS1 was associated with higher relief ratings whereas an opposite pattern was observed to CS2 (all ps ≤ 0.013). In contrast, there was no evidence that valence to the PSs had an effect on relief ratings. The detailed analyses and figures can be found in the supplementary materials.

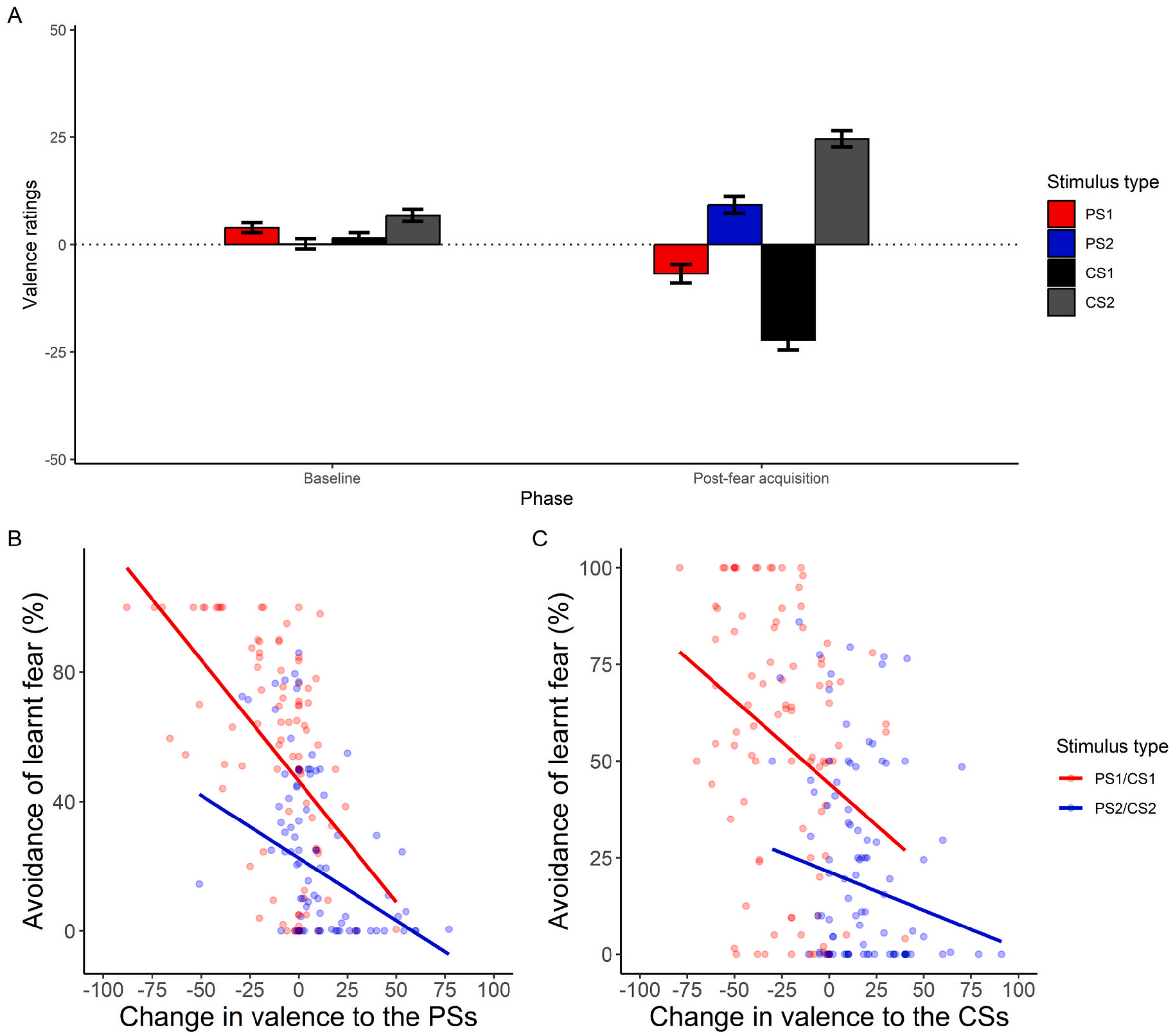

Fig. 4. Valence ratings to the PSs and the CSs at the beginning of the experiment and immediately after *Fear acquisition training* (A). The association between avoidance of learnt fear and the change in valence to the PSs (B) and to the CSs (C).

4. Discussion

Using a sensory preconditioning model, the main goals of this study were to examine whether omission of the threat-predicting CS (and the US that follows) would evoke a feeling of relief, and whether the level of relief was associated with persistent avoidance of learnt fear. Participants acquired avoidance of learnt fear, replicating past findings (e.g., Klein et al., 2021; Wong & Pittig, 2022, 2023). The acquisition of learnt fear was reflected in two patterns. First, participants exhibited stronger avoidance of learnt fear to PS1 (that signaled a threat-predicting CS1) compared to PS2 (that signaled a safety-predicting CS2) during *Avoidance test*. Second, participants showed no differences in avoidance of learnt fear to the PSs before *Fear acquisition training*. However, avoidance of learnt fear increased selectively to PS1 after CS-US pairings. These two patterns suggest that avoidance of learnt fear was acquired selectively to a stimulus that signaled a threat-predicting CS.

During *Avoidance test*, relief ratings to PS1 were greater than to PS2, presumably due to the omission of the expected threat-predicting CS1 (and the US that followed) after PS1 offset. This pattern aligns with past findings in which omission of an expected threat evoked relief (e.g., Papalini et al., 2021; Vervliet et al., 2017; Willems & Vervliet, 2021), additionally extending this pattern to avoidance of learnt fear. Furthermore, relief ratings to PS1 decreased more rapidly across trials when compared to PS2. This pattern aligned with the notion that relief is a pleasant emotion that is closely linked to prediction error (Maia, 2010; Moutoussis et al., 2008), which decreases across trials as the omission of the CS, the US, or both become less surprising (i.e., participants acquired the response – outcome contingency). However, we did not replicate the enhanced SCR to PS1 due to omission of learnt fear (San Martin et al., 2020; Vervliet et al., 2017, but see Papalini et al., 2021). Similarly, we did not observe any differences in EMG responses to the PSs that could reflect differential levels of relief. In sum, the current findings expanded on past findings that threat-omission evoked relief due to safety behaviors could also be found in avoidance of learnt fear; however, this pattern was only limited to self-reported relief but not in physiological data.

One key finding was that the level of relief ratings to PS1 on early test trials was significantly associated with stronger avoidance of learnt fear to PS1 on late test trials, whereas this association was not observed in responses to PS2. This pattern aligns with the notion that the level of relief positively reinforces the degree of avoidance of learnt fear: the pleasant surprise evoked by omission of the threat-predicting CS1 and the US might have reinforced avoidance of learnt fear, thus leading to persistent avoidance of learnt fear observed in late test trials. The current findings suggest that a stronger feeling of relief not only leads to persistent safety behaviors (Papalini et al., 2021; San Martin et al., 2020; Vervliet et al., 2017), but also leads to persistent avoidance of learnt fear. However, it remains unclear how avoidance of learnt fear elicits relief. It is possible that the mere absence of the US elicits relief or the mere absence of the CS is sufficient to evoke relief. Future research is required to delineate these potential pathways.

The current findings showed that anxiety severity and intolerance of uncertainty were associated with a general increase in persistent avoidance of learnt fear. These patterns aligned with preliminary findings that these risk factors were associated with persistent avoidance in general (Wong et al., 2024; Zuj et al., 2020). However, none of these individual factors were associated with relief ratings, thus providing no evidence that individual risk factors were associated with a strong level of relief ratings, which then leads to persistent avoidance of learnt fear. These null findings contradict with the literature, in which intolerance of uncertainty or (low) distress tolerance was associated with increased level of relief when US was omitted, thus leading to persistent safety behaviors even in the absence of realistic threat (San Martín et al., 2020; Vervliet et al., 2017). This discrepancy could be due to safety behaviors and avoidance of learnt fear being distinct avoidance behaviors. Safety behaviors involve an action that prevents US onset (i.e., the threat itself), whereas avoidance of learnt fear involves a response that prevents both the threat-predicting CS and US onset. Given that much is unknown about the underlying mechanisms of avoidance of learnt fear, it is possible that these risk factors are linked to these two avoidance behaviors in distinct ways (Wong, Aslanidou, et al., 2023). We also found no evidence that depression had any effect on avoidance of learnt fear nor relief ratings. This pattern contradicts to findings that showed anhedonia associated with a decrease in relief, and hence a decrease in safety behaviors even when realistic threat was presented (Leng et al., 2022, 2024). Besides the mechanistic difference between safety behaviors and avoidance of learnt fear, a potential explanation for this discrepancy is that Leng et al. (2022, 2024) assessed anhedonia specifically, a construct specifically characterized by a loss of pleasure experience, while the current study examined depression, a construct beyond anhedonia that is not only characterized by an inability to experience pleasure, but also experiencing a lack of positive affect and a persistent feeling of hopelessness.

As expected, after *Fear acquisition training*, there was a negative change in valence to threat-related stimuli whereas a positive change in valence was observed toward safety-related stimuli. Furthermore, the change in valence was stronger for the CSs compared to the PSs, presumably due to the CSs having a direct association with the onset or absence of an US. Consistent with our previous findings (Wong & Pittig, 2022), we found that the more negatively valence changed to the PSs, the stronger the level of avoidance of learnt fear. This pattern supports the notion that negative valence plays a role in driving behavioral avoidance (Chen & Bargh, 1999; Krieglmeyer et al., 2010) . Interestingly, both valence changes to the PSs and the CSs were associated with stronger avoidance of learnt fear, suggesting that negative valence to both stimulus type drives avoidance of learnt fear. Additionally, exploratory analyses showed that a larger negative change in valence to the threat-predicting CS1 was associated with stronger relief ratings. Based on our preliminary findings that relief positively reinforces avoidance of learnt fear, this pattern tentatively suggests that a negative change in valence acquired to the threat-predicting CS is linked to a strong magnitude of relief (presumably due to CS omission). This strong level of relief may then lead to persistent avoidance of learnt fear. Surprisingly, a larger positive change in valence to the safety-predicting CS2 was also associated with stronger relief ratings. One potential reason for this association is stimulus generalization, given that the CSs were perceptually similar as they were both geometric shapes, relief to the threat-predicting CS might have generalized to the safety-predicting CS. It remains speculative whether this increase in relief to safety-predicting CS would then reinforce unnecessary avoidance of learnt fear to safety stimuli. The literature has suggested that unnecessary safety behaviors to safety stimuli increase threat expectancies to them (e.g., Engelhard et al., 2015; Wong, van Dis, et al., 2023), thus future study can examine whether the association between valence and relief to safety stimuli may increase unnecessary avoidance in general, which in turn increase threat expectancies to these safety stimuli. In sum, negative valence seems to play a role in avoidance of learnt fear. Preliminary evidence also suggests that a negative change in valence to a threat-predicting CS and a positive change in valence to a safety-predicting CS were linked to an increase in relief ratings, which were speculatively linked to an increase in avoidance of learnt fear. Future studies can also examine whether minimizing perceptual similarities between the CSs (e.g., using CSs on different modalities) would diminish the relief-valence association for the safety-predicting CS.

In terms of clinical implications, preliminary evidence suggest relief decreases during extinction learning along with prediction error (Papalini et al., 2021). Combined with the current findings, high level of relief may lead to protection from extinction. Protection from extinction, in the context of avoidance, refers to the attribution to US omission to avoidance, thus preventing extinction learning to the CS+ (Lovibond, 2006; Lovibond et al., 2009). The present findings showed that high level of relief ratings leads to persistent avoidance of learnt fear, which in principle, reduced the chances of CS+ onset. Therefore, this limited the opportunity for extinction learning to the CS+, thus it is speculative that a strong feeling of relief may help preventing the disconfirmation of one's threat belief by continuously reinforcing avoidance. Future studies can further establish whether relief is robustly associated with persistent avoidance of learnt fear, and whether this association contributes to protection from extinction. Generally, the current findings suggest that approaches that prevent or neutralize relief evoked by avoidance may enhance treatment outcome. For instance, exposure-based therapy helps reconstructing one's pathological threat belief (e.g., all dogs are aggressive), thus reducing avoidance and associated relief it evokes. On the other hand, acceptance and commitment therapy helps clients to accept their fear and anxiety, thus promoting approach behaviors, which may help alleviating relief. These therapeutic approaches suggest that reducing avoidance alleviates the relief it induces, thus weakening the protection of extinction effect. The current study has some strengths and limitations. One strength of this study is that it is the first study to examine the role of relief in avoidance of learnt fear, adding to the literature that a high level of relief plays a role in the persistent avoidance of learnt fear. Another strength of this study is that it provides preliminary evidence that negative valence and relief may independently reinforce avoidance of learnt fear. Regarding limitations, the phrasing of the avoidance of learnt fear scale, "*How much do you want to avoid the outcome it signals?*", might have assessed both participants' motivation to avoid and avoidance per se. Although we see that the avoidance of learnt fear scale does not purely measure motivation to avoid as responses on this scale determined the likelihood of CS omission (i.e., an instrumental response), future studies can use an alternative phrase such as "*Indicate the extent of avoidance on the scale*". A second limitation was that this study was not able to delineate whether relief was due to CS omission per se, US omission per se, or a combination of both. Third, we failed to find stronger relief to PS1 in the SCR data i.e., stronger SCR after PS1 offset compared to PS2 offset (cf. San Martin et al., 2020; Vervliet et al., 2017). One potential reason is that skin conductance might be less sensitive to detect relief caused by avoidance of learnt fear, as this action indirectly omits the US, compared to safety behaviors that directly omit the US. Similarly, we did not find any EMG responses indexing relief, presumably also due to its insensitivity in reflecting relief. Speculatively, physiological relief may be more sensitively modulated by more automatic avoidance responses, for instance, conditioned avoidance (e.g., Krypotos et al., 2014).

In conclusion, the current study found that the omission of threat-related outcomes induced a feeling of relief; the magnitude of this relief was associated with persistent avoidance of learnt fear. This pattern suggests that relief plays a role in the maintenance of maladaptive avoidance of learnt fear. Anxiety and intolerance of uncertainty were linked to persistent avoidance of learnt fear. Future studies can examine whether relief also plays a long-term role in predicting avoidance of learnt fear, for instance, whether relief predicts the magnitude of avoidance of learnt fear assessed on the following day.

CRediT authorship contribution statement

Alex H.K. Wong: Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Matthias J. Wieser:** Writing – review & editing, Supervision, Conceptualization. **Marta Andreatta:** Writing – review & editing, Supervision, Conceptualization.

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.

This declaration is confirmed by all authors as listed below.

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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.2026.104976.

Data availability

I have shared the data on OSF via this link https://osf.io/z4gmw/?view_only=

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