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Conceptual fear generalization gradients and their relationship with anxious traits: Results from a Registered Report

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ABSTRACT

A hallmark symptom of fear and anxiety disorder is generalization of fear to essentially innocuous stimuli and situations. Such generalization can occur through both perceptual and conceptually similarities. Recent studies indicate that perceptual generalization is inflated in anxiety patients and individuals prone to develop anxiety disorders, suggesting that perceptual generalization may be involved in the etiology of anxiety disorders. In the current Registered Report, we wanted to address whether *conceptual generalization* is potentially implicated in the development of anxiety disorders as well. Therefore, we used a novel paradigm in which the Dutch word *mini* [tiny] or *enorm* [enormous] was paired with an electric shock and assessed fear to the conceptually related words *klein* [small], *medium* [medium], and *groot* [large]. The sample ($N = 120$) consisted of healthy university students. As hypothesized, we observed clear conceptual fear generalization gradients using both self-report and psychophysiological measures. However, in contrast to our expectations, these conceptual generalization gradients were not correlated with different anxious traits (i.e., trait anxiety, intolerance of uncertainty, and behavioral inhibition). These results show that fear can generalize conceptually along a gradient, without requiring perceptual errors as postulated by traditional models of fear generalization. Instead, our results correspond well with inferential reasoning theories of fear generalization. Additionally, we discuss potential reasons for the absence of the expected correlations between conceptual fear generalization and anxious traits, such as restricted variability in both the generalization task and the sample. We conclude that the paradigm has promise for further research on conceptual fear generalization.

1. Introduction

Anxiety disorders are characterized by not only fearing stimuli and situations that are dangerous or that closely resemble the context in which the original trauma occurred, but crucially also fearing stimuli and situations that are objectively safe or only faintly resemble the original trauma context. This 'overgeneralization' of fear causes great distress for anxiety disorder patients and often interferes with their daily tasks and routines. Hence, it has been suggested that overgeneralization may in fact be an etiological mechanism for the development of anxiety disorders (e.g., Lenaert et al., 2014; Lissek et al., 2014; Lissek and Grillon, 2010).

Generalization of fear can be investigated in the laboratory by presenting participants with generalization stimuli (GSs) which resemble a stimulus (conditioned stimulus or CS+) that was previously paired with an electric shock or another aversive stimulus (unconditioned stimulus or US). Typically it is observed that participants show a gradient of fear: they show more fear to GSs that more closely resemble the CS+ and gradually less fear to GSs that resemble the CS+ less closely (Lissek et al., 2008). Previous research has demonstrated that participants at risk for developing anxiety disorders (Lenaert et al., 2014; Wong and Lovibond, 2018) and anxiety patients (Lissek et al., 2010, 2014) express more fear towards the GSs than control participants (i.e., overgeneralization of fear). These findings have been obtained using arbitrary stimuli (e.g., circles with varying diameters, dots on the screen with a varying location) and for different types of anxiety-related disorders (e.g., Generalized Anxiety Disorder, Post-Traumatic Stress Disorder), suggesting that overgeneralization may be a cross-diagnostic vulnerability factor for pathological anxiety (Lissek and Grillon, 2010). However, it should also be mentioned that not all studies have replicated these findings (e.g., Lonsdorf and Merz, 2017; Torrents-Rodas et al., 2012, 2013).

Most often, fear generalization is investigated with simple visual

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stimuli that vary on a perceptual dimension (i.e., circles of increasing size, see above). However, regardless of any perceptual similarity, fear can also generalize because stimuli are semantically related (e.g., doctors and needles), belong to the same category (e.g., honeybees and wasps), or vary along an abstract dimension (e.g., emotionality of faces) (Dymond et al., 2015). Hence, rather than being perceptually similar, these different stimuli can be said to be conceptually similar, and fear may generalize through conceptual relatedness (Dunsmoor and Murphy, 2015).

It is conceivable that conceptual generalization is relatively more important than perceptual generalization in adult humans. That is, humans are highly trained and specialized in processing symbolic information (e.g., words, signs, and digits). Symbols represent information regardless of the perceptual features of the represented objects. Many of the stimuli that adult humans daily encounter have symbolic meaning and their relatedness depends both on conceptual representations (e.g., prior knowledge, category membership, semantic networks) and perceptual features. Indeed, also in clinical features of anxiety disorders conceptual relatedness is most likely relevant. For instance, claustrophobics may fear planes, elevators, and overly crowded places, not because of their physical resemblance, but because all these situations involve a confined space in which no immediate escape is possible (see Radomsky et al., 2001). More generally, fear acquisition in real-world situations rarely involves simple sensory cues but rather consists of complex stimuli and situations with both perceptual features and symbolic meaning (e.g., a car accident with your children present, being humiliated during a presentation at work, losing a close friend due to a progressive disease). Therefore, fear generalization in humans likely involves conceptual generalization processes, and studying these processes may be essential to understand fear overgeneralization in anxiety disorders (Dunsmoor and Murphy, 2015).

In the current research report, we introduce a novel paradigm to investigate conceptual generalization in the laboratory and we examined how the behavioral responses in this paradigm relate to risk factors for developing anxiety disorders (i.e., anxious traits). Particularly, we presented participants with related stimuli along a semantic dimension. After fear conditioning with the word *mini* [tiny] or, counterbalanced, *enorm* [enormous], participants were presented with the words *klein* [small], *medium* [medium], and *groot* [large]. This procedure allows to calculate conceptual generalization gradients across generalization stimuli, which provides additionally crucial variance to discriminate between participants at high and low risk to develop anxiety disorders (see Lenaert et al., 2014; Lissek and Grillon, 2010). To investigate the concurrent validity of our paradigm, we correlated the obtained generalization gradients with different anxious traits (see below). If our paradigm proves useful for the identification of at-risk individuals, it could potentially also be used for the screening, prevention and treatment (e.g., using discrimination training; Dunsmoor and LaBar, 2013) of anxiety disorders.

To assess fear and fear generalization within this paradigm we used physiological responses (skin conductance responses and fear potentiated startle) and subjective ratings (US expectancy), as is common in fear conditioning research (Lonsdorf et al., 2017). There is some debate in the literature about which measures most closely correspond with fear (and about what fear exactly is; Fanselow and Pennington, 2018; LeDoux and Pine, 2016). Our view is that fear constitutes an integrated response of subjective apprehensions, physiological responses and action tendencies. Though the correspondence between these components is not perfect, we see them, particularly in the strong situation of a fear conditioning experiment, as interchangeable indices of fear. Accordingly, we corrected for multiple testing between these different measures of fear when calculating the correlations with anxious traits. As measures of individual differences in the risk of developing anxiety disorders (i.e., anxious traits) we included trait anxiety, behavioral inhibition, and intolerance of uncertainty. These personality traits are related to the development of anxiety disorders (Carver and White, 1994; Clark et al., 1994; Clauss and Blackford, 2012; Lonsdorf and Merz, 2017; McEvoy and Mahoney, 2012; Spielberger et al., 1983). Though these constructs partly overlap (i.e., they have positive non-zero correlations with each other; see for instance Sjouwerman et al., 2018), they have been distinguished from each other in the literature (for a recent review see Lonsdorf and Merz, 2017). At present, it is unclear which of these personality traits would more closely be related to overgeneralization. As such, we did not have a specific focal hypothesis of which personality trait would correlate most strongly with fear generalization.

In summary, our hypotheses were the following:

(1). During acquisition we predicted to find larger fear responses (i.e., expectancy ratings, skin conductance responses, and fear potentiated startle) to the CS+ compared to the CS-.
(2). During generalization we expected to find increasingly larger fear responses to the CS-, the GSs, and the CS+ (i.e., conceptual generalization gradients).
(3). We predicted that smaller differences in fear responses between the CS+ and the GSs (i.e., more conceptual overgeneralization) will be related to anxious personality traits, similar to what has previously been observed for perceptual generalization (Lenaert et al., 2014; Lissek et al., 2008; Morriss et al., 2016; Wong and Lovibond, 2018).
(4). We did not have specific hypotheses about which fear responses will be most sensitive to conceptual fear overgeneralization. Because we believe that the different fear measures operationalize the same construct, we corrected for multiple testing when calculating the correlations between the different fear measures and the personality questionnaires.
(5). We did not have specific hypotheses about which personality trait will be most sensitive to fear generalization. The different personality traits have been distinguished in the literature, but it is unclear which trait most closely relates to fear overgeneralization. Therefore, this aspect of our study was exploratory. Significant correlations between conceptual fear overgeneralization and a specific personality questionnaire were planned to be followed up with additional multiple regression analyses to establish the specificity of the correlations over the shared variance with the other personality questionnaires (see below).

2. Method

2.1. Power analysis

An a priori power calculation was performed using G*power (Faul et al., 2007) to determine the required sample size for the crucial correlations between the amount of conceptual fear generalization and individuals differences in anxious traits. The alpha cut-off criteria was set at 0.017 (i.e., 0.05 divided by 3) to correct for multiple testing (i.e., three different fear measures to assess generalization). The power analysis indicated a required sample size of 120 to detect a medium effect size ($r = 0.3$) with a power of 0.90.

2.2. Participants

Inclusion criteria prior to the study were Dutch as first language; good (corrected) hearing and vision; no medication use which can impair attention, reaction time, memory, or concentration; no psychiatric disorder in the last two years; not being under treatment with a psychiatrist or psychologist currently or in the past two years; no pregnancy; and no current or past serious neurological or medical conditions (such as epilepsy or heart disease). In total, 131 participants took part in this study. Three of these participants did not complete the study and therefore had incomplete data. Additionally, the data of eight

participants were excluded for several different preregistered exclusion criteria (see below). Particularly, four participants were excluded because they were insufficiently certain about their answers to the contingency question (i.e., they indicated the correct CS+, but were either 'fairly uncertain' or 'very uncertain' about their answer). Moreover, two participants did not place the words in the correct order of size and were therefore excluded for the final analysis. Finally, data from two participants were removed from the analysis due to having insufficient physiological data quality. The final sample consisted of 120 participants (37 men and 83 women). The average age was 22.63 years (SD = 2.76).

Participants provided informed consent and received money (8 euros per hour) or course credits as incentives.

2.3. Design

The current study design is based on the generalization paradigm of Lissek et al. (2008). Instead of using different sizes of rings as stimuli, this study used words that differentially refer to 'size' (see Table 1). The experiment consisted of three phases: (1) Practice phase; (2) Acquisition phase; and (3) Generalization phase. In each phase, participants were exposed to two stimuli (i.e., the CS+ and CS-). In the generalization phase, participants also saw generalization stimuli (see below). The different phases followed each other consecutively within the same test session. The design of the experiment was completely within-subjects, except for the between-subjects factor 'counterbalancing'. See Fig. 1 for a schematic overview of the experiment.

2.4. Materials

2.4.1. Stimuli

Five words related to the concept size were used as conditioned stimuli (CS+ and CS-) and generalization stimuli (GSs; see Fig. 1). The most extreme words served as CS+ and CS-. Whether the word *enorm* or *mini* serves as CS+ was counterbalanced across participants. These stimuli were presented on a 21 in. computer screen (HP EliteDisplay E231) with a screen resolution of 1920 by 1080 pixels. The words were displayed in the middle of the screen with font style 'Arial' and font size 36.

2.4.2. Questionnaires

We used three commonly used questionnaires that measure personality traits that are thought to constitute risk factors for the development of anxiety disorders (Lonsdorf and Merz, 2017). Particularly, the State-Trait Anxiety Inventory, trait version (STAI-DY-2; Spielberger et al., 1983; Dutch version: van der Ploeg et al., 2000) was used to assess trait anxiety levels. The STAI consists of 20 items measuring state anxiety (STAI-S) and 20 items measuring trait anxiety (STAI-T). Responses were given on a 4-point Likert scale (1 = *Not at all/Almost never*, 4 = *Very much so/Almost always*). Furthermore, the intolerance of Uncertainty Scale (IUS, Dutch translation: de Bruin et al., 2006; original French version: Freeston et al., 1994) was used to assess emotional, cognitive, and behavioral reactions to ambiguous situations, implications of being uncertain, and attempts to control the future. The scale consists of 27 items that can be answered on a 5-point Likert (1 = *Not at all characteristic of me*, 5 = *Entirely characteristic of me*). Finally, behavioral inhibition was assessed with the behavioral inhibition subscale of the BIS/BAS Scales questionnaire (Carver and White, 1994; Dutch translation: Franken et al., 2005). This questionnaire consists of 24 questions that can be answered with four response options (1 = *strong agreement*, 2 = *slight agreement*, 3 = *slight disagreement*, 4 = *strong disagreement*), of which seven items constitute the behavioral inhibition subscale.

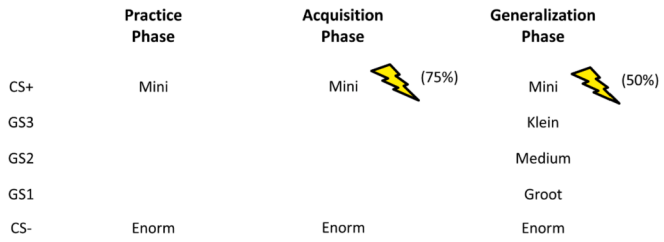

Fig. 1. Schematic overview of the design of the experiment. Allocation of the words *mini* [tiny] and *enorm* [enormous] was counterbalanced over participants. Note: CS- = conditioned stimulus never paired with shock; CS+ = conditioned stimulus occasionally paired with shock; GS = generalization stimulus.

2.4.3. Physiological apparatus

A 500 ms electric shock delivered to the dominant hand served as US, administered using a Digitimer DS7A device (see https://digitimer.com/). Participants determined the level of the shock such that it was not painful but highly uncomfortable (Mertens and De Houwer, 2016).

Skin conductance responses (SCRs) were measured using two BioSemi GSR electrodes (BioSemi, Amsterdam, the Netherlands) filled with conductive gel and attached on the non-dominant hand of the participant. Startle responses were measured using four BioSemi FLAT active electrodes filled with conductive gel. Two electrodes were attached under the left eye (orbicularis oculi muscle) and two on the forehead as ground electrodes. Startle was elicited by a 95 dB white noise probe for 50 ms.

2.4.4. US expectancy

The extent to which participants expect the US during a CS or GS was measured using an online (i.e., during CS/GS presentation) 9-point Likert scale (1 = *Definitely no shock*, 5 = *Uncertain*, 9 = *Definitely a shock*). The US expectancy scale was presented on the bottom of the screen. Participants had to click on a number with the mouse to lock their answer. They could only lock their answer once.

Table 1
Pearson's correlation between the Generalization Indexes for the different outcome measures and three measures of anxious traits (i.e., trait anxiety, intolerance of uncertainty and behavioral inhibition).

	Mean (SD)	GI_fear	GI_expec	GI_SCR	GI_FPS	STAI_T	IUS	BIS
GI_fear	0.27 (0.34)	–	0.60**	0.10	0.10	0.14	0.14	0.13
GI_expec	0.41 (0.18)		–	0.19*	0.11	0.01	0.00	−0.04
GI_SCR	0.75 (0.73)			–	0.05	−0.01	−0.05	0.06
GI_FPS	0.95 (0.07)				–	−0.01	−0.08	−0.12
STAI_T	35.01 (7.28)					–	0.56**	0.50**
IUS	62.82 (12.63)						–	0.85**
BIS	17.13 (4.00)							–

Note: GI = Generalization Index; expec = US expectancy ratings; SCR = Skin Conductance Responses; FPS = Fear Potentiated Startle; STAI_T = State Trait Anxiety Inventory – Trait version; IUS = Intolerance of Uncertainty scale; BIS = Behavioral Inhibition System.
* $p < .05$.
** $p < .001$.

2.5. Procedure

The conditioning and generalization task were programmed and presented using Inquisit (v4). Participants took place in a dimmed and soundproof room, 60 cm away from the computer screen. First, shock electrodes were attached and a shock workup procedure was completed (see Mertens and De Houwer, 2016). Electrodes measuring startle response and skin conductance, and headphones were attached. Participants started by filling in the questionnaires. Hereafter, participants were informed that they would see words appearing on the screen and that these could be followed by an electric stimulus. They were instructed that they should try to predict the electric stimulus. Next, participants continued with the Practice phase consisting of three trials consisting of random words to practice filling in the US expectancy Likert scale. No USs were presented in this phase. Following the Practice phase, participants were presented nine times with the startle probe with an inter-probe interval of 19, 21, or 23 s. After startle habituation, the experiment immediately started with the Acquisition phase. CSs were presented for 8 s in the middle of the computer screen. During CS presentation, participants filled in the US expectancy Likert scale. At 7 s post-CS onset a startle probe was presented. Six of the eight CS+ trials were immediately followed by the US (75% reinforcement schedule), while the CS- was never followed by the US. During an ITI trial, a startle probe was presented without the presentation of a stimulus. Inter-probe interval were maintained at 19, 21, or 23 s throughout the experiment. At the end of the Acquisition phase, participants were asked how anxious they felt about the CS+ and CS- (1 = *Not anxious*, 100 = *Very anxious*). The Generalization phase started after a 10-min break. During the Generalization phase, all CSs and GSs were also presented for 8 s and after 7 s the startle probe was presented. Four out of eight CS+ trials were immediately followed by the US (50% reinforcement schedule; see Lissek et al., 2008). The experiment ended with a manipulation check. To check whether participants interpreted the words as intended, they were asked to list the words used as CSs in increasing order. Furthermore, participants filled in four retrospective questions: (1) Which word predicted the electric shock?; (2) How certain are you about your answer? (1 = *completely certain*, 2 = *fairly certain*, 3 = *fairly uncertain*, 4 = *completely uncertain*); (3) How anxious do you feel about the word 'Enormous'? (1 = *Not anxious*, 100 = *Very anxious*); and (4) How anxious do you feel about the word 'Mini'? (1 = *Not anxious*, 100 = *Very anxious*). Participants were then debriefed and incentives given.

2.6. Data-analysis pipeline

2.6.1. Preprocessing steps

2.6.1.1. Data exclusions. Participants who did not learn the contingency were excluded from the analyses. This was checked by looking at the contingency question. Participants had to correctly state which word is followed by the electric shock and had to indicate that they are completely certain or fairly certain about their answer (Singh et al., 2013).

Furthermore, we checked whether participants perceived the gradient of the words used in the experiment as we intended. If they listed the word in any other order than: *mini*, *klein*, *medium*, *groot*, and *enorm*, their data was excluded from the analyses.

Finally, participants were excluded based on insufficient psychophysiological data quality. Psychophysiological data quality was first assessed based on visual inspection of the signal: Completely flat lines or highly noisy data usually indicates the disconnection of electrodes. The data from participants showing such artefacts was excluded. Additionally, data was excluded if participants do not show any discernible SCRs towards the US administration (no responses >0.02 μS; see below) or more than 50% unusable startle response datapoints (μV maximum peak in the response window < average μV baseline; see below).

Excluded participants were replaced by new participants to maintain the targeted sample size ($N = 120$). We did not exclude any participants based on their performance on the outcome measures (e.g., successful fear acquisition on SCRs/FPS/US expectancy ratings) because this can potentially lead to sample selection effects, which can attenuate correlations with inter-individual differences (Lonsdorf et al., 2017, 2019).

2.6.1.2. Generalization index (GI). A generalization index for each participant was calculated for the Generalization phase. For each participant, the average fear responses towards the three GSs was calculated and divided by the fear responses towards the CS+ (separately for US expectancy, startle responses and SCRs). This formula corrects for individual differences in initial response strength (Leer et al., 2018; Lenaert et al., 2016). Higher GI scores represent more generalization (i.e., '1' reflects full generalization; '0' reflects no generalization). This index was used to correlate the amount of conceptual fear generalization to the trait anxiety, IU, and behavioral inhibition scores of participants.

2.6.1.3. Skin conductance response. The skin conductance signal was first downsampled to 10 Hz using BrainVision Analyzer software (Brain Products, Munich, Germany). Responses were computed by subtracting the mean skin conductance response for the 2 s preceding CS onset from the highest value recorded during the full 7 s CS-US interval (Pineles et al., 2009). A response threshold of 0.02 μS was applied for the SCRs (Boucsein et al., 2012). Responses below this cut-off were replaced with 0. Each participant's SCR score was divided by its maximum response to minimize inter-individual variance (Boucsein et al., 2012). A square-root transformation was applied to normalize the distribution (Dawson et al., 2007).

2.6.1.4. Startle response. The electromyographic signal was filtered (28–500 Hz), rectified, and smoothed (15.9 Hz low-pass filter) using BrainVision Analyzer. Response amplitudes were computed as the difference between the maximum startle response within 21 to 150 ms after stimulus onset and the average startle response during baseline (−30 to 20 ms after stimulus onset). An individual range correction (a T-transformation) was applied by standardizing each blink amplitude using all scores for a given subject as the reference distribution (Blumenthal et al., 2005).

2.6.2. Planned analyses

2.6.2.1. Acquisition. A repeated measures ANOVA with within-subject factors Stimulus (CS+ vs CS-) and Trial (1 to 8) was performed on US expectancy ratings, startle responses, and SCRs. We expected a significant main effect of Stimulus and an interaction between Stimulus and Trial for all the different measures, indicating successful fear acquisition. Paired *t*-tests were performed on the first and last CS+ and CS- trials for all outcome measures to verify fear acquisition.

2.6.2.2. Generalization test. A repeated measures ANOVA with factor Stimulus (CS+, CS-, GS1, GS2, GS3) and Counterbalancing (*mini* or *enorm* as CS+) was performed on US expectancy ratings, startle responses, and SCRs. Only a main effect of Stimulus was expected for all outcome measures. Follow-up paired sample *t*-tests were performed to compare fear responses to CS- with GS1, GS2, GS3, and CS+.

2.6.2.3. Correlational analyses. The correlation between the GI and scores on the three questionnaires was assessed using correlation analyses (Pearson or Spearman, depending on the characteristics of distributions of the variables at hand).

2.6.2.4. Specificity analyses. Significant correlations between GI and the questionnaires were planned to be followed up using tests for specificity.

Particularly, multiple regression analyses were planned to investigate whether the relationship between GI and one of the questionnaires remains significant when controlling for the shared variance with the other questionnaires.

2.7. Timeline

The study plan for this Registered Report was publicly posted on the Open Science Framework on March 22, 2019 (https://psyarxiv.com/zwc2h/). Data collection took place between April 15, 2019 and August 6, 2021 (see the time stamps in the raw data files, which are available through the link below). This was substantially longer than the initially registered data collection period of three months. This delay compared to the original timeframe for the data collection was partly due to overly optimistic expectations regarding participant recruitment and partly due to the coronavirus disease 2019 (COVID-19) pandemic.

2.8. Registered report plan and data availability

The originally accepted Stage 1 Registered Report is available at the following permanent link: https://psyarxiv.com/zwc2h/. We report no deviations from this Registered Report. All raw and working data files are available through the following permanent link: https://osf.io/k36ba/, with the exception of the original data files for the psychophysiological data due to their size (i.e., approximately 150 GB). The latter data files can be obtained by contacting the first author.

3. Results

3.1. Acquisition results

3.1.1. Fear ratings

A paired-samples *t*-test on the fear ratings for the CS+ (M = 62.36, SD = 27.21) and CS- (M = 14.67, SD = 15.70) after acquisition indicated significantly higher fear ratings for the CS+ than for the CS-, $t(119) = 19.89$, $p < .001$ (see Fig. 2).

3.1.2. US expectancy ratings

Analysis of the US expectancy ratings indicated significant effects of Stimulus, $F(1, 119) = 709.28$, $p < .001$, $Eta^2_p = 0.86$, Trial, $F(5.28, 628.22) = 8.16$, $p < .001$, $Eta^2_p = 0.06$, and crucially of the interaction between Stimulus and Trial, $F(4.80, 571.31) = 67.58$, $p < .001$, $Eta^2_p = 0.36$. This interaction was due to significantly higher US expectancy ratings for CS+ (M = 7.85, SD = 1.48) than for CS- (M = 2.17, SD = 1.60) at the end of the acquisition phase, $t(119) = 26.85$, $p < .001$. In contrast, US expectancy ratings for the CS+ and CS- did not reliably differ at the beginning of the acquisition phase (CS+: M = 4.16, SD = 2.01; CS-: M = 4.47, SD = 2.13), $t(119) = -1.01$, $p = .312$ (see Fig. 2).

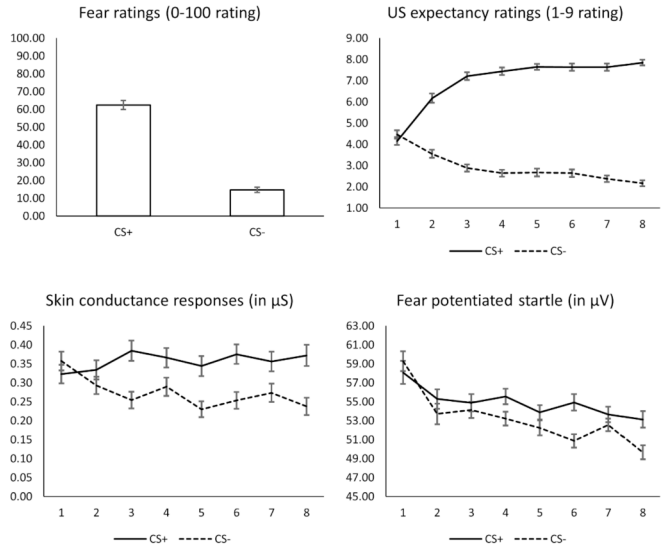

Fig. 2. Results for the different outcome measures for the acquisition phase. Note that skin conductance responses were range corrected and square root transformed. Startle values were T-transformed.

3.1.3. Skin conductance responses

Analysis of the SCRs during the acquisition phase indicated a significant effect of factor Stimulus $F(1, 119) = 65.46$, $p < .001$, $Eta^2_p = 0.36$. The main effect of factor Trial was not significant, $F(5.69, 676.67) = 1.11$, $p = .358$, $Eta^2_p = 0.01$. Crucially, the interaction between Stimulus and Trial was significant, $F(7, 833) = 4.30$, $p < .001$, $Eta^2_p = 0.04$. This interaction was due to significantly larger SCRs for CS+ (M = 0.37, SD = 0.30) than for CS- (M = 0.24, SD = 0.25) at the end of the acquisition phase, $t(119) = 4.65$, $p < .001$. In contrast, SCRs for the CS+ and CS- did not reliably differ at the beginning of the acquisition phase (CS+: M = 0.32, SD = 0.27; CS-: M = 0.36, SD = 0.27), $t(119) = -1.24$, $p = .219$ (see Fig. 2).

3.1.4. Fear potentiated startle

Analysis of the FPS magnitudes indicated significant effects of Stimulus, $F(1, 119) = 16.65$, $p < .001$, $Eta^2_p = 0.12$, and Trial, $F(5.89, 701.39) = 12.38$, $p < .001$, $Eta^2_p = 0.09$. However, in contrast to our hypothesis, the crucial interaction between Stimulus and Trial was not significant, $F(5.98, 711.67) = 1.79$, $p = .099$, $Eta^2_p = 0.02$. Due to our a priori expectations, we still carried out the planned follow-up *t*-tests, although these should be interpreted with care due to the non-significant interaction. Startle responses were significantly larger for CS+ (M = 53.13, SD = 9.46) than for CS- (M = 49.66, SD = 8.19) at the end of the acquisition phase, $t(119) = 2.90$, $p = .004$. In contrast, FPS magnitudes for the CS+ and CS- did not reliably differ at the beginning of the acquisition phase (CS+: M = 58.08, SD = 13.30; CS-: M = 59.28, SD = 11.35), $t(119) = -0.71$, $p = .478$ (see Fig. 2).

3.2. Generalization results

3.2.1. Fear ratings

Analysis of the fear ratings in the generalization phase showed a significant effect of factor Stimulus, $F(2.39, 282.48) = 252.50$, $p < .001$, $Eta^2_p = 0.68$, but not of Counterbalancing, $F(1, 118) = 2.41$, $p = .123$, $Eta^2_p = 0.02$. The interaction between Stimulus and Counterbalancing was also not significant, $F(2.39, 282.48) = 2.45$, $p = .078$, $Eta^2_p = 0.02$. Examining the main effect of Stimulus using follow-up *t*-tests, all fear ratings for the different stimuli differed significantly from each other, *t*-values ≥ 2.47, *p*-values $\leq .015$. The pattern of results showed a clear generalization gradient (see Fig. 3).

3.2.2. US expectancy ratings

Analysis of the US expectancy ratings in the generalization phase showed a significant effect of factor Stimulus, $F(2.40, 283.09) = 632.57$, $p < .001$, $Eta^2_p = 0.84$, but not of Counterbalancing, $F(1, 118) = 1.98$, $p = .162$, $Eta^2_p = 0.02$. The interaction between Stimulus and Counterbalancing was significant, $F(2.40, 283.09) = 16.98$, $p < .001$, $Eta^2_p = 0.13$. This interaction was due to stronger generalization to the GS3 and GS2 in the counterbalancing condition in which *enorm* functioned as the CS+, *F*-values >5.6, *p*-values < .02. When collapsed across counterbalancing conditions, all US expectancy ratings for the different stimuli differed significantly from each other, *t*-values ≥ 7.09, *p*-values < .001. The pattern of results showed a clear generalization gradient (see Fig. 3).

3.2.3. Skin conductance responses

Analysis of the SCRs in the generalization phase showed a significant effect of factor Stimulus, $F(2.83, 334.45) = 55.67$, $p < .001$, $Eta^2_p = 0.32$, but not of Counterbalancing, $F(1, 118) = 2.75$, $p = .100$, $Eta^2_p =$

0.02. The interaction between Stimulus and Counterbalancing was not significant, $F(2.83, 334.45) = 0.50$, $p = .672$, $Eta^2_p = 0.00$. Examining the main effect of Stimulus using follow-up *t*-tests, the SCRs towards the CS+ were significantly stronger than towards all other stimulus types, *t*-values ≥8.8, *p*-values < .001. In addition, the GS3 elicited stronger SCRs than the GS2, GS1 and CS-, *t*-values ≥3.1, *p*-values ≤ .003. SCRs for the other stimulus types (i.e., GS2, GS1 and CS-) did not differ significantly from each other, *t*-values <1.4, *p*-values > .19. These results provide evidence for a fear generalization pattern (see also Fig. 3), although generalization is limited to GS3 and does not extend to GS2 and GS1.

3.2.4. Fear potentiated startle

Analysis of the FPS magnitudes in the generalization phase showed a significant effect of factor Stimulus, $F(3.56, 420.10) = 21.38$, $p < .001$, $Eta^2_p = 0.15$ and of Counterbalancing, $F(1, 118) = 4.93$, $p = .028$, $Eta^2_p = 0.04$. The interaction between Stimulus and Counterbalancing was not significant, $F(3.56, 420.10) = 1.54$, $p = .197$, $Eta^2_p = 0.01$. The main effect of Counterbalancing was due to overall slightly higher FPS responses to all stimuli when *enorm* was the CS+ compared to when *mini* was the CS+ (see Fig. 2). The main effect of Stimulus was further examined using follow-up *t*-tests. The FPS magnitudes towards the CS+ were significantly stronger than towards all other stimulus types, *t*-values >5.8, *p*-values < .001. In addition, the GS3 elicited stronger FPS magnitudes than the CS-, $t(119) = 2.20$, $p = .029$. None of the other direct comparisons was significant, *t*-values <1.7, *p*-values >.09. These results provide evidence for a fear generalization pattern for FPS as well (see also Fig. 3), although also for this physiological measure generalization is limited to GS3 and does not extend to GS2 and GS1 (Fig. 3).

3.3. Correlations between the generalization indexes and anxious traits

A GI was calculated for each of the outcome measures by averaging the responses towards the GSs and dividing this by the response to the CS+ (see above). These GI's were then correlated with one another and each of the anxious traits (i.e., trait anxiety, intolerance of uncertainty, and behavioral inhibition). The results of these analyses are shown in Table 1. Note that, due to zero ratings or physiological responses towards the CS+ during the generalization phase, no GI could be calculated for one participant for the fear ratings and for seven participants for the SCRs (i.e., the average of the GSs could not be divided by the response to the CS+ when this value is zero). As such, the correlations with these two variables are based on a slightly smaller sample (i.e., 119 participants for fear ratings and 113 participants for SCR).

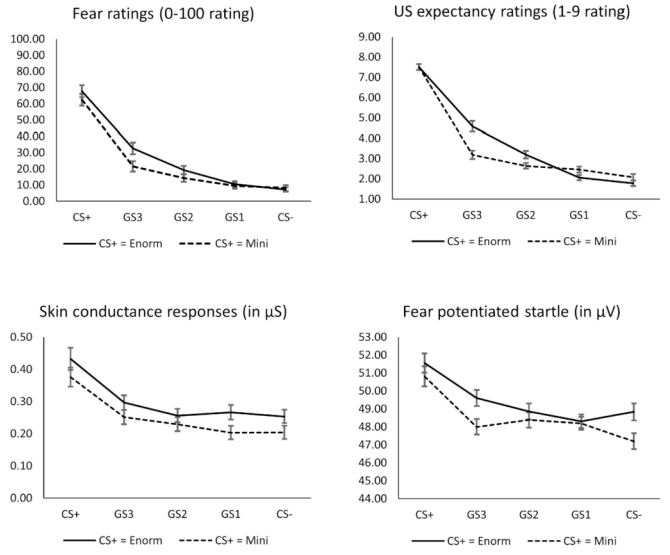

Fig. 3. Results for the different outcome measures for the generalization phase. The different lines refer to the counterbalancing of the CS+ (i.e., "enormous" functioning as the CS+, n = 57; or "mini" functioning as the CS+, n = 63). Note that skin conductance responses were range corrected and square root transformed. Startle values were T-transformed.

As can be seen in Table 1, the GI's for fear ratings and the US expectancy ratings correlated significantly. Likewise, the GI's for US expectancy ratings and SCRs correlated significantly. Furthermore, the different anxious traits correlated strongly with one another. However, in contrast to our hypotheses, none of the correlations between the GI's and the anxious traits were significant and overall the correlations were small (i.e., all below r = |0.15|). Given that there were no significant correlations between the GI's and the anxious traits, no follow-up specificity analyses were performed.

3.4. Exploratory analyses: using alternative ways to operationalize generalization

One possible reason for the lack of correlations between the generalization gradients and anxious traits may be the specific way in which we calculated the gradients. Particularly, it may be that the relevant variance to discriminate high and low anxious individuals is limited to one particular GS (i.e., GS3, given that generalization is most pronounced for this GS; see Fig. 2). Furthermore, it may also be the case that normalizing generalization relative to the CS+ takes away crucial variance to distinguish high and low anxious individuals. To address these issues, we exploratively operationalized generalization in several different ways and correlated these generalization indexes with the anxious traits. Particularly, we operationalized generalization as: (1) Fear responses to the GS3; (2) Fear responses to the GS3 divided by responses to the CS+; (3) The average fear response towards all the GSs, without any further transformation; and (4) The average fear response towards all the GSs divided by responses to the CS-. However, regardless of how we operationalized generalization, we did not find any significant correlations and all correlation were consistently smaller than r = |0.20|.

4. Discussion

In this study, we investigated conceptual fear generalization gradients in a fear conditioning paradigm. While most prior studies on fear generalization have focused on perceptual generalization, more recent studies have also shown that fear can generalize according to conceptual relationships (Dunsmoor et al., 2011; Dunsmoor and Murphy, 2014). In the current study, we extended this work by showing that fear generalization *gradients* can be obtained according to conceptual relatedness. We demonstrated the presence of such gradients with several different outcome measures (i.e., fear ratings, US expectancy ratings, SCR and FPS). In addition, we examined the relationship of these gradients with anxious traits. However, in contrast to our expectations, none of the anxious traits correlated significantly with conceptual fear generalization gradients. We discuss the relevance of our findings in detail below.

Regarding conceptual fear generalization gradients, this study is one of the first to actually show them. Prior work has established that fear can generalize along conceptual relatedness (Dunsmoor and Murphy, 2014). However, no previous study has shown that this generalization follows a linear gradient according to conceptual similarity (i.e., size in this case). Hence, the current work shows that generalization gradients can be investigated using conceptually related stimuli. This also implies that generalization gradients are not necessarily the result of perceptual errors. That is, when using visually related stimuli as GSs, a popular theory for explaining fear generalization gradients proposes that participants make perceptual errors and mistakenly perceive a GS as the CS+, particularly for those GSs most similar to the CS+ (e.g., Struyf et al., 2017). The current work shows that such perceptual errors are not needed for fear generalization gradients, given that our stimuli (words) did not have a gradient of perceptual similarity with each other and thus

were unlikely misperceived as the CS+. Instead, it is conceivable that participants spontaneously infer that the probability of receiving a shock is dependent on the conceptual relatedness of the stimuli to the CS+ (e.g., participants' reason that it is more likely that *groot* will be followed by an electric shock than *klein* when *enorm* is being paired with an electric shock, and vice versa when *mini* is being paired with the electric shock). This interpretation fits well with the inferential reasoning explanation for fear generalization (Wong and Lovibond, 2017).

Another interesting finding is that we observed that generalization tended to differ slightly depending on which word functioned as the CS+. Particularly, overall startle responses and US expectancy ratings towards GS3 and GS2 were slightly higher when the CS+ was '*enormous*' rather than '*tiny*'. A possible interpretation is that fear responses and generalization are more pronounced when the CS+ refers to a large size compared to when it refers to a smaller size, possibly because large physical size is evolutionary related to greater potential threat and therefore tends to evokes stronger fear responses (Öhman and Mineka, 2001). However, this is currently only a speculative interpretation and the statistical pattern was quite subtle and inconsistent across outcome measures, so this finding requires further replication.

With regard to the correlations between the anxious traits and the fear generalization gradients, we unexpectedly found that there were no significant relationships between any of the traits and the generalization gradients of the different outcome measures. This is surprising, given that fear generalization is thought to be an important process explaining excessive fear and anxiety disorders. As such, it was expected that anxious traits (which are also related to anxiety disorders) would correlate positively with the fear generalization gradients. There are at least three potential explanation for the lack of correlations between anxious traits and fear generalization gradients in the current study. First, the correlation between anxious traits and fear generalization may be weaker than commonly assumed. Indeed, several studies in the literature have failed to find the expected correlations between anxious traits and fear generalization (Tinoco-González et al., 2015; Torrents-Rodas et al., 2013), although other studies did report the expected correlations (e.g., Morriss et al., 2021; Wong and Lovibond, 2018). Thus, it may be that the correlations between anxious traits and fear generalization are weaker than commonly assumed or even non-existing (for a recent meta-analysis see Sep et al., 2019). Second, perhaps our sample did not vary sufficiently in anxious traits. It consisted of healthy university students, so perhaps the range in anxious traits was not sufficient to uncover the correlations with fear generalization. Indeed, we excluded participants who suffered from psychiatric disorders (including anxiety disorders) and those who visited a psychologist or psychiatrist. Nonetheless, the STAI-T and IUS scores in the current sample were comparable to previous studies reporting a significant correlation between these questionnaires and fear generalization (Bauer et al., 2020; Dunsmoor et al., 2011; Morriss et al., 2016). Third and final, perhaps there paradigm does not elicit sufficiently varied fear responses. Particularly, our study may constitute a "strong situation", meaning that it elicits a uniform response pattern across participants (Beckers et al., 2013; Lissek et al., 2006). If all participants react the same within the study, there is insufficient variation to uncover significant correlations. This explanation seems rather unlikely given that we observed clear generalization gradients for the different outcome measures, suggesting that the generalization phase was quite ambiguous for the participants. On the other hand, for the physiological measures generalization was only reliably observed for GS3 and not for the other GSs. This may indicate that only the GS3 was truly ambiguous for the participants. Nonetheless, even when calculating the correlations only with fear responses towards the GS3, or using several other operationalization of generalization, we did not find the expected correlations. Possibly, some combination of the above-mentioned issues may have weakened the correlations between generalization and anxious traits and may therefore account for the absence of significant correlations in the current study. These issues can be addressed in future studies, for instance by examining conceptual fear generalization gradients in healthy and anxiety patient populations in order to increase the variance in anxious traits.

As limitations, it can be mentioned that our sample was quite young and homogeneous, thereby limiting the generalizability of findings. Furthermore, we were unable to calculate GI's for fear ratings and SCRs for a small number of participants, leading to some loss of statistical power for these analyses (although the statistical power for all correlations remained >0.88). Finally, the COVID-19 pandemic possibly influenced the sample size constellation. Particularly, it seems that participants in the current study were somewhat less anxious than in comparable previous studies, possibly because only less anxious participants came to the university to participate in studies during the COVID-19 pandemic. For comparison, students in a recent comparable pre-pandemic study had STAI-T scores that were ~ 6 points higher on average than in the current study (Mertens et al., 2021). Thus, the COVID-19 pandemic may have led to some sample selection bias. However, as mentioned previously, it is worth noting that the mean and range of scores for the STAI-T and IUS were comparable to previous related studies that did find significant correlations between fear generalization and anxious traits (Bauer et al., 2020; Dunsmoor et al., 2011; Morriss et al., 2016).

As strengths, it can be mentioned that this work was carried out as a Registered Report, meaning that our materials and procedures were in place and peer-reviewed prior to conducting the study, thereby limiting researcher's degrees of freedom (Chambers, 2013). Furthermore, the journal committed to publishing the results regardless of the outcome, thereby countering publication bias against non-significant findings. Additionally, our sample was quite large and sufficiently powered to detect medium sized ($r = 0.30$) correlations. Finally, conceptual fear generalization was assessed with multiple response systems (i.e., self-report, physiological), thereby ensuring generalization of our findings across response systems and limiting potential experimental demand effects.

In conclusion, the current study investigated conceptual fear generalization gradients using words referring to different sizes as conditioned stimuli. As hypothesized, we found conceptual fear generalization gradients using different outcome measures (i.e., fear ratings, US expectancy ratings, SCR and FPS). However, unexpectedly, we found no significant correlations between the fear generalization gradients and anxious traits (i.e., trait anxiety, intolerance of uncertainty, and behavioral inhibition). Future studies can use and adapt the paradigm we developed here to further study conceptual fear generalization gradients.

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