



Taxonomic and thematic generalization of safety behaviors

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ABSTRACT

Fear generalization refers to the spread of fear to novel stimuli. Recent evidence suggests that fear generalization is linked with inductive reasoning. In the inductive reasoning literature, inferences are stronger to taxonomically related stimuli that share conceptual features with the target stimulus (e.g., duck and swan), compared to thematically related stimuli that often co-occur with the target stimulus (e.g., duck and pond). Preliminary evidence also shows greater fear generalization to taxonomically related stimuli compared to thematically related stimuli in a fear conditioning framework. The current study aimed to extend this pattern to safety behavior, a behavioral response that minimizes the onset of an expected threat. In a fear and avoidance conditioning framework, participants ($N = 74$) first acquired stronger safety behaviors to a threat predicting conditioned stimulus (CS+) than to a safety predicting conditioned stimulus (CS-). In a following generalization test, participants showed stronger generalized safety behaviors to novel generalization stimuli (GSs) that were taxonomically related to the CS+ compared to those thematically related to the CS+. Low distress tolerance, a risk factor for clinical anxiety, was associated with less differentiated generalized safety behaviors to the GSs. The findings suggest that taxonomic generalization of safety behaviors is stronger than thematic generalization of safety behaviors.

1. Introduction

Fear conditioning is widely accepted as a valid laboratory framework modelling the etiology, maintenance, and interventions for clinical anxiety (Beckers et al., 2023; Scheveneels et al., 2016). In this framework, an initially neutral conditioned stimulus (CS, e.g., a sound) is paired with a biological aversive unconditioned stimulus (US, e.g., an electric shock). After repeated pairings, the CS alone is able to evoke conditioned fear. Conditioned fear acquired to the CS also generalizes to novel generalization stimuli (GSs) that perceptually or conceptually resemble the CS, despite these stimuli not having a history of direct association with the US. Laboratory studies have shown that anxiety-related disorders such as panic disorder (Lissek et al., 2010), generalized anxiety disorder (Lissek et al., 2014), and trauma- and stressor-related disorders (Kaczurkin et al., 2017) are associated with excessive fear generalization (for reviews see Cooper et al., 2022; Fraunfelder et al., 2022). There is some preliminary evidence that risk factors of developing anxiety-related disorders, for instance, trait anxiety and intolerance of uncertainty (Carleton, 2016; Chambers et al., 2004; Jorm et al., 2000), are linked to stronger fear generalization

(Aslanidou, Andreatta, Wong, & Wieser, 2024; Haddad et al., 2012; Morriss et al., 2016; Wong & Lovibond, 2018; Wong & Lovibond, 2021; see Lonsdorf & Merz, 2017). However, the relationship between excessive fear generalization and risk factors for anxiety-related disorders remains inconsistent in the literature (e.g., Bauer et al., 2020; Torrents-Rodas et al., 2013). Despite this inconsistency, excessive fear generalization is widely regarded as maladaptive as it creates false alarms of perceived threat to a range of innocuous objects or situations, resulting in persistently elevated anxiety levels. Combined, these studies suggest that excessive fear generalization is a pathological marker or even a behavioral risk factor for anxiety-related disorders.

In the past decade, fear conditioning studies have shown that conditioned fear acquired to the CS generalizes to novel generalization stimuli (GSs) that are categorically related to the CS. For instance, after training with mammal CS exemplars that were paired with a US, participants selectively generalized conditioned fear to other novel GSs that belong to the mammal category but not to GSs that belong to other categories (e.g., Dunsmoor et al., 2012; Wong & Lovibond, 2021). These findings suggest that categorical generalization of fear can be seen as a type of inductive reasoning (e.g., Dunsmoor & Murphy, 2014; Lee et al.,

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2019). For instance, upon learning that a dog CS predicts a US whereas a hammer CS predicts an absence of the US, participants make the inference that novel animal exemplars signal the US while novel tool exemplars signal safety, and hence generalize their fear accordingly. Laboratory studies also found that factors that affect the strength of inferences in inductive reasoning had similar effects on the strength of generalized fear in fear conditioning tasks, providing support to the notion that categorical generalization of fear is a type of inductive reasoning. For instance, when trained with typical exemplars that are highly representative of their category (e.g., cows for mammals) compared to training with atypical exemplars that are not representative of their category (e.g., bats for mammals), participants make stronger inferences to novel mammal exemplars in inductive reasoning tasks (e.g., Osherson et al., 1990) and exhibit stronger generalized fear to novel mammal GSs in fear conditioning tasks (Dunsmoor & Murphy, 2014; Wong & Beckers, 2021). Similarly, when trained with a diverse range of exemplars of the same category, participants show stronger inference to novel exemplars in inductive reasoning tasks (e.g., Feeney & Heit, 2011; McDonald et al., 1996) and exhibit stronger generalized responding to novel GSs in a conditioning task (Lee et al., 2019).

More recently, Lei et al. (2020) examined whether fear generalizes differently to taxonomically related GSs and thematically related GSs. A taxonomic relation refers to exemplars that share similar features because they belong to the same category (Coley et al., 1997; Markman & Wisniewski, 1997). For example, one feature of mammals is that they have hair or fur. Dogs and gorillas share this feature because they are taxonomically related (as mammals). A thematic relation, on the other hand, refers to exemplars that frequently co-occur in events or situations rather than share features (Estes et al., 2011; Lin & Murphy, 2001). For example, ducks and ponds are thematically connected as they often co-occur. Lei et al. (2020) found that after training with a CS (e.g., pencil), fear generalized to both taxonomically related GSs (e.g., pen) and thematically related GSs (e.g., paper). Interestingly, participants exhibited greater fear generalization to taxonomically related GSs than to thematically related GSs. This pattern aligns with what is found in the inductive reasoning literature where participants make stronger inferences to taxonomically related exemplars compared to thematically related exemplars, as taxonomic induction is thought to be a default strategy (Coley et al., 2005; López et al., 1997; Osherson et al., 1990; Shafto & Coley, 2003). Thematic induction is thought to be only stronger than taxonomic induction under certain conditions. For instance, when thematically related stimuli are presented simultaneously rather than sequentially (Rey & Berger, 2001) or when the thematic relations are made particularly salient (Lin & Murphy, 2001).

While Lei et al.'s (2020) finding focused on fear generalization as reflected by self-reported ratings and electroencephalography, the current study loosely adapted their procedure and aimed to expand their findings to more overt safety behaviors, that is, whether safety behaviors acquired to a feared stimulus generalize more strongly to taxonomically related GSs compared to thematically related GSs. Safety behaviors are behavioral responses that minimize an expected and imminent threat. For example, someone with a peanut allergy always bringing an EpiPen along. Safety behaviors are oftentimes adaptive as they minimize harm. However, safety behaviors acquire pathological qualities in anxiety-related disorders when they are performed out of proportion of threat, in the absence of realistic threat, or are performed so excessively that they interfere with one's daily life (Mendlowicz, 2000; Olatunji et al., 2007). For example, someone with social anxiety disorder may refrain from contributing to a group conversation to avoid being perceived as unintelligent, even though this perceived threat rarely occurs. The maladaptive nature of such safety behaviors becomes more pronounced when individuals attribute the absence of a perceived threat to their use of these behaviors. This misattribution reinforces the reliance on safety behavior usages, preventing individuals from learning that the perceived threat is unlikely to occur (i.e., protection from extinction; Lovibond et al., 2009; Meulders, Traxler, Vandael, & Scheepers, 2024;

Pittig, 2019), thus maintaining or even exacerbating fear to innocuous situations or objects over time. Although it is widely agreed that safety behaviors are primarily motivated by fear (see Krypotos, 2015; for a review), the literature indicates that these behaviors are also influenced by other factors, such as the cost of using safety behaviors, personality traits, and social demands (Pittig et al., 2020). This signals that fear and safety behaviors do not share a simple one-to-one relationship (e.g., Glogan et al., 2020; Vervliet & Indekeu, 2015; Wong & Lovibond, 2021). Therefore, it is valuable to explore whether the asymmetry between generalized fear to taxonomically related exemplars and thematically related exemplars extends to safety behaviors or not.

Safety behaviors have been successfully modelled in a fear conditioning framework: After acquiring conditioned fear to the CS, by performing a designated response (e.g., pressing a specific key) during CS presentation participants can prevent the upcoming US (Pittig et al., 2020). Using a fear conditioning framework, the current study examined whether the differential extent of taxonomic and thematic fear generalization reported by Lei et al. (2020) would also show in behavioral avoidance responses.

Given that preliminary evidence suggests that risk factors for anxiety-related disorders, such as trait anxiety and intolerance of uncertainty are associated with excessive fear generalization (Cooper et al., 2022; Fraunfelder et al., 2022; Sep et al., 2019), the current study also explored whether these personality traits are associated with stronger generalization in safety behaviors. In addition, low distress tolerance, a transdiagnostic risk factor characterized by difficulty in enduring negative emotions, has been linked to various anxiety-related symptoms (Keough et al., 2010; Simons & Gaher, 2005). Individuals with low distress tolerance are likely to have a low capacity to cope with potential threats, which in turn is expected to be associated with an increase in safety behavior usage (e.g., Lemmens et al., 2021; Vervliet et al., 2017). Therefore, we also explored whether low distress tolerance is associated with enhanced generalization in safety behaviors.

In sum, this study had two research aims. First, we examined whether participants show stronger generalization of safety behaviors (referred to as US-avoidance in the Method section) to novel stimuli that are taxonomically related to the CS compared to those that are thematically related to the CS, using a modified approach loosely based on Lei et al. (2020). Second, we explored whether risk factors for anxiety-related disorders, such as trait anxiety, intolerance of uncertainty, and low distress tolerance, are associated with enhanced generalization of safety behaviors.

2. Method

2.1. Participants

Seventy-six psychology undergraduates at Erasmus University Rotterdam were recruited and received partial course credits for participation. According to the "Summary statistics based power analysis" shiny app (Murayama et al., 2022), a sample size of 66 participants was required to obtain a target power of 0.90. This was computed using the main effect of conceptual relation (taxonomically related generalization stimuli compared with thematically related generalization stimuli) in a generalization test measured via US expectancy ratings in Lei et al. (2020). The required sample size also took into account an approximately 38 % reduction in effect size from US expectancy ratings to US avoidance (see Wong et al., 2023, for similar adjustment). We recruited more participants ($N = 76$) than the computed sample size ($N = 66$) to account for attrition rates due to exclusion criteria (e.g., not acquiring the CS-US contingencies) or technical difficulties (see our pre-registration on OSF, <https://osf.io/3zftq/>). This study was approved by the Ethics Committee of the Erasmus School of Social and Behavioural Sciences (ETH2223-0323) in accordance to the Declaration of Helsinki.

2.2. Apparatus and materials

The words *beer* and *suitcase*, served as the CSs. Eight taxonomically related words, four related to beer (*vodka*, *gin*, *whiskey*, and *rum*) and four to suitcase (*backpack*, *bag*, *handbag*, and *purse*) served as the taxonomically related generalization stimuli (GSs). For the thematically related GSs, we used the words *party*, *drunk*, *bar*, and *glasses* for beer and the words *clothes*, *travel*, *plane*, and *airport* for suitcase. These stimuli were chosen through a free association task (that was conducted independently of the main study) in which forty-five participants each generated 6 words that were taxonomically related and 6 words that were thematically related to the target words beer and suitcase. The GSs were chosen because they were most frequently and consistently generated (see Supplementary Materials for details).

US expectancy ratings were assessed by a visual analog scale ranging from 0 % to 100 % with a minimal interval of 1 %; 0 % indicates certain absence of electric shock, 50 % indicates uncertain of the presence of electric shock, 100 % indicates certain presence of electric shock. Similarly, US-avoidance responses were assessed by a visual analog scale ranging from 0 % to 100 % with a minimal interval of 1 %; 0 % indicates certainly not avoid an electric shock whereas 100 % indicates certainly avoid an electric shock. All stimuli, visual analog scales, and instructions were presented via Presentation software (Neurobehavioral Systems Inc., Berkeley, CA, Version 20.1).

The electric shock was a train of 2 ms electric pulses amounting to a total of 500 ms. It was generated by a DS7A Digitimer stimulator, delivered via a pair of bar-electrodes attached to the wrist of the participants' non-dominant hand. Skin conductance was measured via a pair of Ag/AgCl electrodes attached to the hypothenar muscles of the same hand. Skin conductance was measured at a 1000 Hz sampling rate by a Biopac MP150 system equipped with a EDA100 amplifier.

We assessed three psychometric constructs. The first one was trait anxiety, a risk factor for developing clinical anxiety characterized by a tendency to respond negatively to situations in general (Gershuny & Sher, 1998; Jorm et al., 2000). Trait anxiety was assessed by the anxiety-subscale of the Depression Anxiety and Stress scale – 21 (DASS-21, Lovibond & Lovibond, 1995). We used the trait version of DASS-21 to assess trait anxiety because of its ability to differentiate anxiety from other related constructs (e.g., Antony et al., 1998; Brown et al., 1997; Gloster et al., 2008), as opposed to the commonly used STAI-T which has been criticized for assessing a broad negative affect rather than anxiety (e.g., Andrade et al., 2001; Caci et al., 2003). The second construct was intolerance of uncertainty, another risk factor for clinical anxiety characterized by an incapacity to tolerate situations with high level of ambiguity (Carleton et al., 2012; Sexton et al., 2003). Intolerance of uncertainty was assessed by the Intolerance of Uncertainty Scale (IUS; Freeston, Rh  aume, Letarte, Dugas, & Ladouceur, 1994). The third construct was distress tolerance, an arguably protective factor against clinical anxiety characterized by a capacity to endure negative emotional states, which was measured by the Distress Tolerance Scale (DTS; Simons & Gaher, 2005).

2.3. Procedure

After providing informed consent, participants were asked to fill in the three psychometric questionnaires. The SCR electrodes filled with isotonic gel and the shock electrodes were then attached to their non-dominant hand. An electric shock workup procedure was carried out next. Participants were first asked to sample an electric shock with an intensity of 0.2 mA. The electric shock intensity was gradually increased until it reached a level that was reported as 'definitely unpleasant but not painful'. Then, we carried out a reward-matching procedure, which aimed to capture a level of cost that was neither too low nor too high to minimize ceiling or floor effects on US-avoidance (e.g., Schlund et al., 2016). In this matching procedure, 14 questions entailing "Are you willing to tolerate the selected level of shock if you are given €_?" with

the amount ranging from 5 to 31 cents in odd numbers (i.e., 5 cents, 7 cents ... 29 cents, 31 cents) presented in a randomized order. Participants had to answer either 'Yes' or 'No' to each question. The value between the highest amount that received a 'No' and the lowest amount that received a 'Yes' was selected as the financial incentive for US-avoidance disengagement. For example, if one was unwilling to tolerate an electric shock up to 21 cents (i.e., answering 'No' to all questions up to 21 cents), but was willing to endure it when given 23 cents or more (i.e., answering 'Yes' to all questions from 23 cents onwards), the amount in between (22 cents) would be selected as the maximum amount of incentive per trial. Participants were informed that the reward they received was hypothetical, meaning that the reward would not be paid financially. The main experiment consisted of three consecutive phases: Fear acquisition training, US-avoidance training, and US-avoidance generalization test (see Table 1).

Fear acquisition training. Participants were instructed that some words would appear on screen, and might or might not be followed by an electric shock. The word 'beer' served as the CS+ whereas 'suitcase' served as the CS-, counterbalanced across participants. This phase consisted of two blocks. In each block, the CS+ and CS- were presented 4 times each. The CS+ was reinforced by an electric shock at a 75 % rate whereas the CS- was never reinforced. On each trial, the CS was presented on screen along with a US expectancy scale for 8 s. Participants were prompted to indicate their US expectancies during this 8 s CS presentation. Immediately after CS offset, an electric shock would be administered but only on reinforced CS+ trials. The intertrial intervals were randomized between 15 and 18 s to allow sufficient time for skin conductance to return to baseline. The presentation order of the CS was pseudo-randomized so that the same CS type would not appear more than twice in a row.

US-avoidance acquisition training. Before this phase began, participants were informed that they had the opportunity to reduce the chances of electric shock onset. This could be done by indicating their US-avoidance responses via the US-avoidance visual analog scale. The selected US-avoidance response was negatively proportional to US onset. For instance, a US-avoidance response of 90 % would lead to a 90 % chance of US absence, if a US was to follow the CS. However, US-avoidance was also negatively proportional to the reward obtained per trial. For instance, a US-avoidance response of 90 % would yield only 10 % of the maximum reward. This phase consisted of two blocks. In each block, the CS+ and the CS- were presented 4 times each. The CS was presented with the US-avoidance visual analog on screen until a US-avoidance response was made. Immediately after CS offset, an electric shock might be administered depending on the US-avoidance response made and the CS type. A reward feedback informing how much reward participants obtained for that trial then appeared for 2 s. The intertrial intervals were randomized between 15 and 18 s.

Generalization test. This phase continued seamlessly from the previous phase. Four novel stimuli taxonomically related and four novel stimuli thematically related to the CS+ were presented (tax-GS+ & theme-GS+, respectively). Likewise, eight stimuli that were taxonomically or thematically related to the CS- were presented (tax-GS- & theme-GS-, respectively). Each GS was presented once, amounting to a total of

Table 1
CS+ refers to a CS reinforced by a US at a 75 % rate; CS- refers to a CS never reinforced. * indicates US-avoidance availability; GS+ refers to generalization stimuli related to the CS+; GS- refers to generalization stimuli related to the CS-. Between brackets are the number of trials.

Fear acquisition training	US-avoidance acquisition training	Generalization test
CS+ (8)	CS+* (8)	Taxonomic GS+* (4)
CS- (8)	CS-* (8)	Thematic GS+* (4) Taxonomic GS-* (4) Thematic GS-* (4)

16 trials in this phase. On each trial, a GS was presented along with the US-avoidance visual analog scale until a US-avoidance response was made. Regardless of US-avoidance response made and GS type, none of the stimuli were reinforced by a US. Immediately after GS offset, reward feedback was presented for 2 s. The presentation order of the GSs was pseudo-randomized so that the same GS type (GS + or GS-) and the same relation type (taxonomically or thematically related) would not appear more than twice in a row.

2.4. Scoring and analysis

Only skin conductance measured during the 8 s of CS presentation during *Fear acquisition training* was analyzed. We applied a 1 Hz low-pass filter and a 50 Hz notch filter to the SCR data via BrainVision Analyzer. The SCRs were identified by identifying a peak response 1 s after CS onset until CS offset. They were then baseline corrected by the averaged skin conductance level 2 s before CS onset. The SCR data were then square-root transformed to reduce skewness (Society for Psychophysiological Research Ad Hoc Committee on Electrodermal Measures, 2012). The SCR data processing was carried out by research assistants blinded to the trial types.

All data were analyzed with linear mixed models. The analyses were separated into three parts: Manipulation check, Main hypotheses, and Exploratory analyses. We carried out frequentist analyses and Bayesian models for all models. For the frequentist analyses, we used the standard $p < .05$ criteria for determining whether the null hypothesis is rejected or not. For the Bayesian analyses, we obtained Bayes Factors (BF_{10}). We consider Bayes factors larger than 10 as strong evidence in favor of the alternative hypothesis, and Bayes factors less than 0.10 as strong evidence in favor of the null hypothesis (Lee & Wagenmakers, 2014).

2.5. Manipulation check

We analyzed whether participants acquired stronger responding to the CS + compared to the CS- during *Fear acquisition training* and *US-avoidance acquisition training*. To this end, US expectancy ratings, SCRs (during *Fear acquisition training*) or US-avoidance (during *US-avoidance acquisition training*) served as a continuous dependent variable, whereas CS type, Block, and their interaction served as fixed effects. Participants served as a random effect, which applies to all the linear mixed models below. Noted that to maintain model parsimony, we only included random intercepts for participants in our models. This approach has been suggested to improve statistical power while balancing Type I error rates, improving convergence, and minimizing overfitting (Matuschek et al., 2017).

2.6. Main hypotheses

We first analyzed whether participants exhibited generalization of US-avoidance, as indexed by stronger US-avoidance responses to GS + than to GS-. To this end, US-avoidance served as dependent variable whereas GS type (GS + vs GS-) served as fixed effect. We then analyzed whether participants showed any differences in US-avoidance generalization to taxonomically related GSs and thematically related GSs. Thus, US-avoidance served as dependent variable whereas GS type, Relation (taxonomic vs thematic), and their interaction served as fixed effects. Given that each GS was presented once in the Generalization test, the observations were not organized in separate blocks. Therefore, Block was not included as a factor in these models.

2.7. Exploratory analyses

We explored the effects of trait anxiety, intolerance of uncertainty, and distress tolerance on the 1) acquisition of differential responding to the CSs during *Fear acquisition training* and *US-avoidance acquisition training*, 2) generalization of US-avoidance, and 3) differential

generalization to taxonomically and thematically related GSs. For these purposes, trait anxiety, intolerance of uncertainty, and distress tolerance were added as continuous variables. We explored these effects using two approaches. First, each risk factor was included individually in separate models. Second, all risk factors were included together in a 'full factor' model, with the risk factors mean-centered to reduce multicollinearity (Iacobucci et al., 2016). Because these risk factors are intercorrelated (Buhr & Dugas, 2002; Leyro et al., 2010), the 'full factor' model allowed us to assess their unique contributions while controlling for each other.

In all the models above, the degree of significance is reported with Satterthwaite approximation for degrees of freedom (Satterthwaite, 1941). The main effects and higher-order interactions were analyzed in separate models (Hayes et al., 2012). Main effects are not reported if their interactions were significant. All analyses were carried out via R (R core team, 2023, Version 4.3.2) with the *lmer* package for the frequentist linear mixed models (Bates et al., 2015). The effect sizes for the frequentist analyses are reported as partial- R^2 with the *r2glmm* package (Jaeger, 2017). The Bayesian analyses were carried out with the *brm* package (Bürkner, 2017). The data is available via <https://osf.io/7g4dk/files/osfstorage>.

3. Results

Statistical analyses were restricted to participants who had acquired the CS-US contingency (see preregistration). This was defined as higher averaged US expectancy ratings to the CS + compared to the CS- during the last block of *Fear acquisition training*. Two participants were excluded from the data analyses based on this criterion, leading to a final sample size of 74 participants. In addition, SCRs from two participants were not recorded due to technical issues. Therefore, 74 participants were included for behavioral data analyses while 72 participants were included for SCR data analyses (see Table 2 for the descriptive statistics of the final sample of $N = 74$).

3.1. Manipulation checks

During *Fear acquisition training* (Fig. 2A), participants acquired greater US expectancy ratings to the CS + compared to the CS- (see Fig. 1). This pattern was greater in Block 2 than in Block 1. This pattern was supported by a significant interaction between CS type and Block, $bCS\ type \times Block = -20.09$, $SE = 3.28$, $p < .001$, $R^2 = 0.11$, $BF_{10} = 15.26$. For the SCR data (Fig. 2B), participants exhibited greater responding to the CS + compared to the CS- averaged across blocks, $bCS\ type = 0.18$, $SE = 0.03$, $p < .001$, $R^2 = 0.065$, $BF_{10} > 1000$. However, this effect did not significantly interact with Block, $bCS\ type \times Block = -0.058$, $SE = 0.064$, $p = .367$, $R^2 = 0.002$, $BF_{10} = 0.10$.

During *US-avoidance acquisition training* (Fig. 3A), participants used greater US-avoidance responses to the CS + compared to the CS- averaged across blocks, $bCS\ type = 40.41$, $SE = 1.33$, $p < .001$, $R^2 = 0.43$, $BF_{10} > 1000$. This effect did not further interact with Block, $bCS\ type \times Block = -3.62$, $SE = 2.66$, $p = .175$, $R^2 = 0.002$, $BF_{10} = 0.58$. In sum, participants acquired differential fear responding and US-avoidance to the CSs in the acquisition phases.

Table 2

Descriptive statistics for the sample. DTS = Distress tolerance scale; IUS = Intolerance of uncertainty scale; DASS21 = Depression Anxiety Stress scale –21.

	Mean (SD)	Cronbach's α
Gender (Women/Men)	58/16	NA
Age	20.54 (2.37)	NA
DTS (1–5)	3.54 (0.80)	0.91
IUS (27–135)	58.24 (17.62)	0.94
DASS21-Anxiety (0–42)	9.05 (8.28)	0.79
DASS21-Depression (0–42)	10.86 (9.22)	0.86
DASS21-Stress (0–42)	13.84 (9.23)	0.84

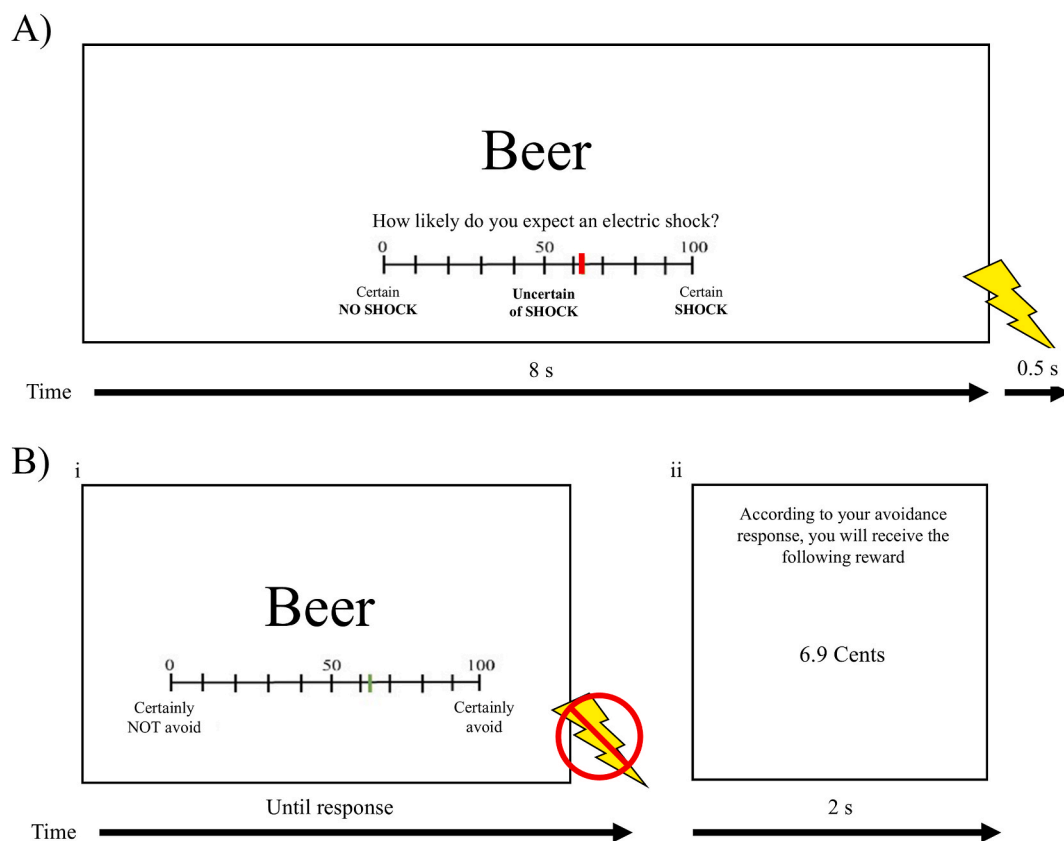


Fig. 1. (A) Trial structure during *Fear acquisition training*. The CS was presented along with the US expectancy scale for 8 s. Participants were prompted to indicate their US expectancy ratings on each trial. Immediately after CS offset, an electric shock might be delivered depending on the CS type. (B) Trial structure during *US-avoidance acquisition training* and *Generalization test*. (i) The CS/GS was presented, and participants were prompted to indicate their US-avoidance responses on each trial. In the *US-avoidance acquisition training*, an electric shock might be delivered depending on the CS type and US-avoidance response made. In the *Generalization test*, none of the GSs were reinforced. (ii) A reward feedback appeared on screen for 2s.

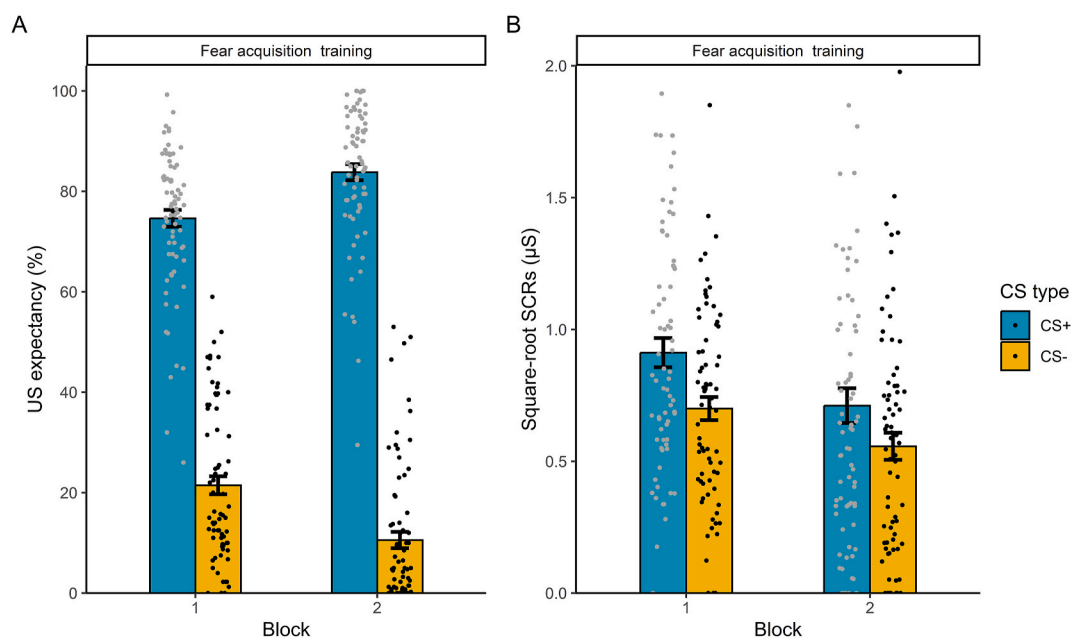


Fig. 2. Mean US expectancy ratings (A) and mean square-root SCR (B) of participants during Fear acquisition training. CS + indicates the CS that was reinforced at a 75 % rate; CS- indicates the CS that was never reinforced. Error bars indicate standard error of the mean. For interpretation of the references to color in this figure caption, the reader is referred to the Web version of this article.

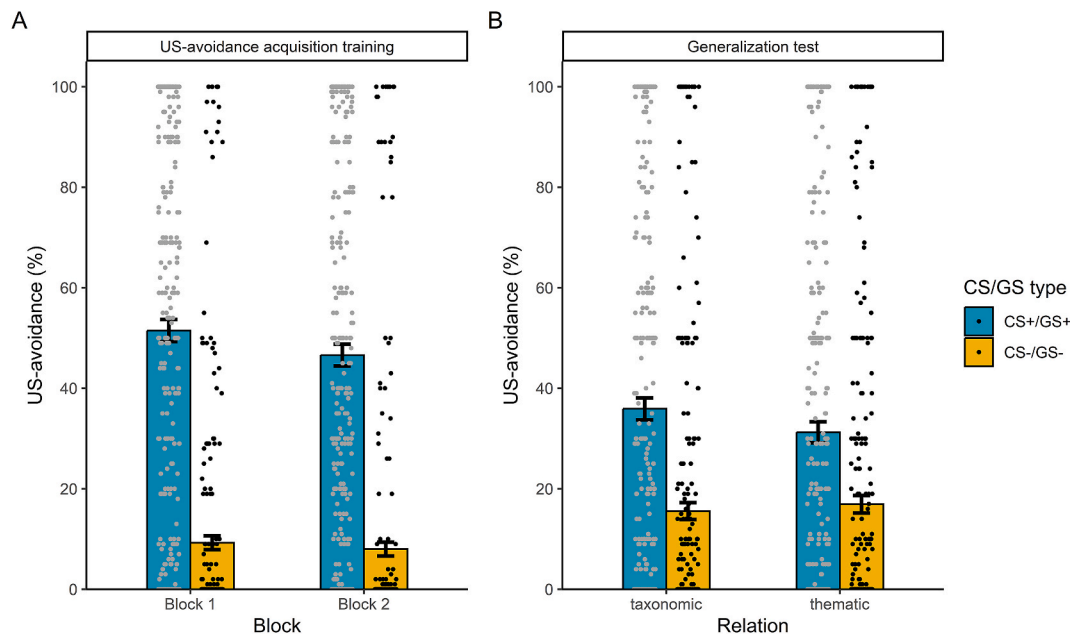


Fig. 3. Mean US-avoidance during *US-avoidance acquisition training* (A) and during *Generalization test* (B). Error bars indicate standard error of the mean. For interpretation of the references to color in this figure caption, the reader is referred to the Web version of this article.

3.2. Main hypotheses

Averaged across taxonomically related and thematically related GSs, participants showed greater US-avoidance responses averaged across all GS+ compared to GS-, $bGS\ type = 17.33$, $SE = 1.21$, $p < .001$, $R^2 = 0.14$, $BF_{10} > 1000$, indicating that US-avoidance generalizes strongly to GSs related to the CS+. The main effect of Relation (taxonomic/thematic), which we powered our study for, did not reach significance, $bRelation = -1.65$, $SE = 1.20$, $p = .170$, $R^2 < 0.001$, $BF_{10} = 1.10$. However, we observed a significant interaction between GS type and Relation, $bGS\ type \times Relation = 6.02$, $SE = 2.40$, $p = .012$, $R^2 = 0.18$, $BF_{10} = 13.96$, indicating greater differential US-avoidance responses to the taxonomically related GSs compared to the thematically related GSs. Given our primary interest in examining whether generalized US-avoidance was greater for taxonomically related GS+ compared to thematically related GS+, we first followed up on the interaction by assessing responses to the GS+. US-avoidance responses were significantly greater for taxonomically related GS+ compared to thematically related GS+, $bRelation\ (GS+) = 4.67$, $SE = 1.70$, $p = .006$, $R^2 = 0.006$, $BF_{10} > 1000$. We further examined whether this pattern extended to the GS-. There was no evidence to suggest that US-avoidance responses differed between taxonomically and thematically related GS-, $bRelation\ (GS-) = 1.36$, $SE = 1.70$, $p = .424$, $R^2 = 0.001$, $BF_{10} = 0.97$.

3.3. Exploratory analyses

During *Fear acquisition training*, the models in which one risk factor was included in each model showed that all risk factors were positively associated with less differential US expectancy ratings (all $ps \leq 0.014$, all $BF_{10} > 1000$). However, there was limited evidence that any risk factors had an effect on differential US expectancy ratings in the 'full factor' model (all $ps \geq 0.068$, all $BF_{10} \leq 1.04$). For the SCR data, there was no evidence that any risk factors were associated with differential responding to the CSs, regardless of the model (all $ps \geq 0.310$, $BF_{10} \leq 0.06$). During *US-avoidance acquisition training*, there was limited evidence that any risk factor had an effect on differential US-avoidance to the CSs in the single models (all $ps \geq 0.309$, $BF_{10} \leq 0.90$). However, in the 'full factor' model, when controlling for other risk factors, low distress tolerance was associated with stronger differential US-

avoidance to the CSs averaged across blocks, $bCS\ type \times Distress\ tolerance = -4.59$, $SE = 1.77$, $p = .006$, $R^2 = 0.006$ in the frequentist model. However, the Bayesian analysis was not consistent with the frequentist model, $BF_{10} = 1.39$. The highest Variance Inflation Factor (VIF) among the interaction terms was 2.35, suggesting limited multicollinearity issues (James et al., 2013). No other effects reached significance (all $ps \geq 0.117$, all $BF_{10} \leq 1.00$; see Figs. S1 and S2 in the Supplementary Material).

Fig. 4 shows the effect of the risk factors on US-avoidance in the *Generalization test*. In the separate models, while there was no evidence that trait anxiety had an effect on differential generalized US-avoidance to the GSs, $bGS\ type \times Trait\ anxiety = 0.14$, $SE = 0.15$, $p = .344$, $R^2 = 0.001$, $BF_{10} = 0.92$, distress tolerance associated with stronger differential responding to the GSs, $bGS\ type \times Distress\ tolerance = -5.90$, $SE = 1.50$, $p < .001$, $R^2 = 0.012$ in the frequentist model, whereas the Bayesian model provided moderate evidence for it, $BF_{10} = 8.97$. Intolerance of uncertainty too was associated with stronger differential responding to the GSs, $bGS\ type \times Intolerance\ of\ uncertainty = -154$, $SE = 0.069$, $p = .026$, $R^2 = 0.004$ in the frequentist model, however, the Bayesian analysis suggested limited evidence for this pattern, $BF_{10} = 1.78$. Consistent with the separate models, the 'full factor' model, showed that distress tolerance was associated with stronger differential responding to the GSs, $bGS\ type \times Distress\ tolerance = -6.05$, $SE = 1.56$, $p < .001$, $R^2 = 0.012$ in the frequentist model, with the Bayesian model providing moderate evidence for the association, $BF_{10} = 5.96$. Inconsistent with the separate models in the 'full factor' model, trait anxiety was found to be associated with less differential responding to the GSs, $bGS\ type \times Trait\ anxiety = 5.72$, $SE = 1.56$, $p < .001$, $R^2 = 0.002$, $BF_{10} = 5.88$, and there was no evidence that intolerance of uncertainty had an effect on differential responding to the GSs, $bGS\ type \times Intolerance\ of\ uncertainty = -2.41$, $SE = 1.76$, $p = .169$, $R^2 < 0.01$, $BF_{10} = 0.91$. The highest VIF among the interaction terms of this model was 2.27, suggesting limited multicollinearity issues (James et al., 2013). Furthermore, there was no evidence that any of the risk factors had an impact on the differential generalization of US-avoidance to taxonomically related and thematically related GSs (all $ps \geq 0.290$, $BF_{10} \leq 0.99$), nor did any main effects of risk factors reach significance (all $ps \geq 0.187$, $BF_{10} \leq 1.02$). In summary, there was mixed evidence that trait anxiety nor intolerance of uncertainty had an effect on differential responding to the

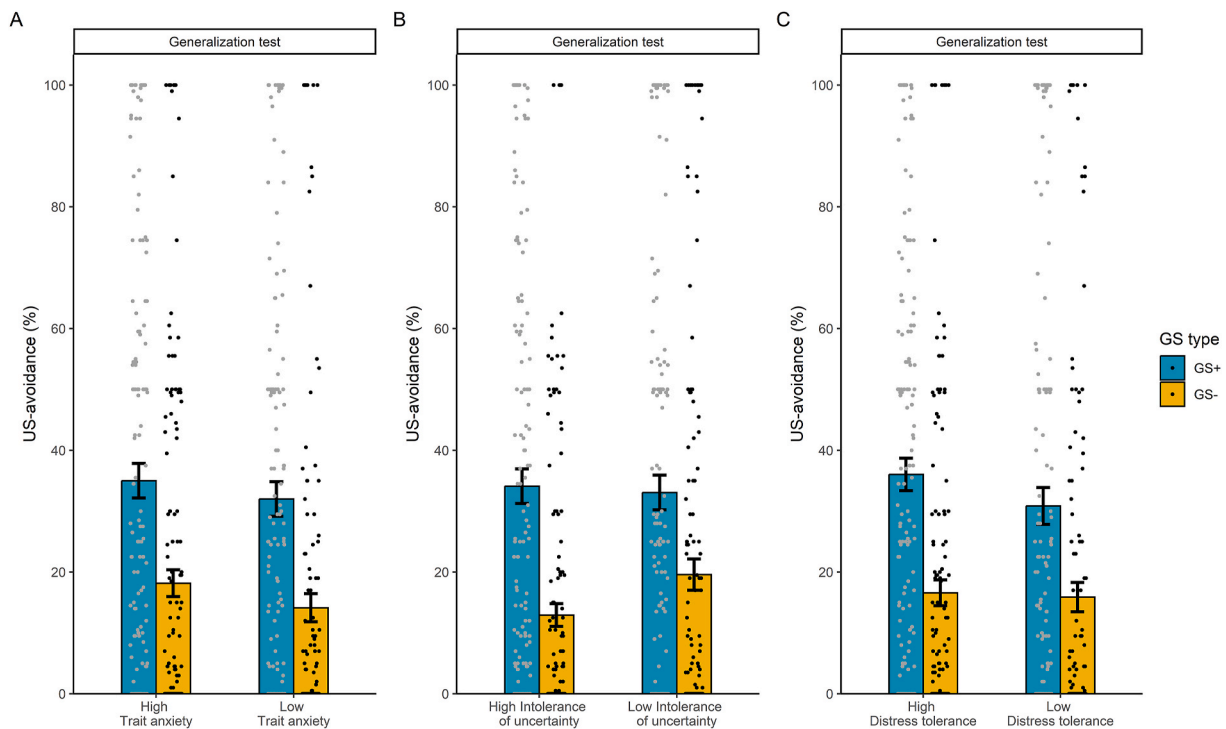


Fig. 4. The effect of trait anxiety (A), intolerance of uncertainty (B), and distress tolerance (C) on US-avoidance during the *Generalization test*. All risk factors were median split for descriptive purposes (trait anxiety = 8; intolerance of uncertainty = 54.5; distress tolerance = 1.33). Error bars indicate standard error of the mean. For interpretation of the references to color in this figure caption, the reader is referred to the Web version of this article.

GSs. Distress tolerance, on the other hand, consistently associated with stronger differential responding to the GSs across multiple models.

4. Discussion

The current study examined whether safety behaviors generalize more strongly to taxonomically related stimuli than to thematically related stimuli. We further explored whether risk factors of anxiety-related disorders were associated with enhanced safety behaviors generalization.

We found that participants exhibited stronger safety behaviors to novel GSs that belonged to the CS + category than to novel GSs that belonged to the CS- category, averaged across taxonomic and thematic relations. This pattern replicates findings of conceptual generalization of safety behaviors (e.g., Boyle et al., 2016; Kloos et al., 2022; Wong et al., 2024) and suggests that higher-order generalization of safety behaviors is a robust phenomenon. Our primary finding was that participants showed stronger generalized safety behaviors to taxonomically related GS + s than to thematically related GS + s. This pattern aligns with the inductive reasoning literature, which suggests that taxonomic inference is a more standard strategy compared to thematic inference (Coley et al., 2005; López et al., 1997; Shafto & Coley, 2003). These observed differences toward taxonomically and thematically related stimuli may reflect a similarity difference. Taxonomically related stimuli are more likely to share visual similarities because they have attributes in common and have similar shapes (Estes et al., 2011; Rosch et al., 1975). People also tend to interact with them similarly (Rosch et al., 1975). Taxonomically related stimuli may in addition also be thematically related in that they are likely to co-occur or occur in similar circumstances (Mirman & Graziano, 2012). Although we ensured that the taxonomic and thematic GSs were equally strongly associated with the CS (see Supplementary Materials), it may thus be the case that the taxonomically related GSs were overall more similar to the CS than the thematically related GSs were, which would explain our results. In the concepts and categories literature, a two-semantic-systems account

(Crutch & Warrington, 2005, 2010; Duñabeitia et al., 2009; Papagno et al., 2013) has been proposed that posits that taxonomic relationships are relatively more important for concrete concepts whereas thematic relationships are relatively more important for abstract concepts (but see Geng & Schnur, 2015). The results of our study are in line with this account in that we found taxonomic relatedness to be most important for avoidance behavior for the concrete concepts (beer and suitcase) that we associated with threat. The two-semantic-systems account also suggests that the results might look different if we were to pair more abstract stimuli with electric shocks. One would then expect safety behaviors to be generalized primarily toward thematically related GSs, reflecting the relative importance of thematic over taxonomic relationships in the representation of abstract concepts. This is an obvious direction to take future research in.

Our findings also align with Lei et al. (2020), but suggest that the bias in favor of taxonomic generalization over thematic generalization is rather isolated to the threat-related GS + s. This pattern could be attributed to safety behaviors being costly (although the cost was hypothetical). Because of this, participants might use safety behaviors more selectively to the threat-related GS + s but not to the safety-related GS-s. Differences in taxonomic and thematic generalization were perhaps not observed in response to the safety-related GS- due to a floor effect imposed by the limited generalized safety behaviors to the GS-s. The hypothetical cost associated with safety behaviors might also explain the relatively low level of generalized safety behaviors to the threat-related GS + s in the current study. This reflects an adaptive pattern among healthy individuals as it is relatively unnecessary to engage in costly safety behaviors to innocuous generalization stimuli. Overall, the current findings replicated the pattern that safety behaviors generalize beyond perceptual similarities. Importantly, the current findings further suggest that aspects of the GSs, in this case the conceptual relation to the CSs, may affect the degree of safety behaviors generalization.

In our exploratory analyses, we found mixed evidence that risk factors of anxiety-related disorders had an impact on the generalization of

safety behaviors. When risk factors were examined individually in separate models, both intolerance of uncertainty and distress tolerance were associated with stronger differential generalized safety behaviors (i.e., stronger discriminative responding between the threat- and safety-related GSs). However, when all risk factors were included in one model, distress tolerance was still associated with stronger differential generalized safety behaviors, whereas intolerance of uncertainty no longer was and trait anxiety became associated with weaker differential generalized safety behaviors. In sum, there was no strong evidence that trait anxiety or intolerance of uncertainty had a consistent effect on generalized safety behaviors, consistent with the mixed findings for these two risk factors in the literature (e.g., Wong et al., 2023). In contrast, distress tolerance was consistently associated with stronger discriminative responding to the GSs across the two models, adding to the mixed findings of the role of distress tolerance in generalized safety behaviors in the literature (e.g., Hunt et al., 2017; Lemmens et al., 2021; San Martín et al., 2020). Nonetheless, the effects, or lack thereof, of these risk factors on generalized safety behaviors in our study should be interpreted with caution. Our analyses were exploratory, and the sample was not specifically powered to detect individual differences in safety behavior generalization (see Wong et al., 2023).

In terms of clinical implications, the current findings suggest that safety behaviors generalize more strongly to stimuli taxonomically related to the feared stimulus compared to stimuli thematically related to the feared stimulus, based on the assumption that fear more strongly generalized to taxonomically related stimuli. This tentatively suggests that exposing clients to taxonomically related stimuli during exposure-based treatment, one of the gold standard treatments for anxiety-related disorders (Bandelow et al., 2015; Watts et al., 2015), may lead to better treatment outcomes than exposing them to thematically related stimuli. Treatment outcome has been suggested to depend on the amount of expectancy violation that occurs within (and between) exposure sessions (Craske et al., 2014). Expectancy violation refers to a mismatch between the expected outcome (e.g., a threat that follows the feared stimulus) and the actual outcome (e.g., the absence of threat). The larger this mismatch, the stronger the learning that the feared stimulus is non-threatening, hence leading to better treatment outcome. However, it is important to acknowledge that the relative strength of taxonomic and thematic semantic knowledge has been found to differ between people (Mirman & Graziano, 2012; Simmons & Estes, 2008) and the treatment suggestions above might therefore not apply to everyone. This is not something we have looked at in the current study but could be exploited in future ones.

This study had some limitations. First, it is common in the literature to present each GS multiple times (Lonsdorf et al., 2017); mean responding to a repeatedly presented GS may reflect a more stable and reliable index of generalization. However, as the GSs are typically presented without any US reinforcement, responses to the GSs are likely to be confounded with ongoing extinction learning. To reduce confounding extinction learning, we only presented each GS once¹ (Ahmed & Lovibond, 2019; Wong & Lovibond, 2018). However, this procedure resulted in a missed opportunity to test whether extinction learning to taxonomically related GSs differs from extinction learning to thematically related GSs. One would expect participants to show faster extinction learning to the taxonomically related GSs compared to the thematically related GSs, as the former are expected to evoke larger expectancy violations compared to the latter. Future studies can present the same GSs in multiple blocks to assess extinction learning. Understanding the nuances of extinction learning to taxonomically and thematically related stimuli can be informative to exposure-based treatments. Second, the mixed findings regarding risk factors and generalization of safety

behaviors could be due to insufficient power (De Houwer et al., 2023; Wong et al., 2023). In addition, given that we did not preselect our sample, the range of risk factors was limited, thus potentially restricting the effect of risk factors on generalized safety behaviors. Third, we did not measure US expectancy ratings or SCR data during the Generalization test. This prevented us from examining whether the asymmetry in fear generalization between taxonomically related and thematically related stimuli, as observed in Lei et al. (2020), could be replicated. Furthermore, this prevented examining whether generalized fear directly predicts generalized safety behaviors.

In conclusion, the current study extended the finding of greater taxonomically related generalization than thematically related generalization to safety behaviors. A key finding is that this differential generalization is isolated to generalization stimuli that were related to the threat-related CS+; this pattern was presumably due to participants limiting their safety behaviors to the threat-related GSs due to the cost of using safety behaviors.

CRediT authorship contribution statement

Alex H.K. Wong: Writing – original draft, Visualization, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jonas Zaman:** Writing – review & editing, Methodology, Conceptualization. **Steven Verheyen:** Writing – review & editing, Methodology, Investigation, Conceptualization.

Preregistration

This study was preregistered on the Open Science Framework (<https://osf.io/3zftq>).

Data availability statement

The datasets generated and analyzed during the current study are available in the Open Science Framework repository <https://osf.io/7g4dk/files/osfstorage>

Reporting

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

Ethical approval

This study was approved by the Ethics Committee of the Erasmus School of Social and Behavioural Sciences (ETH2223-0323) in accordance to the Declaration of Helsinki.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Corresponding author serves as an Associate Editorial Board Member for Behaviour Research and Therapy. Given his role as Associate Editorial Board Member, had no involvement in the peer review of this article and had no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to another journal editor. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

¹ There was some evidence for extinction learning to the GSs even if they were presented once each, reflected by lower responding to GSs that appeared late in the Generalization test phase. See Supplementary Materials for details.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.brat.2025.104881>.

Data availability

I have shared the link to the data (<https://osf.io/7g4dk/files/osfstorage>)

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