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Clinical Psychology

The Effect of Avoidance Behavior on Generalization of Threat-Expectancy

Kristof Vandael[1,2a], Jonas Zaman[3,4], Bram Vervliet[1]

[1] Laboratory of Biological Psychology, KU Leuven, Leuven, Belgium, [2] Clinical Psychological Science, Maastricht University, Maastricht, the Netherlands, [3] REVAL Rehabilitation Research, Hasselt University, Diepenbeek, Belgium, [4] Centre for Learning and Experimental Psychopathology, KU Leuven, Leuven, Belgium

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The excessive spreading (or generalization) of fear toward safe situations is characteristic of anxiety disorders. Understanding factors that contribute to this is crucial. The current study hypothesized that avoidance leads to increased generalization; relentless avoidance may blur the perceptual memory of the avoided situation, thereby increasing the perceived similarity of this situation with novel situations, increasing generalization. To test this fundamental hypothesis, we conducted a serial fear conditioning experiment, using a convenience sample primarily composed of students. During fear acquisition, a geometric shape (preCS+) predicted a colored lamp (CS+), which was followed by an aversive electrical stimulus (US). Another geometric shape (preCS-) predicted another colored lamp (CS-), which was never followed by the US. Next, one group of participants avoided the CS+ and US by performing a response on the preCS+. Another group could not avoid, but saw a signal indicating no US would follow. During generalization, new lamp colors were presented (GSs); the avoidance group was more likely to identify a stimulus as CS+ during generalization, whereas the control group was more likely to identify a stimulus as GS. Importantly, when a stimulus was identified as CS+, the avoidance group showed higher US-expectancy compared to the control group. When a stimulus was identified as GS however, the avoidance group showed lower US-expectancy. Results thus partially supported that avoidance increases generalization, as this was dependent on stimulus identification. The current study is the first to show that avoidance may contribute to excessive fear through biased memory and perception.

Introduction

Fear is an adaptive emotion in response to imminent threat; it prepares an individual to cope appropriately with threat, for example, by activating the peripheral and central nervous systems for swift responding (Beckers et al., 2023). However, when fear exceeds the level of threat, it becomes maladaptive, potentially leading to an anxiety disorder. A key characteristic of anxiety disorders is that fear is not limited to situations that were associated with threat: fear spreads, or *generalizes*, towards instances that were never associated with threat (Ghirlanda & Enquist, 2003). For example, when someone is attacked by a Pit Bull, they will likely not only fear this particular dog, but also dogs similar to it. This is adaptive to some extent because this means we do not have to learn about every particular situation. However, it becomes excessive when a wide range of situations elicit fear; for example, when fear is elicited by encountering dogs that are highly unlikely to show aggressive behavior. Such excessive generalization is characteristic of anxiety disorders (Dunsmoor & Paz, 2015; Dymond et al., 2015).

Research on generalization often employs conditioning procedures where an initially neutral stimulus (conditional stimulus; CS+) elicits fear responses after being repeatedly paired with an aversive stimulus (unconditional stimulus; US). Following such fear acquisition, novel test stimuli (generalization stimuli; GSs) are introduced; typically, fear responding decreases as perceptual similarity between the GS and CS+ decreases (Lissek et al., 2008). Traditionally, these response gradients are attributed to the generalization process (i.e., the extrapolation of previous learning). However, recent work emphasized the role of perception and memory in generalized responding (Struyf et al., 2015; Zaman, Chalkia, et al., 2021): the perception of the presented GS needs to be compared to the memory of the

a Correspondence concerning this article should be addressed to Kristof Vandael, Tiensestraat 102, 3000, Leuven, Belgium. E-mail address: kristof.vandael@kuleuven.be.

CS+ to determine similarity (also referred to as mnemonic discrimination). Increasing evidence indeed supports that variations in response gradients may not solely result from differences in generalization, but also reflect differences in stimulus perception and memory (Bernstein et al., 2021; Struyf et al., 2017; Zaman, Ceulemans, et al., 2019; Zaman et al., 2023; Zaman, Struyf, et al., 2019, 2021). Importantly, this work suggests that poorer mnemonic discrimination manifests itself in a biased tendency to recognize a GS as CS+, rather than vice versa. Both from a clinical and theoretical perspective, it then becomes imperative to identify and scrutinize factors that could reduce mnemonic discrimination, and may thus contribute to excessive fear responding.

One such factor is avoidance; a key characteristic of fear is that it motivates avoidance behavior, which is a defensive action aimed at preventing confrontation with a threat (Krypotos et al., 2015). This can constitute a complete avoidance of threat-related situations, meaning that cues that predict threat are avoided as well – referred to as CS-avoidance (Krypotos et al., 2018). Returning to the example of dogs, this could mean avoiding a park, because there can be dogs in it, thus avoiding confrontation with dogs. Importantly, if stimuli that predict potential threat are avoided, these stimuli are encountered less, providing fewer opportunities for precise encoding in memory, leading to poorer mnemonic discrimination. In other words, CS-avoidance could make it more likely that a GS is misidentified as CS+, and thus lead to increased fear generalization (Zaman, Chalkia, et al., 2021).

Despite CS-avoidance being pervasive in anxiety disorders, it has received surprisingly little attention in the scientific literature (compared to US-avoidance; Wong et al., 2022). To investigate CS-avoidance in the lab, serial conditioning procedures can be used (Klein et al., 2021). In such procedures, the CS+ is always preceded by another stimulus (preCS+) during fear acquisition. During avoidance acquisition, the CS+ (and subsequent US) can then be prevented by performing a response on preCS+ presentation. Previous lab work confirmed that the preCS+ triggers avoidance behavior (Klein et al., 2021).

Investigating whether CS-avoidance indeed boosts fear generalization can provide insight into factors that contribute to anxiety disorders, and may eventually inform prevention and intervention strategies. This work also contributes to a growing literature on the interactions between fear and avoidance: fear indeed motivates avoidance behavior, but avoidance can also maintain fear because it prevents learning that the threat does not occur (Pittig et al., 2020). Moreover, preliminary evidence shows that avoidance may even increase fear: avoidance in the presence of a safety cue (CS-) leads to increased threat-expectancy (often used as a proxy for fear; Engelhard et al., 2015; van Dis et al., 2022; Wong et al., 2023). Wong et al. (2024) recently showed that threat-expectancy induced by avoidance also generalizes to GSs that are conceptually related to the CS-. However, these studies focused solely on US-avoidance – meaning that a response was performed upon CS presentation to cancel the US – and did not test generalization along a dimension of perceptual similarity.

The current study adapted a previously validated serial conditioning procedure (Klein et al., 2021). Similar to the study by Klein et al. (2021), one group of participants could avoid the CS+ and US during the avoidance acquisition phase by performing a response when a preCS+ was presented (avoidance group). However, in the current experiment, another group of participants was unable to avoid (control group); instead, they saw a safety signal during presentation of the (pre)CS+ indicating no US would be presented. We expected more generalization of threat-expectancy in the avoidance group compared to the control group. Because we expected that this effect would be (at least partially) due to reduced mnemonic discrimination (due to reduced exposure to the CS+ in the avoidance group), we explored the role of memory and perceptual processes in the current procedure. Specifically, we investigated whether the generalization gradients at least partially related to errors in identifying new generalization stimuli (GSs) as the CS+.

In the current experiment, a picture of an office room with a desktop lamp that could light up in two different colors served as CS+ and CS- (which was never followed by a US). During the generalization test, new colors were introduced that fell between the CSs on the color spectrum, as well as colors that extended beyond the range of the CSs. The latter colors were included because US-expectancy does not necessarily peak at the CS+ during a generalization test: the response peak can shift away from the CS+ in the direction opposite to the CS- (peak shift; Hanson, 1959). In other words, US-expectancy can be higher for stimuli that are perceptually similar to the CS+, than for the CS+ itself. Furthermore, the generalization gradient tends to be skewed, in the direction away from the CS- (area shift). Importantly, these shifts in responding have been related to poor mnemonic discrimination, meaning they can be (partially) explained by stimulus misidentification (Zaman, Struyf, et al., 2021). Therefore, we investigated the effect of avoidance on these generalization phenomena as well.

Method

Ethics and Registration

The Social and Societal Ethics Committee of KU Leuven approved this study (G-2023-7335). We preregistered the experimental protocol, sample size, and analyses at the Open Science Framework (https://osf.io/bh786).

Participants

We tested 46 participants (23 per group), allowing to detect a small-to-medium within-between interaction effect of f = .15 with .80 power in a repeated measures analysis of variance (alpha = .05, number of groups = 2, number of measurements = 7, corr among rep measures = .50, nonsphericity correction = 1). Such an interaction effect would indicate a difference in the generalization gradients be-

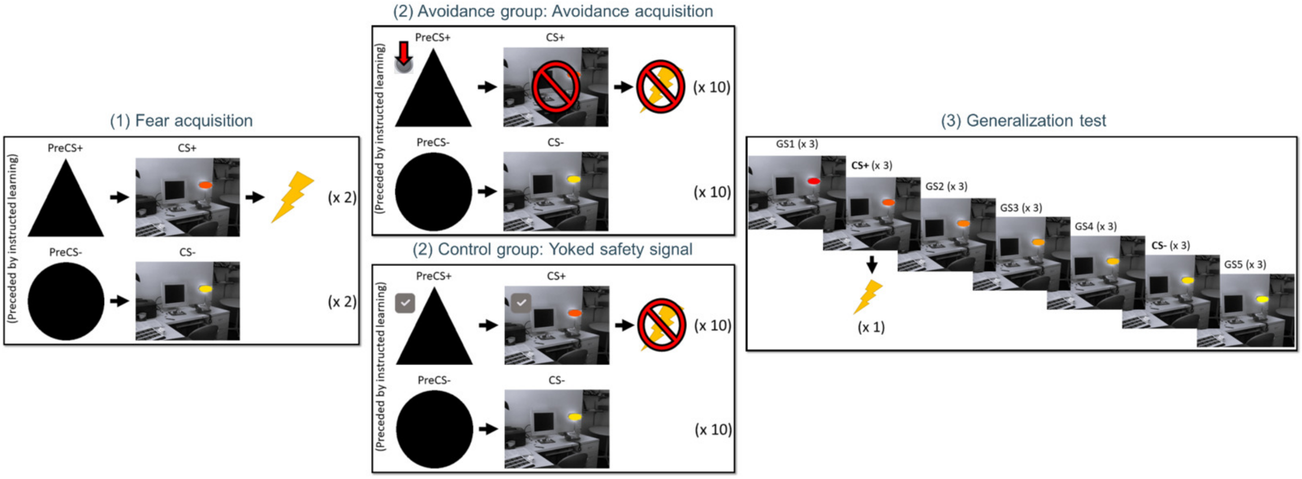

Figure 1. Experimental Phases and Stimuli

Note. CS = conditional stimulus; GS = generalization stimulus. Geometric shapes and colors were counterbalanced between participants. The red prohibition sign indicates that the CS/US was not presented when avoidance behavior was performed/the checkmark appeared.

tween groups. G*Power was used for the power calculation (Faul et al., 2007). Given that we used mixed effects modeling, this calculation is rather an overestimation of the number of participants needed.

Participants were recruited using the online recruitment system at KU Leuven and received either course credit or money for their participation. Exclusion criteria were pregnancy, heart condition or any other cardiovascular condition, neural condition (e.g., epilepsy), any other serious medical condition, any diagnosed psychiatric condition, electronic implant (e.g., cardiac pacemaker), pain at hands or wrists, color blindness.

Stimuli

A picture of an office room with a desktop lamp that could light up in two different colors (light orange, dark orange) served as CS+ and CS- (Figure 1; counterbalanced between participants). These CSs were initially preceded by a geometric shape (a triangle or circle), which served as preCS+ and preCS- (counterbalanced between participants).

Pictures of the office room with three lamp colors that were morphed in between the two CS colors served as GSs (GS2-3; Figure 1). Additionally, a yellow and red lamp served as GSs (GS1 & 5) to investigate the peak/area shift. Note that the CSs and GS2-3 were linearly interpolated colors between yellow and red, with the CSs being perceptually most similar to yellow and red. We used CIELUV color space for linear interpolation, which allows generating colors that are approximately equidistant in terms of perceptual differences (see Table S.1 in supplementary material for the exact color coordinates).

A 2 ms electrical pulse generated by a Digitimer DS7 (Digitimer Ltd, Welwyn Garden City, UK) served as US and was delivered by a bar electrode (8 mm diameter, 30 mm spacing), filled with KY gel, at the forearm of the non-dominant hand. The participant selected the intensity of the stimulation before the start of the experiment (see Arrival and Calibration section).

Procedure

Arrival and Calibration

Upon arrival, participants sat at a desk in front of a computer screen, and they completed a checklist to confirm that none of the exclusion criteria applied. They were also informed about the nature of the experiment and the use of electrical stimulation. After signing the informed consent form and attachment of the electrodes, the US was calibrated using a standard work-up procedure; participants rated stimuli of gradually increasing intensity on a scale from 0 to 10, with 0 indicating that they "*feel nothing*", and 10 indicating the "*maximum tolerable pain*". Participants selected a stimulus that was "*definitely unpleasant, but not painful*".

Fear Acquisition

The experimental task was programmed in PsychoPy (Peirce et al., 2019) and started with a serial fear conditioning phase; the preCS+ was presented on-screen first, followed by the CS+, which co-terminated with the US (Figure 2). The CS- (which followed the preCS-) was never presented with the US. Participants were informed about these contingencies and the use of trial-by-trial ratings (see US-Expectancy Ratings section) before the start of the phase. The inter-trial interval during this phase, and the next ones, was randomized between 2 and 4 s. Each (pre)CS was presented twice in randomized order (4 trials in total).

Avoidance Acquisition/Safety Signal

During the next phase, for the avoidance group, a button image appeared on top of the preCS+ (Figure 1 & 2). Participants could left mouse-click this button (using the dominant hand) to avoid the CS+ and US. Participants were in-

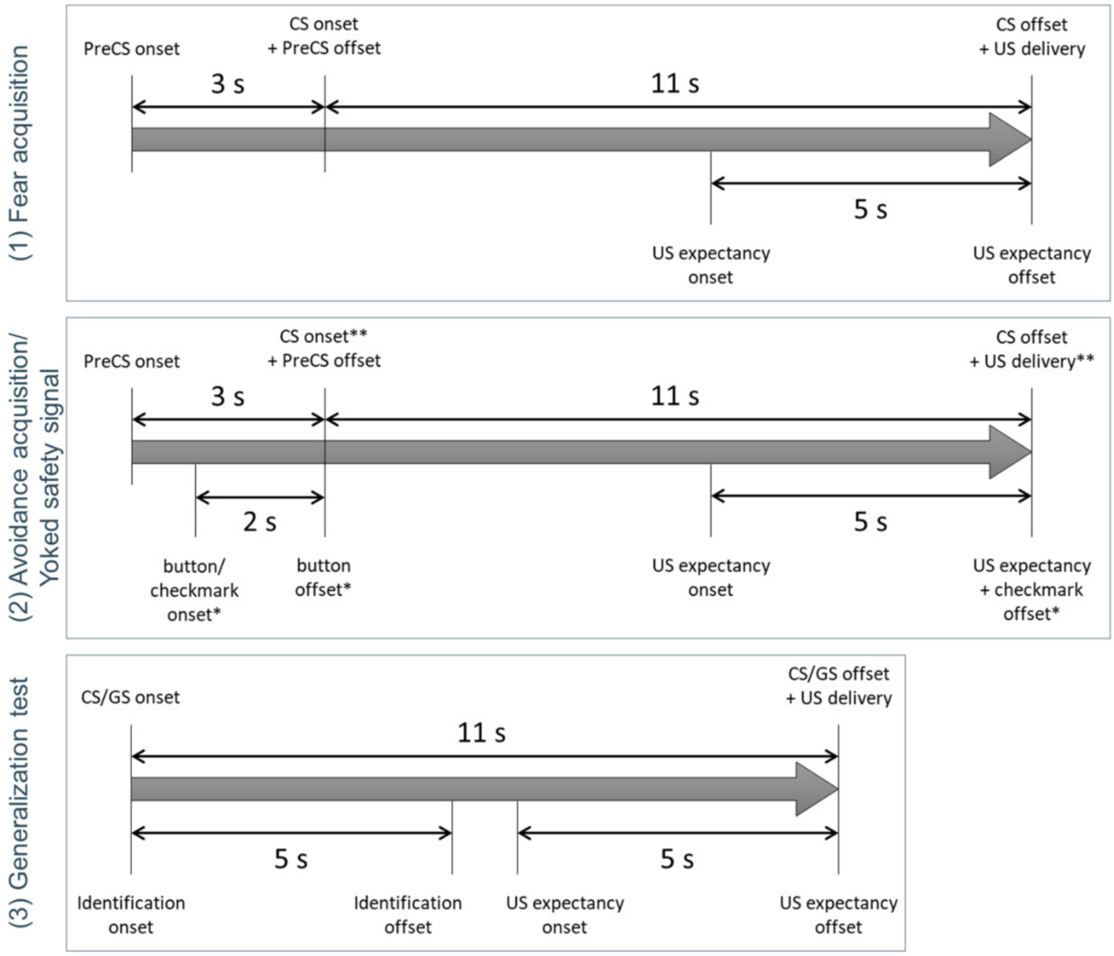

Figure 2. Trial Structures

Note. CS = conditional stimulus; GS = generalization stimulus; US = unconditional stimulus. *The button/checkmark was only presented on the (pre)CS+; the button was presented in the avoidance group, whereas the checkmark was presented in the control group. **In the avoidance group, the CS+ and US were not presented when avoidance behavior was performed (button click), while in the control group, only the US was not presented when the safety signal (checkmark) appeared.

formed about this before the start of the phase and were instructed to avoid the US as much as possible. The control group was unable to perform avoidance behavior, but saw a safety signal on the preCS+ and CS+ indicating that no US would follow. Again, participants were informed about this. The number of trials on which the signal was presented was matched to the number of avoidance responses of the previous participant in the avoidance group (yoked control). This way, the number of USs remained equivalent between groups. Due to this yoked design, participants were assigned to groups based on the order in which they arrived in the lab, alternating between the avoidance and the control group. Each preCS was presented 10 times in semi-randomized order, with no more than two consecutive presentations of a preCS (20 trials in total).

Generalization Test

The generalization test included three presentations of the two CSs and the five GSs (3 blocks of 7 trials; 21 trials in total) without the preCSs or avoidance button/safety signal. During this phase, one US was presented after the second CS+ presentation. Participants were informed about the absence of the avoidance button/safety signal and the addition of a trial-by-trial question (see Identification section) before the start of the phase, but were not informed about the presentation of the GSs and the US. A practice trial was presented before the generalization test to familiarize participants with the additional question. The CSs and GSs were presented in randomized order within each block.

Reconstruction and Post-Experimental Questionnaire

During the reconstruction phase, participants were asked to reconstruct the CSs (3 trials per CS; 6 trials in total). No USs were presented during this phase. After the experimental task, the participants completed a post-experimental questionnaire and received a debriefing.

Measures

US-Expectancy Ratings

Throughout the experimental phases (except reconstruction), a visual analogue scale appeared together with each presented CS/GS to rate the expectancy of the US occurring, ranging from “*certainly no stimulus*” to “*certainly stimulus*”

(0-100). In case no CS was presented (during avoidance conditioning), the question still appeared.

Identification

During the generalization test, participants were asked whether the presented color was one of the original CSs, or a novel GS. They received three answer options: "*color without stimulus*", "*color with stimulus*", and "*new color*". Note that "stimulus" referred to the US, and that participants were instructed that these answer options referred to the colors presented (with or without electrical stimulus) in the previous phases of the experiment.

CS-Reconstruction

After the generalization test, participants were asked to accurately reconstruct the original CSs. A slider button allowed them to gradually change a presented lamp color until they thought they reconstructed the original color of the CS+/CS-. The difference between the actual CS color coordinate and the reconstructed color coordinate served as measure of reconstruction accuracy. Positive values reflect deviations toward the extremes of the color spectrum, while negative values reflect deviations toward the color of the other CS. Note that GS1 and GS5 served as anchors for this scale; on which side of the scale these GSs appeared was counterbalanced between participants.

Post-Experimental Questionnaire

After the experiment, participants rated how unpleasant they found the US and to what extent they wanted to avoid it, using a visual analogue scale ranging from "*not at all*" to "*very much*" (0-100). Next, they completed three trait questionnaires: the Distress Tolerance Scale (Simons & Gaher, 2005), Intolerance of Uncertainty Scale (12 item version; Carleton et al., 2007), and trait version of the State-Trait Anxiety Inventory (Spielberger et al., 1970). Finally, participants were asked to report their age and sex.

Analyses

Independent *t*-tests were used to test for significant differences between the avoidance and control groups in terms of calibrated US intensity (physical and subjective), trait questionnaire scores, post-experimental US unpleasantness, avoidance tendency, and age.

As a manipulation check, we ran a mixed effects model on the average US-expectancy ratings during fear acquisition (averaged over the phase), with fixed predictors Group (avoidance, control) and Stimulus (CS+, CS-), and the interaction between these two predictors. The same model was run on the avoidance acquisition/safety signal phase.

Regarding our main analysis, we used a mixed effects model to test whether the avoidance group showed more generalization of average US-expectancy (averaged per stimulus over the generalization phase) compared to the control group. Specifically, we used a model with fixed predictors Group (avoidance, control) and Stimulus (GS1, CS+, GS2, GS3, GS4, CS-, GS5), and the interaction between these two predictors. Next, identification responses were transformed to probabilities by calculating the different response probabilities per stimulus per participant, resulting in three probability distributions across the stimulus spectrum (one for each response option). To model these probabilities, we used a mixed effects model with fixed predictors Identification response (color with stimulus, new color, color without stimulus), Group (avoidance, control), and Stimulus (GS1, CS+, GS2, GS3, GS4, CS-, GS5), and the interactions between these predictors. Note that for the analyses on US-expectancy and identification probability during generalization we tested models with Stimulus as categorical variable, as well as models with Stimulus as continuous variable (to model a linear curve) and Stimulus as second-order polynomial (to model a quadratic curve). The models with categorical variable were selected based on the Bayesian Information Criterion, which was used to compare model fits.

We then reran the main analyses on US-expectancy as outcome (trial level), with Identification response (color with stimulus, new color, color without stimulus) added as fixed predictor, and the interactions between Identification response, Group and Stimulus. Note that this model omitted the three-way interaction (and only included two-way interactions), thus slightly deviating from the preregistration. This approach was used because the model with the three-way interaction was unreliable (rank deficient) due to unbalanced data. This is because a CS+ was highly unlikely to be misidentified as CS- for example, meaning there was a lack of US-expectancy data for such instances. Finally, to model average CS-reconstruction (averaged over the reconstruction phase), we used a mixed effects model with fixed predictors Group (avoidance, control) and Stimulus (CS+, CS-), and the interaction between these two predictors.

All mixed effects models included a participant-specific random intercept. Pairwise comparisons were used to investigate significant interaction effects (and to investigate peak/area shifts); Holm-Bonferroni corrections were applied. The family-wise α-level was set at .05. Effect size partial eta squared (η_p^2) is reported for omnibus tests, and Cohen's *d* for pairwise comparisons. All analyses were performed in RStudio (RStudio, Boston, MA, USA).

Results

Group Characteristics

There were no significant differences between the avoidance and control groups in terms of calibrated US intensity (physical and subjective), trait questionnaire scores, post-experimental US unpleasantness, and age (Table 1). After the experiment, participants in the avoidance group rated their avoidance tendency significantly higher compared to the control group. The avoidance group contained 3 men, and the control group 4.

Table 1. Group Characteristics and Comparisons

	Avoidance Group (n = 24) M (SD)	Control Group (n = 24) M (SD)	p Value	Eta^2
Physical Intensity US (0 – 99.9 mA)	16.04 (10.42)	19.78 (12.96)	.287	.03
Subjective Intensity US (0 – 10)	5.74 (2.28)	6.30 (1.82)	.358	.02
Intolerance of Uncertainty (IUS)	33.65 (7.16)	33.04 (8.25)	.791	< .01
Distress Tolerance (DTS)	56.57 (8.51)	57.04 (9.41)	.857	< .01
Anxiety (STAI-T)	43.26 (7.16)	43.26 (8.85)	1.000	< .01
US Unpleasantness (0 – 100)	61.26 (20.75)	62.00 (17.29)	.896	< .01
US Avoidance Tendency (0 – 100)	**85.65 (13.67)**	**66.82 (21.60)**	**< .001**	**.22**
Age	20.70 (3.65)	20.78 (3.72)	.937	< .01

Note. US = unconditional stimulus; IUS = Intolerance of Uncertainty Scale; DTS = Distress Tolerance Scale; STAI-T = trait version of the State-Trait Anxiety Inventory. Results in bold indicate significant p-values (< .05; not corrected for multiple testing).

Manipulation Checks

Fear Acquisition

Analysis of **average US-expectancy** during the fear acquisition phase showed a significant main effect of Stimulus, $F(1, 88) = 454.31$, $p < .001$, $\eta_p^2 = .84$. This result confirms successful acquisition of US-expectancy, with higher ratings for the CS+ compared to the CS- (Figure 3). As expected, the main effect of Group was not significant, $F(1, 88) = 0.04$, $p = .835$, $\eta_p^2 < .01$, nor was the interaction between Group and Stimulus, $F(1, 88) = 0.02$, $p = .897$, $\eta_p^2 <$ .01.

Avoidance Acquisition/Safety Signal

There was no significant difference in **average US-expectancy** between the avoidance and control groups during the avoidance acquisition/safety signal phase (no significant main effect of Group, $F(1, 44) = 0.09$, $p = .761$, $\eta_p^2 < .01$, nor was there a significant interaction between Group and Stimulus, $F(1, 44) = 3.04$, $p = .088$, $\eta_p^2 < .01$). The main effect of Stimulus was not significant either, $F(1, 44) = 0.23$, $p = .635$, $\eta_p^2 = .06$. As expected, US-expectancy ratings were overall relatively low during this phase (M = 7.85, SD = 17.19; Figure 3).

Importantly, as instructed, all participants in the avoidance group pressed the avoidance button on each trial of this phase.

Main Analyses

Generalization Test

Average US-expectancy ratings during the generalization test showed a significant main effect of Stimulus, $F(6, 264) = 67.91$, $p < .001$, $\eta_p^2 = .61$. Pairwise comparisons confirmed the presence of a generalization gradient (Table 2). Results did not show the presence of an area shift (Table 2: GS1 vs. GS2) or a peak shift (Table 2: CS+ vs. GS1). Against expectations, both the main effect of Group, $F(1, 44) = 0.13$, $p = .720$, $\eta_p^2 < .01$, and the interaction between Group and Stimulus were not significant (Figure 3), $F(6, 264) = 0.20$, $p = .975$, $\eta_p^2 < .01$.

Analysis of the **identification probabilities** showed a significant interaction between Identification response and Stimulus, $F(12, 924) = 49.05$, $p < .001$, $\eta_p^2 = .39$. As expected, the probability that participants identified stimuli as the CSs peaked on presentation of the respective CSs (Figure 4), with *declining* probabilities as stimuli were less similar to the CSs (see Table S.2 in supplementary material for pairwise comparisons between stimuli per response). Conversely, the probability of identifying stimuli as a GS *increased* as stimuli were less similar to the CSs. Results did not show a perceptual area shift [GS1 vs. GS2: $t(924) = 1.84$, $p = .334$, $d = 0.29$], nor a peak shift [CS+ vs. GS1: $t(924) = 4.01$, $p < .001$, $d = 0.67$] in the probabilities to identify stimuli as the CS+. Note that participants in the avoidance group only correctly identified 51.34% of the GSs as different from the CSs (i.e., as a new color), while the control group correctly identified 63.80% of the GSs. Importantly, the analysis also showed a significant interaction between Identification response and Group, $F(2, 924) = 4.90$, $p = .008, \eta_p^2 = .01$. Pairwise comparisons confirmed that the probability that a stimulus was identified as CS+ was higher in the avoidance group compared to the control group (Figure 4), $t(924) = 2.02$, $p = .043$, $d = 0.18$, while the probability that a stimulus was identified as GS was lower in the avoidance group compared to the control group, $t(924) = -2.14$, $p = .032$, $d = -0.18$. The probability of a stimulus being identified as CS- did not differ significantly between groups, $t(924) = 1.23$, $p = .220$, $d = 0.11$. The two-way interaction between Group and Stimulus was not significant,

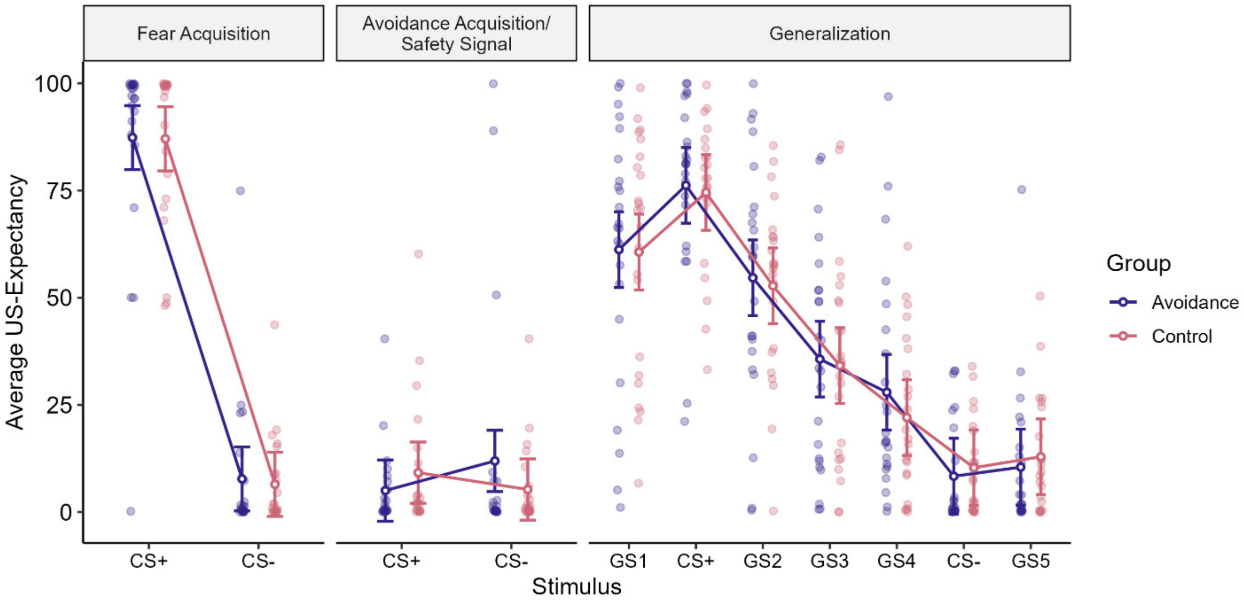

Figure 3. Average US-expectancy during the experimental phases

Note. CS = conditional stimulus; GS = generalization stimulus; US = unconditional stimulus. Observed average US-expectancies, estimated marginal means and 95% confidence intervals are displayed.

Table 2. Pairwise comparisons of average US-expectancy between stimuli during generalization

Pairwise Comparison		*p*-value	Cohen's *d*
GS1	vs. GS2	.197	0.28
CS+	vs. GS1	**< .001**	**0.61**
	vs. GS2	**< .001**	**1.00**
	vs. GS3	**< .001**	**1.85**
	vs. GS4	**< .001**	**2.45**
	vs. CS-	**<.001**	**4.24**
	vs. GS5	**<.001**	**4.39**
CS-	vs. GS5	.591	-0.17
	vs. GS4	**.002**	**-0.89**
	vs. GS3	**< .001**	**-1.34**
	vs. GS2	**< .001**	**-2.33**
	vs. GS1	**< .001**	**-2.41**

Note. CS = conditional stimulus; GS = generalization stimulus; US = unconditional stimulus. Results in bold indicate significant *p*-values (< .05).

$F(6, 924) = 0.03$, $p = 1.000$, $\eta_p^2 < .01$, nor was the three-way interaction between Identification response, Group and Stimulus, $F(12, 924) = 0.99$, $p = .455$, $\eta_p^2 = .01$.

Next, we analyzed **trial-by-trial US-expectancy** data including Identification response as predictor. As expected, the main effect of Stimulus was significant, $F(6, 856.85) = 7.34$, $p < .001$, $\eta_p^2 = .05$; US-expectancies declined as stimuli were less similar to the CS+ (see Table S.3 in supplementary material for pairwise comparisons between stimuli). Results also showed a significant interaction between Group and Identification response, $F(2, 865.15) = 12.04$, $p < .001$, $\eta_p^2 = .03$. Pairwise comparisons confirmed that in both groups, US-expectancy ratings were higher when a stimulus was identified as CS+ compared to when it was identified as GS [avoidance: $t(864) = 14.39$, $p < .001$, $d = 2.87$; control: $t(871) = 8.61$, $p < .001$, $d = 1.82$; Figure 5], and that ratings were higher when a stimulus was identified as GS compared to when it was identified as CS- [avoidance: $t(876) = 2.94$, $p = .003$, $d = 0.79$; control: $t(875) = 3.67$, $p < .001$, $d = 1.00$]. Importantly, pairwise comparisons also confirmed that when a stimulus was identified as CS+, the avoidance group provided significantly *higher* US-expectancy ratings compared to the control group, $t(164.83) = 2.75$, $p = .007$, $d = 0.43$. Unexpectedly, when a stimulus was identified as a GS, the avoidance group provided significantly *lower* US-expectancy ratings compared to the control group, $t(70.13) = -2.30$, $p = .024$, $d = -0.27$. When a stimulus was identified as CS-, the two groups showed no significant difference, $t(186.54) = -0.51$, $p = .612$, $d < 0.01$.

Reconstruction

Analysis of the **CS-reconstruction** data showed a significant main effect of Group, $F(1, 44) = 4.14$, $p = .048$, $\eta_p^2 = .09$; as expected, the avoidance group's reproductions of the CSs were generally less accurate than those of the control group, as the avoidance group's reconstructions deviated further from the color coordinates of the CSs (avoidance: $M = -0.13$, $SD = 0.44$; control: $M = 0.05$, $SD = 0.31$). The main effect of Stimulus was not significant, $F(1, 44) = 1.79$, $p = .188$, $\eta_p^2 = .04$, nor was the interaction between Group and Stimulus, $F(1, 44) = 0.09$, $p = .766$, $\eta_p^2 < .01$.

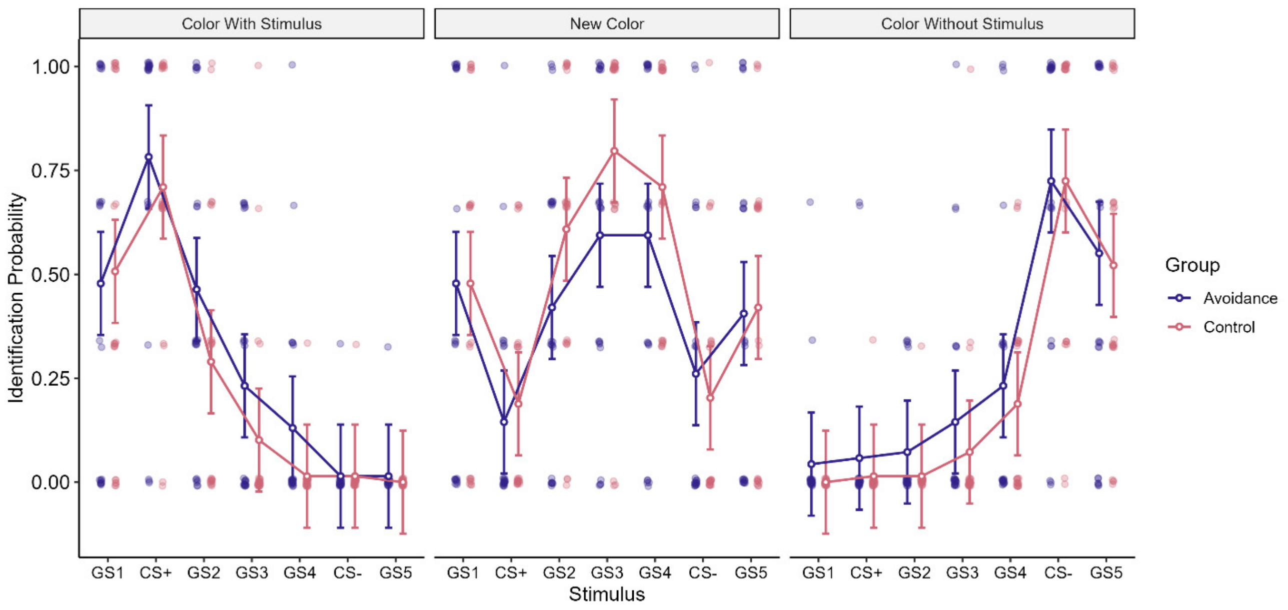

Figure 4. Identification probabilities during the generalization test

Note. CS = conditional stimulus; GS = generalization stimulus. Observed identification probabilities, estimated marginal means and 95% confidence intervals are displayed.

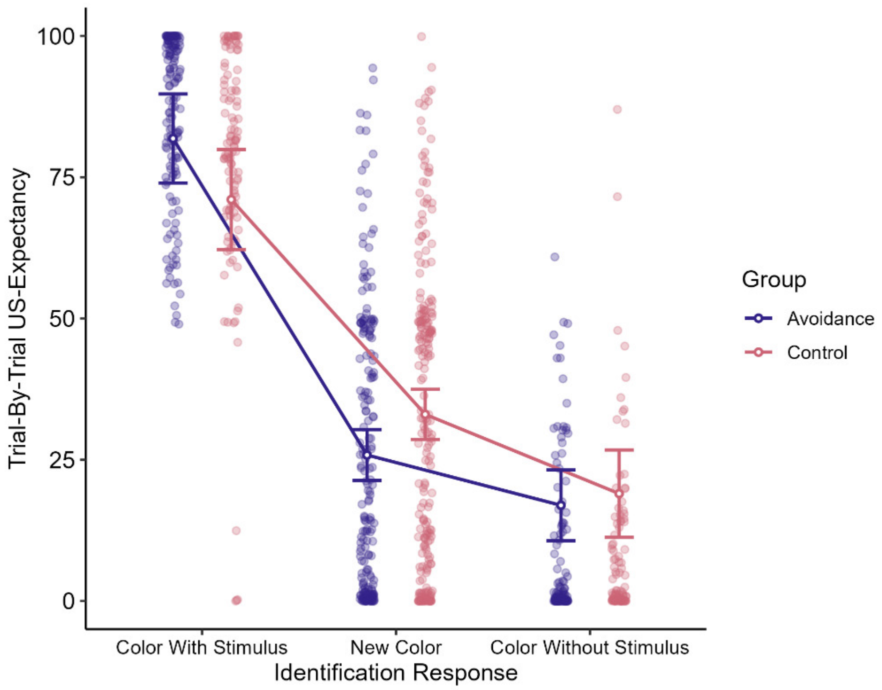

Figure 5. Trial-by-trial US-expectancy during the generalization test per identification response

Note. US = unconditional stimulus. Observed US-expectancies, estimated marginal means and 95% confidence intervals are displayed.

Discussion

The current study investigated whether CS-avoidance leads to increased generalization of US-expectancy, by adapting a validated serial conditioning procedure. When comparing the avoidance and control groups, results initially showed no difference in generalization of US-expectancy. However, when considering stimulus identification, group differences became apparent; the avoidance group was more likely to identify a stimulus as the CS+ during the generalization test, whereas the control group was more likely to identify a stimulus as GS. Importantly, when a stimulus was identified as the CS+, the avoidance group showed higher US-expectancy compared to the control group. When a stimulus was identified as GS however, the avoidance group showed lower US-expectancy compared to the control group. In other words, the results only partially supported that CS-avoidance leads to increased generalization, as this was dependent on stimulus identification. Furthermore, results showed that US-expectancy was highest when a stimulus was identified as the CS+, lower when identified as GS, and lowest when identified as the CS-. Given that many of the GSs were misidentified as a CS, these results confirm that generalization of US-expectancy relates to stimulus (mis)identification. Note that due to the lack of a peak/area shift in US-expectancy, we could not investigate the extent to which these phenomena relate to mnemonic discrimination.

The finding that the avoidance group was more likely to identify a stimulus as the CS+ during the generalization test, whereas the control group was more likely to identify a stimulus as GS, is in line with the well-established effect of repetition and recency on memory (Buchsbaum et al., 2015; Hintzman, 1970). Given that all participants in the avoidance group avoided the CS+ as instructed, they saw the CS+ significantly less compared to the control group before the generalization test (a difference of 10 presentations). This also means that once the generalization test started, more time had passed since participants in the avoidance group had encountered the CS+ compared to participants in the control group. Together, reduced repetition and recency are thought to have reduced perceptual memory accuracy, which is indeed reflected by the result that participants in the avoidance group identified less GSs correctly as novel (near chance level) than the control group. Results from the reconstruction phase further corroborated these findings, as the avoidance group showed less accurate reconstructions of the CSs, suggesting that memory is indeed involved. However, surprisingly, the reconstruction test showed no difference between CSs, suggesting that reconstruction of the CS- was less accurate as well in the avoidance group, even though the number of CS- presentations was equivalent between groups. Moreover, the current data do not allow disentangling the respective contributions of memory and perception to stimulus misidentification. Taken together, results suggest that CS-avoidance can affect generalized responding by reducing mnemonic discrimination: situations are more likely to be misidentified as threat-associated. This emphasizes the importance of investigating this specific type of avoidance, as unique mechanisms (such as mnemonic discrimination) may be at play that could contribute to excessive fear.

The finding that US-expectancy was higher in the avoidance group compared to the control group when a stimulus was identified as the CS+ is in line with previous work showing that avoidance leads to increased threat-expectancy (Engelhard et al., 2015; van Dis et al., 2022; Wong et al., 2023, 2024). A potential mechanism through which this occurs is *behavior as information*: threat could be inferred from avoidance behavior (Engelhard et al., 2015; Gangemi et al., 2012; van den Hout et al., 2014). Using vignettes, Gangemi et al. (2012) showed that anxious individuals indeed tend to infer threat based on the use of avoidance, even in the absence of information about actual threat. However, the extent to which this mechanism contributed to the current results requires empirical investigation. Importantly, the current study extends previous work by showing that the effect of avoidance on US-expectancy also occurs toward a (perceived) CS+, as previous studies investigated the effect toward a CS-. Moreover, previous studies focused on US-avoidance (safety behavior), whereas the current study shows that CS-avoidance can also lead to increased US-expectancy. Relating this finding back to the effect of CS-avoidance on mnemonic discrimination, an interesting hypothesis is whether CS-avoidance leads to poorer mnemonic discrimination through increased US-expectancy; previous experimental work has indeed shown that threat learning reduces mnemonic discrimination (Starita et al., 2019). In sum, CS-avoidance not only prevents confrontation with the CS+, therefore preventing learning when a CS+ no longer signals threat, but can also lead to more fear for a (perceived) CS+.

However, the fact that CS-avoidance only lead to increased US-expectancy when the presented stimulus was identified as the CS+, and not when it was identified as novel, is not in line with previous work. Wong et al. (2024) showed that threat-expectancies induced by avoidance generalize toward novel stimuli (GSs) as well. Importantly, they used GSs that *conceptually* resembled the original stimuli, meaning that perceptual similarity between stimuli was minimal, arguably making stimulus misidentification (i.e., identifying a GS as CS+) unlikely – although they did not test this. Contrary to the findings by Wong et al. (2024), avoidance lead to reduced US-expectancy when a stimulus was identified as novel in the current study. A potential explanation is that when participants were uncertain whether a stimulus was novel or not, participants in the avoidance group were more likely to identify a stimulus as CS+. This would mean that participants in this group only identified stimuli as novel when relatively certain that it was *not* a CS+, therefore showing lower US-expectancy when identifying a stimulus as novel. In other words, avoidance may have led to a "better-safe-than-sorry" processing strategy, biasing perception toward threat-related cues (Van den Bergh et al., 2021). This interpretation is supported by the finding that the avoidance group was more likely to (mis)identify a stimulus as the CS+ compared to the control group. However, the extent to which uncertainty and perception played a role in this needs further investigation.

The current results are in line with previous studies showing that generalized responding is related to mnemonic discrimination (Bernstein et al., 2021; Struyf et al., 2017; Zaman et al., 2023; Zaman, Struyf, et al., 2019, 2021). Indeed, the generalization test showed that US-expectancy was highest when a stimulus was identified as the CS+, lower when identified as GS, and lowest when identified as the CS-, and that many GSs were misidentified as CSs. The current data showed no area or peak shift in US-expectancy, meaning that we could not investigate to what extent such generalization phenomena can be explained by poor mnemonic discrimination (Zaman, Struyf, et al., 2021). The lack of shifts may be due to properties of the stimulus set used in the current study: prototypical yellow and red lamp colors served as (extreme) GSs to investigate shifted responding. This meant that the CSs and other (in-between) GSs were different shades of orange. This may have led to distinct color categorization of the shift GSs, rather than viewing them as extensions of the same color continuum of the CSs and in-between GSs, thus interfering with the area/peak shift phenomenon. However, given that we do not have data on stimulus categorizations in terms of color, this explanation remains speculative.

It should be noted that we used US-expectancy as a proxy for fear, but did not measure any physiology. Future studies should tap into different response systems, given that these may diverge, thus potentially showing different response patterns (Mauss & Robinson, 2009). Furthermore, the current design does not allow disentangling the effects of avoidance behavior and reduced CS+ presentation, as both co-occurred in the avoidance group (to model CS-avoidance). Future work can pit CS-avoidance against US-avoidance to disentangle the two, as US-avoidance involves confrontation with the CS+. This could also provide insight into whether the unexpected reduction in US-expectancy following avoidance when a stimulus was identified as novel is related specifically to avoidance behavior or reduced CS+ presentation. Future studies can also investigate additional factors that modulate mnemonic discrimination; negative affectivity for example has been suggested to reduce stimulus discrimination, biasing perception toward threat (Van den Bergh et al., 2021). Also in prevention-focused individuals, perception is probably biased toward threat, as they interpret ambiguous situations more negatively, focusing on potential risks (see regulatory focus theory; Higgins, 1997). However, the current study was not powered to reliably interpret effects of trait scores. Another modulating factor can be the preCSs; the current study did not present any preCSs during the generalization test, however, inclusion of these second-order CSs may bias perception of GSs toward CSs. In addition, time deserves consideration; in the current study, relatively little time passed between fear acquisition and the generalization test (as the avoidance acquisition phase consisted of only 20 trials). However, studies have shown that the mere passage of time can broaden generalization (Jasnow et al., 2017). It deserves investigation whether this effect is (partially) driven by poorer mnemonic discrimination. Finally, given that current results are based on a sample mainly consisting of university students, the extent to which poor mnemonic discrimination is relevant for clinical disorders deserves investigation.

In conclusion, our findings partially supported that avoidance leads to increased generalization, as this was dependent on stimulus identification, and confirmed that generalized responding is closely related to mnemonic discrimination. These results make the current study the first to show that avoidance may contribute to excessive fear generalization through reduced mnemonic discrimination: avoidance can make it more likely that safe situations are misinterpreted as threatening, and increase threat-expectancy when interpreting situations as threatening. These results emphasize the importance of investigating CS-avoidance, and mnemonic discrimination specifically to understand the interactions between avoidance and fear.

Contributions

Contributed to conception and design: KV, JZ, BV

Contributed to acquisition of data: KV

Contributed to analysis and interpretation of data: KV, JZ, BV

Drafted and/or revised the article: KV, JZ, BV

Approved the submitted version for publication: KV, JZ, BV

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Competing Interests

The authors report no conflict of interest.

Data Accessibility Statement

All the stimuli, presentation materials, participant data, and analysis scripts can be found on this paper's project page on the Open Science Framework (https://osf.io/6cn2y/).

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Supplementary Materials

Table S1

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Table S2

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Table S3

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