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Author(s): Wang, Jinxia; E, Mei; Wu, Qi; Xie, Tao; Dou, Haoran; Lei, Yi

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Influence of Perceptual and Conceptual Information on Fear Generalization:

A Behavioral and Event-Related Potential Study

Jinxia Wang^{a,b,c}, Mei E^a, Qi Wu^a, Tao Xie^a, Haoran Dou^{a,b,c}, Yi Lei^{a,d,*}

^aInstitute of Brain and Psychological Sciences, Sichuan Normal University, Chengdu 610066, China

^bSchool of Psychology, Shenzhen University, Shenzhen 518060, China

^cFaculty of Education and Psychology, University of Jyväskylä, Jyväskylä, Finland

^dShenzhen Institute of Neuroscience, Shenzhen 518060, China

*Corresponding author:

Dr. Li Yei

Institute of Brain and Psychological Sciences

Sichuan Normal University

No. 5, Jing' an Road, Jinjiang District, Chengdu, 610066

Tel: +86 19130658312; E-mail: leiyi821@vip.sina.com

19 **Abstract**

20 Learned fear can be generalized through both perceptual and conceptual information. This
21 study investigated how perceptual and conceptual similarities influence this generalization
22 process. Twenty-three healthy volunteers completed a fear-generalization test as brain activity
23 was recorded in the form of event-related potentials (ERPs). Participants were exposed to a
24 *de novo* fear acquisition paradigm with four categories of conditioned stimuli (CS), two being
25 conceptual cues (animals and furniture) and two being perceptual cues (blue and purple
26 shapes). Animals (C+) and purple shapes (P+) were paired with the unconditioned stimulus
27 (US), while furniture (C-) and blue shapes (P-) never were. The generalized stimuli were
28 thus blue animals (C+P+, determined danger), blue furniture (C-P+, perceptual danger),
29 purple animals (C+P-, conceptual danger), and purple furniture (C-P-, determined safe). We
30 found that perceptual cues elicited larger fear responses and shorter reaction times than did
31 conceptual cues during fear acquisition. This suggests that a perceptually related pathway
32 might evoke greater fear than a conceptually based route. During generalization, participants
33 were more afraid of C+ exemplars than of C- exemplars. Further, C+ trials elicited greater
34 N400 amplitudes. Thus, participants appear able to use conceptually based cues to infer the
35 value of the current stimuli. Additionally, compared with C+ exemplars, we found an
36 enhanced late positive potential effect in response to C- exemplars, which seems to reflect a
37 late inhibitory process and might index safety learning. These findings may offer new
38 insights into the pathological mechanism of anxiety disorders.

39

40 **Keywords:** conceptual-based fear generalization, learning, ERP, conditioning

41 **Introduction**

42 Fear generalization is an evolutionarily adaptive mechanism in which individuals quickly
43 respond to potential threats based on learned experience (Lange et al., 2017). However, when
44 individuals exhibit excessive fear responses to similar but safe stimuli, fear generalization can
45 be maladaptive, a phenomenon termed overgeneralization (Tsafrir et al., 2013). Previous
46 studies have demonstrated that overgeneralization underlies the pathogenesis of emotional
47 disorders such as anxiety and post-traumatic stress disorder (PTSD) (Lissek, 2012;
48 Kaczurkin & Burton, 2017), and can severely affect an individual's daily life, as per the
49 phrase "once bitten, twice shy" (Lei et al., 2019). Clinically, exposure therapy encourages
50 patients to approach perceived threats in efforts to learn that the fearful stimuli are not
51 actually associated with the anticipated danger (Raij & Nummenmaa, 2018). However,
52 overgeneralization may increase excessive avoidance behavior and adversely affect the
53 effects of exposure therapy (van Meurs & Wiggert, 2014).

54 Experimental models of fear conditioning are commonly composed of fear acquisition,
55 generalization, extinction, and return of fear (Lonsdorf et al., 2017). In fear acquisition, a
56 conditioned stimulus (CS) (such as a 500-Hz tone, CS+) is repeatedly presented with an
57 unconditioned stimulus (US, such as an electric shock). The CS+ alone can subsequently
58 elicit the fear response. In the generalization test, a series of generalized stimuli (GS, such as
59 200–1000-Hz tones) would also elicit fear (Norrholm et al., 2014). Thus, fear can be
60 generalized via similarities between stimuli. Stimulus generalization has been hypothesized
61 to be a categorization outcome based on perceptual (primary) or conceptual (secondary)
62 similarity (Leventhal, 1968). Primary stimulus generalization thus occurs when the

63 generalized stimuli are physically similar to the originally learned stimuli, while secondary
64 stimulus generalization occurs when they are conceptually similar. Additionally, research on
65 fear generalization is divided into two areas: perceptually based fear generalization and
66 category-based fear generalization (Dunsmoor & Murphy, 2015).

67 Perceptually based fear generalization typically employs simple sensory stimuli that
68 vary in physical dimensions. The GS and CS will thus have physical features that are similar,
69 but differ in one aspect, such as light that differs in color (Raij & Nummenmaa, 2018), circles
70 that differ in size (Hunt & Cooper, 2017), or tones that differ in frequency (Resnik & Sobel,
71 2011). In conceptually based fear generalization, the similarity between the GS and CS is
72 conceptual. For instance, if the word “help” (CS) is paired with an electric shock (US) in the
73 acquisition phase, the word “assist” (GS), which is synonymous with “help”, would also elicit
74 fear responses in the generalization test (Boyle & Roche, 2015). Similarly, if the “animal”
75 category appears with the US, presentation of different animals can also lead to fear
76 responses during the generalization test (Dunsmoor & Murty, 2015). Previous research on
77 fear generalization has ignored conceptual factors in percept-based fear generalization.
78 However, classifying fear generalization according to perceptual or conceptual similarities is
79 difficult in real life because both factors operate concurrently to promote the generalization of
80 fear. For example, patients who are afraid of Tibetan mastiffs are not only afraid of physically
81 similar dogs, but are also afraid of a series of dog-like and dog chain-related stimuli (Bennett
82 & Vervoort, 2015).

83 The fear response of patients with arachnophobia can be activated by specific perceptual
84 cues or conceptual information related to spiders. In Peperkorn et al. (2014), patients with

85 arachnophobia and healthy participants were randomly assigned to a fear-relevant perceptual
86 cue condition, a fear-relevant information condition, or a congruent combination of both.
87 They found that the combined cues elicited the greatest fear response, followed by the
88 perceptual cues alone, and lastly the conceptual cues. Perceptual cues play a crucial role in
89 the treatment of phobias (Phan & Wager, 2002). c examined whether the arachnophobia
90 results applied to spatial phobias such as claustrophobia. Although both conditions are
91 phobias (one of spiders, the other of an environment), they are essentially different (Hofmann
92 et al., 2009; Loken et al., 2014). Shiban et al. (2016) found that, as in Peperkorn et al. (2014),
93 individuals exhibited greater fear in response to perceptual cues alone than to conceptual cues
94 alone. However, combining conceptual and perceptual cues did not result in a significant
95 increase in fear response. Thus, for spatial phobias, simply presenting a perceptual cue can
96 trigger a sufficiently strong fear response.

97 The weight that these two types of information have in the generalization process is not
98 yet clear. Nor is how perceptual and conceptual cues work together to activate the brain's fear
99 network to promote the generalization of fear. One possibility is that participants are more
100 inclined to make decisions based on conceptual characteristics because they might focus on
101 the internal characteristics of the stimuli. Here, we tested this hypothesis by examining
102 behavior and brain activity in the form of event-related potentials (ERPs). Several ERPs have
103 already been associated with fear learning. For example, compared with neutral stimuli,
104 threatening and emotional stimuli have been shown to elicit an enhanced early P1 amplitude
105 (Gupta, Kujawa, & Vago, 2019). Other related ERPs include early posterior negativity (EPN)
106 and late positive potential (LPP). EPN is distributed over the parieto-temporo-occipital

107 regions, and typically emerges around 150–300 ms after stimulus onset (Schupp et al., 2006).
108 In contrast, LPP is usually observed around 400 ms after stimulus onset with an
109 occipito-parietal and central scalp distribution (Schupp et al., 2000; Hajcak et al., 2010;
110 Desatnik et al. 2017). EPN and LPP are generally considered to reflect selective attentional
111 orientation toward emotional stimuli (Schupp et al., 2004; Schupp et al., 2006). Studies have
112 demonstrated that LPP is modulated by the degree to which observed stimuli are arousing
113 (e.g., salient pictures; positive or negative) and that enhanced LPP might reflect downstream
114 feedback from the amygdala to the visual cortical areas (de Rover et al., 2012). Studies of
115 time dynamics in fear conditioning have demonstrated that compared to the CS–, the CS+
116 elicited enhanced EPN and LPP during the fear-association phase (Ferreira de Sá et al., 2019).
117 The increased EPN indicates that newly learned fear can automatically capture attention and
118 the enhanced LPP suggests elaborative processing of salient stimuli. Since its discovery in
119 1980, the N400 component of electroencephalograms (EEGs) has become a hallmark of
120 cognitive studies in the fields of language processing, object and facial recognition, actions,
121 gestures, mathematics, and semantic and recognition memory, as well as a wide range of
122 developmental or acquired disorders. Kutas et al. (1980) examined N400 amplitudes using an
123 oddball paradigm in which they presented a series of consistent statements (e.g., “I just
124 shaved my beard”) interspersed with infrequently occurring inconsistent statements (e.g., “He
125 planted beans in the car”). They found that inconsistent statements led to larger N400
126 amplitudes. In addition, emotional words have also been shown to elicit larger N400
127 amplitudes, indicating that N400 potentials can be modulated by the emotional content of
128 stimuli (Kanske et al., 2011). However, P1, EPN, N400, and LPP responses have not been

129 examined as a means to explore the fear-generalization process with concurrent perceptual
130 and conceptual cues.

131 This study aimed to examine how perceptual and conceptual cues simultaneously affect
132 the degree to which people feel that a stimulus is dangerous, and to evaluate the time course
133 of this process. We used a novel paradigm to evaluate the influence that the threat and safety
134 values of perceptual and conceptual information have on an individual's fear response. The
135 conditioning phase had a 2×2 experimental design: stimulus type (conceptual, perceptual) \times
136 conditioning type (CS+, CS-). Specifically, four types of stimuli were used. The conceptual
137 cues were animals and furniture were, with animals paired with the US (C+) and furniture
138 never paired with the US (C-). The perceptual cues were randomly colored blue and purple
139 shapes, with purple paired with the US (P+) and blue never paired with the US (P-). We
140 hypothesized that the US-expectancy ratings and the mean response time (RT) in the
141 acquisition phase would be significantly greater for CS+ conditions than for CS- conditions.
142 According to Peperkorn et al. (2014), we also predicted that US-expectancy ratings would be
143 significantly larger for the C+ stimuli than for the P+ exemplars. From a learning perspective,
144 category learning involves more elaborate processing; thus, we expected conceptual cues to
145 have longer RTs than perceptual cues.

146 In the generalization phase, we measured fear responses using US expectancy, RT, and
147 ERP magnitudes. The four kinds of CS (C+, C-, P+, and P-) were fully crossed to create four
148 types of generalized stimuli: purple animals (C+P+, determined danger), purple furniture
149 (C-P+, perceptual danger), blue animals (C+P-, conceptual danger), and blue furniture
150 (C-P-, determined safe). Behaviorally, we hypothesized that individuals would be more

151 inclined to infer the attributes of the stimulus based on conceptual cues. Specifically, the
152 US-expectancy ratings and RTs for the C+P+ and C+P- conditions would be significantly
153 greater than those for the C-P+ and C-P- conditions. In terms of brain activity, based on
154 previous studies, we hypothesized that perceptually related threat cues would evoke an early
155 attentional bias characterized by two ERP components, P1 and EPN. Additionally, we
156 expected to see the largest N400 responses for the C+P- and C-P+ conditions, when stimulus
157 attributes were inconsistent. N400 is a crucial EEG indicator that reflects the brain's
158 higher-order cognitive processes (Chwilla et al., 1995). We expected that conceptual threat
159 cues (C+P+, C+P-) would elicit larger N400 and LPP potentials than would the C-P+ or
160 C-P- cues. Finally, we expected LPP amplitude to be modulated by perceptually threatening
161 characteristics when the conceptual information was a safety signal.

162

163 **Materials and Methods**

164 *Participants*

165 We performed a power analysis before data collection. The *a priori* calculation of statistical
166 power (G*Power) suggested that the recruitment target of 24 participants would achieve a
167 medium effect size of 0.25, with an alpha level of 0.05, and a 1-beta level of 0.80 (Hendrikx
168 et al., 2021; Faul et al., 2007). The sample we recruited (N = 27) was large enough to detect
169 an effect at the given significance level ($\alpha = 0.05$). The number of repeated measures was 4,
170 the assumed sphericity correction was 1, and the repeated-measures correlation for the power
171 analyses was 0.5. One participant was excluded due to unsuccessful fear acquisition (i.e., the
172 US-expectancy ratings for the CS+ were smaller than those for the CS-), and three other

173 participants were excluded due to artefacts in the EEG signal. Thus, the current study
174 included 23 volunteers (12 women) between the ages of 18 and 25 years. All participants
175 were right-handed, had normal or corrected-to-normal eyesight, and were without
176 neurological or psychological disorders. All participants provided written informed consent
177 and received monetary compensation. The investigation was approved by the Medicine
178 Ethics Committee of Shenzhen University.

179

180 *CS and GS*

181 Animals and furniture were selected as target conceptual categories to ensure familiarity, as
182 these two types of objects are common in daily life. We then selected images from a database
183 (<http://www.iconfont.cn>) that corresponded to the 50 most frequently listed animals and
184 altered the colors (20 black and white, 15 blue, and 15 purple). We did the same for the 50
185 most frequently listed furniture. Next, using an online questionnaire method (questionnaire
186 star), 45 college students were asked to evaluate the valence and arousal of these stimuli on a
187 scale of 1 to 9 (1: extremely unpleasant/extremely calm or relaxed; 9: extremely
188 pleasant/extremely excited). We then selected 12 neutral black and white animals and
189 furniture pictures as the CSs 10 each of neutral blue animals, blue furniture, purple animals,
190 and purple furniture pictures as the GSs. Independent sample t-tests revealed no significant
191 difference in valence between the furniture ($M = 5.33$, $SD = 0.34$) and animals ($M = 5.24$, SD
192 $= 0.52$; $p = 0.356$) and no significant difference in arousal (furniture: $M = 5.24$, $SD = 0.18$;
193 animals: $M = 5.15$, $SD = 0.23$; $p = 0.09$). All pictures of animals and furniture were different,
194 and each CS or GS was a different basic-level exemplar of the categories (Keller &

195 Dunsmoor, 2019). We generated the perceptual cues using Adobe Photoshop and the shapes
196 were all different (e.g., different shapes of clouds). Thus, all images were different during
197 both the acquisition phase and the generalization phase.

198

199 *US*

200 Electric shock combined with fearful images served as the US. Fear images were selected
201 from the fear picture system created by Yi et al. (2019). We applied a calibration procedure to
202 set the intensity of electrical stimulation according to each participant's electrical fear
203 thresholds. An Ag/AgCl electrode was attached to the left wrist of the participant and
204 connected to a constant current stimulator (SXC-4A, Sanxia Technique Inc., China). Weak
205 current stimulation was delivered to the wrist through the pair of electrodes. Participants
206 received a series of electrical stimulations of different intensities (100 ms duration; starting at
207 250 μ A and increasing in 50 μ A steps), and were required to rate the intensity of each
208 stimulation on a verbal analog scale, where 1 indicated not unpleasant/painful/annoying and
209 10 indicated very unpleasant/painful/annoying. The magnitude of the stimulation intensity
210 was set to the level which obtained a rating of 7 from the participant, which corresponded to a
211 feeling of aversiveness (very unpleasant, but not painful) (Haaker et al., 2013).

212 For the fearful pictures, we first asked 115 participants (54 women; mean age, 21.92
213 years; SD, 1.43) to provide as many fear-inducing nouns as possible (e.g., snake) through a
214 free-association task. We then selected the 90 most frequently given nouns from the image
215 database and classified them into three categories (animals, scenes, and objects) with 30
216 images in each category. Then, we enrolled 84 participants (39 men; mean age, 20.55 years;

217 SD, 1.43) to rate each image in terms of fear, valence, and arousal on a 9-point scale. Finally,
218 a total of 81 fear-evoking pictures were chosen. The mean ratings were 4.80 ± 1.06 ($M \pm SD$)
219 for fear, 3.57 ± 0.16 for valence, and 6.16 ± 0.58 for arousal. For the current study, we
220 selected 20 stimuli among these 81 as the fearful USs.

221

222 *Procedure*

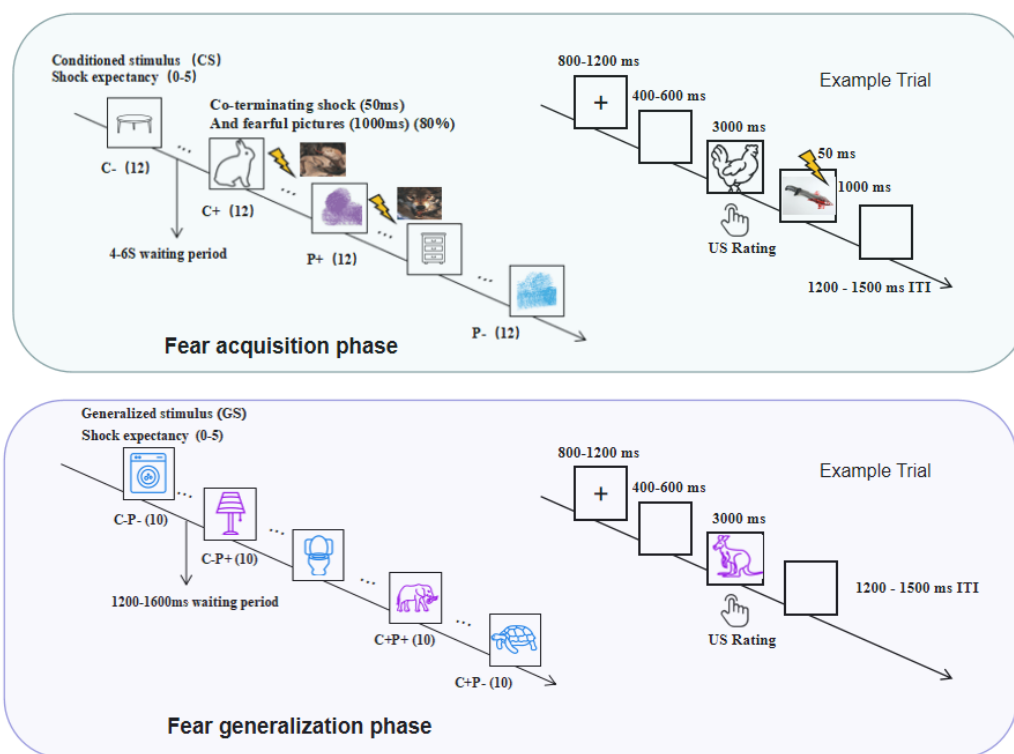
223 Experimental stimuli were presented by E-Prime (version 3.0), and the background of the
224 computer during the experiment was gray. The experimental procedure comprised a
225 fear-acquisition phase and generalization test (Fig. 1). Previous studies have demonstrated
226 that giving explicit instructions to participants regarding threat association (i.e., the CS-US
227 contingency) before the experiment leads to stronger fear acquisition and extinction and
228 prevents overgeneralization (Duits et al., 2017). In the present study, we did not provide
229 direct instructions to the participants. Before the fear-acquisition phase, participants were
230 instructed to learn the association between the pictures and the US. In the acquisition phase,
231 the computer screen randomly presented two types of pictures: “perceptual” or “conceptual.”
232 The number of trials in the acquisition phase was 60 (30 perceptual and 30 conceptual). The
233 perceptual trials included 15 blue images and 15 purple images, whereas the conceptual
234 pictures included 15 animal images and 15 furniture images (all were different from each
235 other). The CS+ (i.e., “animals, C+”; “purple, P+”) was paired with the US with an 80%
236 reinforcement schedule (12/15), whereas the CS- (i.e., “furniture, C-”; “blue, P-”) was
237 never paired with a US. Moreover, the assignment of CS+ and CS- was counterbalanced; i.e.,
238 “animals” and “purple” served as the CS+ for half of the participants, whereas “furniture”

239 and “blue” were defined as the CS+ for the other 14 participants.

240 The generalization test comprised four types of GS: purple animals (C+P+, determined
241 danger), purple furniture (C–P+, perceptual danger), blue animals (C+P–, conceptual danger),
242 and blue furniture (C–P–, determined safe). Each condition contained 10 different GSs, and
243 each stimulus was presented 5 times. Hence, each condition included 50 trials. To prevent the
244 extinction effect in the generalization process, the CS+ and CS– (i.e., the stimuli presented
245 during acquisition, C+, C–, P+, and P–) were each presented 10 times, and the CS+ was
246 followed by the US at an 80% reinforcement rate (Dunsmoor & Murphy, 2014). Thus, the
247 total number of generalization trials was 240.

248 In both the conditioning and generalization phases, trials began when a fixation point
249 appeared in the center of the screen, lasting 800–1200 ms. After a blank screen was presented
250 for a random duration between 400–600 ms, a stimulus was presented pseudorandomly with a
251 3000-ms duration. The same stimulus did not occur consecutively. During the 3000 ms,
252 participants were asked to rate the possibility of receiving the US (the electric shock
253 combined with the fearful picture) using a five–alternative forced–choice scale (a US
254 expectancy of 1–5; 1, impossible; 3, moderate; and 5, very likely). They were instructed to
255 press the corresponding number key with their right hand within 3000 ms. When an original
256 CS+ was presented during the acquisition and generalization phase, the electric shock and
257 fearful image followed together (on 80% of trials) after the 3000-ms period. The shock lasted
258 50 ms and the image lasted 1000 ms. The inter–trial interval (ITI) for both phases was
259 1200–1500 ms.

260



271

272 Figure 1. Experimental procedure for fear acquisition and the generalization test. (1)

273 Acquisition phase: participants viewed conceptual and perceptual images for 3 s and were

274 asked to use a 5-point scale to rate the possibility of receiving the US. The CS+ was followed

275 by a 50–ms shock and a 1000–ms fearful image (12 of 15 trials). The CS– was never paired

276 with the US. The intertrial interval (ITI) was 1200–1500 ms. (2) Generalization test: four

277 kinds of GS were pseudorandomly presented. Each category contained 10 different stimuli

278 which were each presented 5 times.

279

280 *ERP recordings and data pre-processing*

281 Continuous EEGs were recorded with a 64-channel Brain Products system (Brain Products

282 GmbH, Munich, Germany; passband, 0.05–100 Hz; sampling rate, 500 Hz) using a standard

283 10-20 acquisition system EEG cap. The ground electrode was located on the medial frontal
284 line, with the left and right mastoids as reference electrodes during recording. Vertical
285 electrooculograms (vEOGs) were recorded via facial electrodes located above and below the
286 left eye. Horizontal EOG (hEOG) electrodes were attached at the outer canthi of the eyes.
287 The impedance was kept below 10 k Ω for all recordings. ERP data were analyzed using the
288 EEGLAB Matlab toolbox (Delorme & Makeig, 2004) and were band-pass filtered at 0.1–20
289 Hz. Blinking and eye movements were corrected using independent component analysis.
290 Activity above 100 μ V or below –100 μ V were removed by a semi-automatic procedure. The
291 ERP analysis window ranged from 100 ms before stimulus onset to 1000 ms after onset. The
292 average number of trials included for each condition were as follows: C+P+, 49 (SD, 2.09;
293 max, 50; min, 43); C–P+, 49 (SD, 1.81; max, 50; min, 43); C+P–, 49 (SD, 1.57; max, 50;
294 min, 45); and C–P–, 48.83 (SD, 1.83; max, 50; min, 45).

295

296 *Statistics*

297 The acquisition phase had a 2 \times 2 experimental design: stimulus type (conceptual, perceptual)
298 \times conditioned type (CS+, CS–). US-expectancy data and RTs in the acquisition phase were
299 analyzed using stimulus type \times conditioned type repeated-measures analyses of variance
300 (ANOVAs). US-expectancy data and RTs in the generalization phase were calculated using
301 perceptual type (P+, P–) \times conceptual type (C+, C–) repeated measures ANOVAs. The ERP
302 analysis window ranged from 100 ms before stimulus onset to 1000 ms after onset. Based on
303 previous studies and the grand-averaged ERP waveform, we scored P1 as the mean response
304 between 125–165 ms (at electrode P3), EPN as the mean response between 260–280 ms

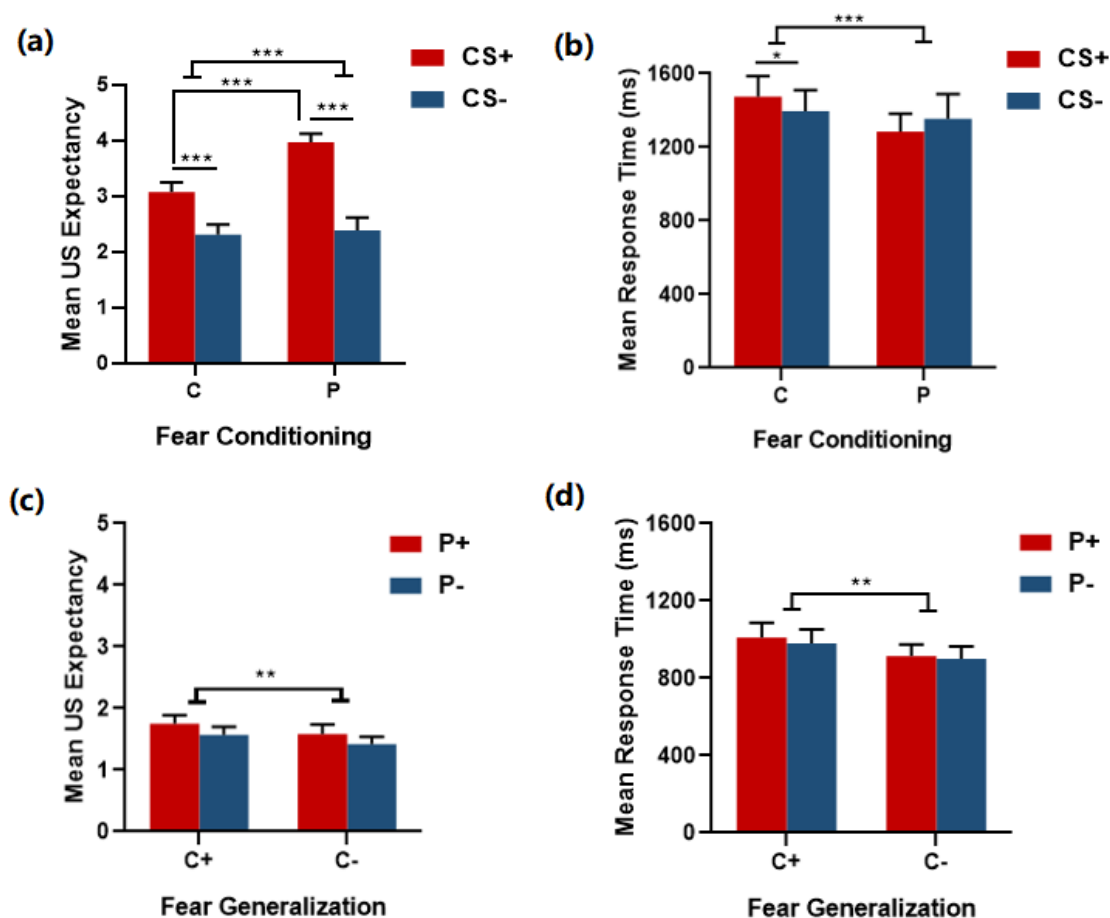
305 (Schupp et al., 2004), N400 as the mean response between 380–480 ms (Cz, C1, C2, C3,
306 C4), and LPP as the mean response between 500–630 ms (Fz, Cz) (Pavlov & Kotchoubey,
307 2019). Repeated measures ANOVAs were performed for Perceptual (P+, P–) and Conceptual
308 (C+, C–) stimuli for the average P1, EPN, N400, and LPP amplitudes. Throughout our
309 analysis, the effects were considered significant when $P < 0.05$.

310

311 **Results**

312 *Behavioral Results*

313 During the acquisition phase, the shock expectancy was 3.07 ± 0.17 (M \pm SEM) for C+, 2.31
314 ± 0.18 for C–, was, 3.97 ± 0.15 for P+, and 2.39 ± 0.23 for P–. Repeated–measures
315 ANOVA with the Stimulus Type (concept, perception) \times Conditioning Type (CS+, CS–) as
316 factors revealed a significant main effect of Stimulus Type ($F_{1,22} = 13.51$; $p < 0.001$; $\eta^2 =$
317 0.34) and a significant main effect of Conditioning Type ($F_{1,22} = 32.68$; $p < 0.001$; $\eta^2 = 0.56$),
318 which demonstrated that participants successfully learned the contingency between the CS
319 and the US. Furthermore, there was a significant interaction between these two factors ($F_{1,22}$
320 $= 7.84$; $p = 0.010$; $\eta^2 = 0.23$). Follow-up simple effects tests revealed that the shock
321 expectation for P+ was significantly larger than that for C+ (Fig.2a).



322 Figure 2. The US-expectancy ratings (a) and mean response time (b) for fear acquisition and
 323 fear generalization (c, d). Note: *P*, perceptual stimulus; *C*, conceptual stimulus. *C*⁺,
 324 conceptual CS⁺; *C*⁻, conceptual CS⁻; *P*⁺, perceptual CS⁺; *C*⁻, perceptual CS⁻. Means and
 325 SEM are given. ****p* < 0.001; ***p* < 0.01; **p* < 0.05

326 During the acquisition phase, the response times were 1475.65 ± 111.59 ms for *C*⁺,
 327 1397.05 ± 112.99 ms for *C*⁻, 1285.13 ± 97.99 ms for *P*⁺, and 1355.22 ± 133.32 ms for *P*⁻.
 328 Repeated-measures ANOVA with Stimulus Type (conceptual, perceptual) × Conditioning
 329 Type (CS⁺, CS⁻) as factors showed a significant main effect of Stimulus Type ($F_{1,22} = 5.494$;
 330 $p = 0.027$; $\eta^2 = 0.174$), indicating that participants needed more time to evaluate the
 331 conceptual cues compared than they did the perceptual cues. The effect of Conditioning Type

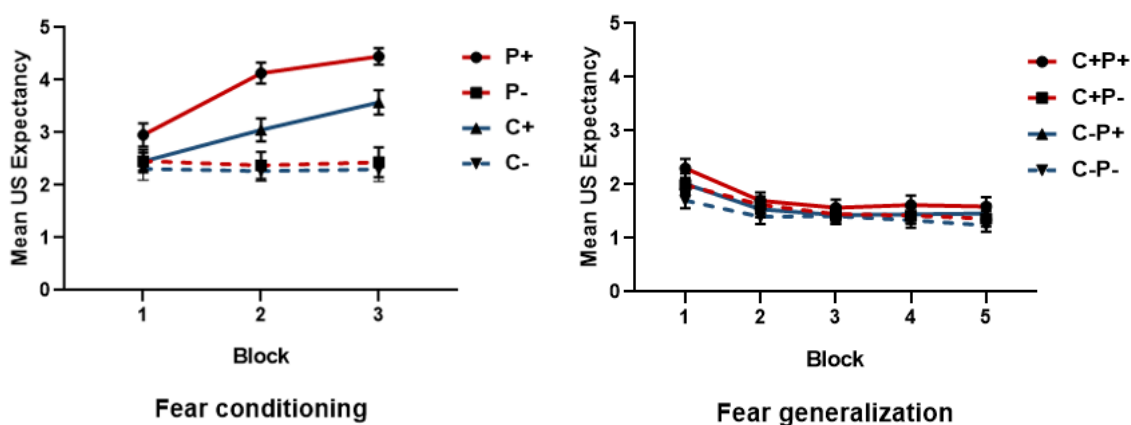
332 was not significant ($F_{1,22} = 0.336$; $p = 0.567$, $\eta^2 = 0.013$). A significant interaction was found
333 between the two factors ($F_{1,22} = 6.003$; $p = 0.021$, $\eta^2 = 0.188$). Simple effects tests revealed
334 that response times for the C+ was significantly longer than that for the C- (Fig. 2b).

335 During the generalization test, shock expectancy was 1.75 ± 0.14 for C+P+, 1.57 ± 0.13
336 for C+P-, 1.58 ± 0.16 for C-P+, and 1.42 ± 0.12 for C-P-. Repeated-measures ANOVA
337 with Perceptual Type (P+, P-) \times Conceptual Type (C+, C-) as factors revealed a significant
338 main effect of Conceptual Type ($F_{1,22} = 8.70$; $p = 0.007$, $\eta^2 = 0.25$), but not Perceptual Type
339 ($F_{1,22} = 3.56$; $p = 0.071$, $\eta^2 = 0.12$). No significant interaction was noted between the two
340 factors ($F_{1,22} = 0.26$; $p = 0.614$, $\eta^2 = 0.01$; Fig. 2c), suggesting that fear responses were
341 greater for C+ stimuli than for C- stimuli. The response times for these four kinds of GS
342 were 1011.71 ± 75.14 ms for C+P+, 980.56 ± 72.12 ms for C+P-, 914.32 ± 60.83 ms for C-P+,
343 and 900.99 ± 63.76 ms for C-P-. Repeated-measures ANOVA revealed a significant main
344 effect of Conceptual Type ($F_{1,22} = 9.52$; $p = 0.005$, $\eta^2 = 0.26$), but not for Perceptual Type
345 ($F_{1,22} = 1.60$; $p = 0.216$, $\eta^2 = 0.06$). No significant interaction was observed between the two
346 factors ($F_{1,22} = 0.62$; $p = 0.438$, $\eta^2 = 0.022$; see Fig. 2d).

347 For an overview of fear conditioning, we plotted the participants' learning courses.
348 Statistical analysis was conducted using repeated-measures ANOVA with Stimulus Type
349 (conceptual, perceptual) \times Conditioning Type (CS+, CS-) \times Time (1, 2, 3) as factors. The US
350 expectancy showed a significant main effect of Time ($F_{2,44} = 14.518$; $p < 0.001$, $\eta^2 = 0.358$)
351 and a Conditioned Type (CS+, CS-) \times Time interaction ($F_{2,44} = 21.186$, $p < 0.001$, $\eta^2 =$
352 0.449), indicating a fear learning curve in the conditioning phase.

353 Considering the possibility of an extinction effect as the generalization test progressed,

354 we analyzed the US-expectancy ratings across trials. Statistical analysis was conducted using
 355 repeated-measures ANOVA that included the Perceptual Type (P+, P-), Conceptual Type
 356 (C+, C-), and Time (1, 2, 3, 4, 5) as factors. We found a significant main effect of Time ($F_{4,88}$
 357 = 16.435; $p < 0.001$, $\eta^2 = 0.460$) on US-expectancy rating, but no significant Perceptual
 358 Type \times Time, Conceptual Type \times Time, or Perceptual Type \times Conceptual Type \times Time
 359 interaction, indicating general extinction during the generalization test (see Fig. 3). Pairwise
 360 comparison showed that US-expectancy ratings for C+P- in Block1 and Block2 were much
 361 higher than those for C-P- ($p = 0.034$, $p = 0.009$), and US-expectancy ratings for C-P+ in
 362 Block1 and Block4 was much higher than those for C-P- ($p = 0.062$, $p = 0.047$).



363
 364 Figure 3. The US-expectancy ratings during the course of fear conditioning (a) and
 365 generalization (b).

366

367 *ERP waveform analysis for the fear-generalization test*

368 **P1**

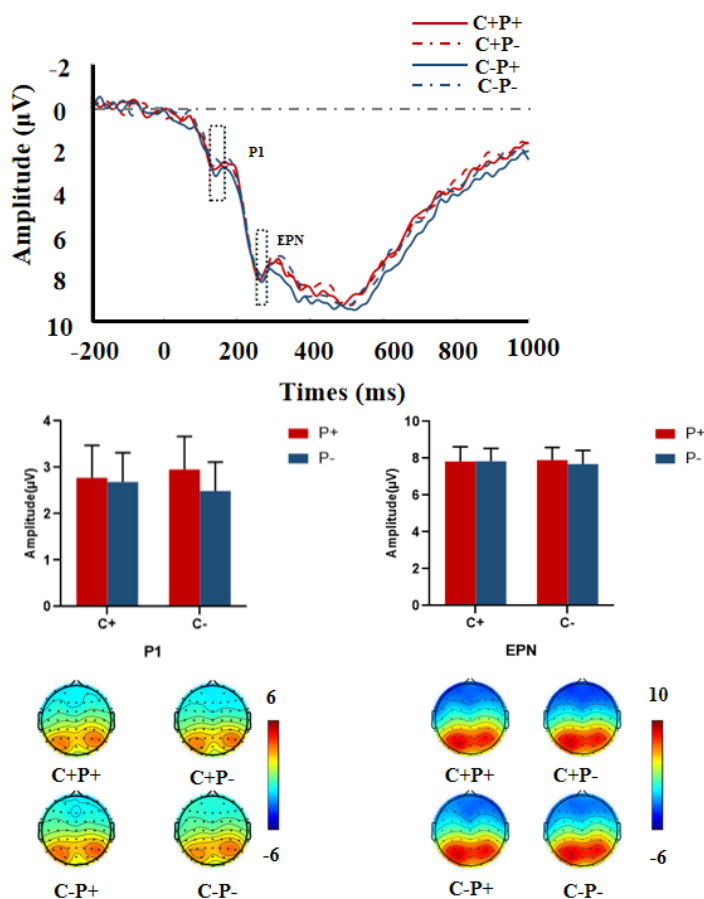
369 The P1 time window was between 125–165 ms (at electrode P3). Analysis showed that P1
 370 amplitude did not significantly differ between CS+ and CS- conditions (no significant effect

371 of Conceptual Type ($F_{1,22} = 0.001$; $p = 0.975$), perceptual type ($F_{1,22} = 0.447$; $p = 0.511$), or
 372 any interaction of the two ($F_{1,22} = 0.880$; $p = 0.358$) (Fig. 4).

373

374 **EPN**

375 According to previous studies, the time window for EPN was set to 260–280 ms (at electrode
 376 P3) (Schupp et al., 2004). We found no significant effect for conceptual type ($F_{1,22} = 0.008$; p
 377 = 0.928), perceptual stimuli ($F_{1,22} = 0.080$; $p = 0.780$), or any interaction between the two
 378 ($F_{1,22} = 0.192$; $p = 0.665$) (Fig. 4).



379 Figure 4. P1 and EPN ERP results. Top: Grand average event-related potential (ERP)
 380 waveforms for the four kinds of generalized stimuli (GS) at electrode P3, 125–165 ms after
 381 stimulus onset for P1 and 260–280 ms after onset for EPN. Middle: Grand averaged ERP

382 amplitudes for P1 and EPN. Bottom: Scalp topography of the grand average amplitudes for
383 P1 and EPN.

384

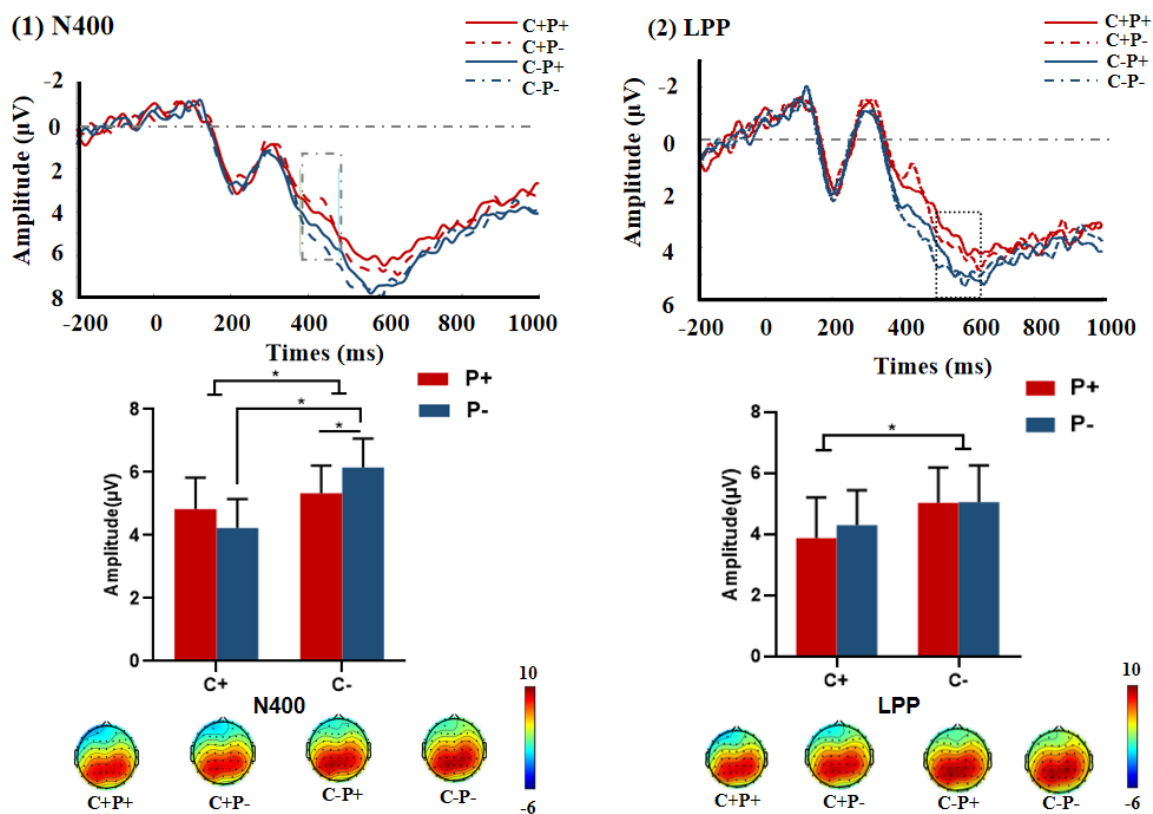
385 ***N400***

386 Analysis revealed a significant main effect of Conceptual Type ($F_{1,22} = 5.91$; $p = 0.024$, $\eta^2 =$
387 0.21), but not for Perceptual Type ($F_{1,22} = 0.03$; $p = 0.869$, $\eta^2 = 0.01$). It is worth noting that
388 the interaction between these two factors showed was marginally significant ($F_{1,22} = 3.96$; p
389 $= 0.059$, $\eta^2 = 0.15$). Follow-up simple effects tests (Bonferroni-adjusted for multiple
390 comparisons) indicated that the N400 amplitudes for the C-P+ and C+P- conditions were
391 significantly larger than those for the C-P- condition ($p = 0.035$ and $p = 0.008$, respectively).
392 Further, N400 amplitudes did not statistically differ between C+P+ and C+P- conditions ($p =$
393 0.282 , $p > 0.05$) or between C+P+ and C-P+ conditions ($p = 0.361$, $p > 0.05$) (see Figure 5).

394

395 ***LPP***

396 Analysis showed a significant main effect of Conceptual Type ($F_{1,22} = 5.967$; $p = 0.023$, $\eta^2 =$
397 0.206), but not Perceptual Type ($F_{1,22} = 0.244$; $p = 0.626$, $\eta^2 = 0.010$) or their interaction
398 ($F_{1,22} = 0.184$; $p = 0.672$, $\eta^2 = 0.008$ (Fig. 5)).



399
 400 Figure 5. N400 and LPP ERP results. (1) N400: *Top*. Grand average ERP waveforms for the
 401 four kinds of generalized stimuli (GS) at electrode C1 during the 380–480 ms after stimulus
 402 onset. *Middle*. Grand average ERP amplitudes during the 380–480 ms time window at Cz,
 403 C1, C2, C3, and C4 electrodes. *Bottom*. Scalp topography of the grand average amplitudes for
 404 N400. (2) LPP: *Top*. Grand average ERP waveforms for the four kinds of generalized stimuli
 405 (GS) at the CPz electrode during the 500–630 ms after stimulus onset. *Middle*. Grand average
 406 ERP amplitudes during the 500–630 ms time window at CPz electrodes. *Bottom*. Scalp
 407 topography of the grand average amplitude for LPP. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

408
 409 **Discussion**

410 This study evaluated the effects of perceptual and conceptual cues on fear acquisition and

411 generalization. First, during the acquisition phase, expectations of the US for C+ and P+
412 stimuli were significantly greater than those for the C- and P- stimuli, indicating that
413 participants successfully learned the association between the CS and the US (Davidson et al.,
414 2018). Because P+ exemplars shared the same physical color (i.e., perceptually based) and
415 C+ exemplars shared the same object category (i.e., conceptually based), this demonstrated
416 that fear can be facilitated through different pathways (Bennett et al., 2015). Peperkorn et al.
417 (2014) reported that both spider-related perceptual cues and conceptual information could
418 elicit fear responses in healthy participants and patients with arachnophobia. Compared with
419 presenting conceptual information alone, they found that perceptual cues alone could elicit a
420 stronger fear response. Our findings here were similar: US-expectancy ratings for P+ stimuli
421 were higher than those for C+ stimuli, suggesting that a perceptually based route might be
422 evoke fear more than a conceptually based path. RTs for conceptual cues were longer than
423 those for perceptual cues. Craddock et al. (2012) concluded that RTs could be used to
424 evaluate associative strength; longer RTs indicate more uncertain signal value with
425 conceptual cues (Lissek et al., 2008). The C+ vs. C- comparison here confirms this
426 explanation. RTs in response to C+ stimuli were significantly longer than those for C- stimuli,
427 which might be due to the probabilistic (80%) match between the C+ and the US, whereas C-
428 stimuli were always presented alone. Thus, compared with C- stimuli that indicated safe
429 information, the values of C+ stimuli were more uncertain. Another possible explanation is
430 that having the same physical stimulus elements could influence the speed of processing
431 differently than having different physical elements, and conceptually based fear learning
432 involves higher-order cognitive processes.

433 In the subsequent generalization test, participants reported higher US-expectancy ratings
434 for C+ exemplars (i.e., C+P+ and C+P-) than for C- exemplars (i.e., C-P+ and C-P-). This
435 is an interesting finding considering that each GS was a different basic-level exemplar of
436 animals or furniture and did not overlap the CS in terms of perceptual features. This result is
437 consistent with that of a previous study which showed that conditioned fear might generalize
438 to a variety of stimuli because of their conceptual similarity to the CS (Dunsmoor et al.,
439 2011). Additionally, the RTs for the conceptually based threat signals (C+P+, C+P-) were
440 longer than those for conceptually related safety stimuli (C-P+, C-P-). In combination with
441 the US-expectation scores, C+ stimuli were expected to be followed by the US, but not
442 always. It is possible that the longer RTs reflect a mismatch between what was expected
443 (CS-US association) and what actually happened. However, we found no differences
444 between P+ (C+P+, C-P+) and P- (C+P-, C-P-) in US expectation. We note that
445 US-expectancy ratings for the C-P+ trials in Block1 and Block4 were higher than those for
446 C-P- trials. This was probably due to the extinction of generalization as the number of
447 generalization trials increased. In a study by Zbozinek and Craske (2018), participants were
448 randomly exposed to three different extinction conditions: Extinction_CS+ (extinguished
449 using the conditional stimulus), Extinction_Singular (extinguished using a single
450 generalization stimulus), and Extinction_Variety (extinguished using various generalization
451 stimuli). The results revealed that extinction with GSs could reduce fear to novel GS.

452 In contrast to what had been expected initially, there were no P1 or EPN component
453 differences between the four conditions. Thus, the current results show that threat-related
454 attentional bias occurs much later, and that perceptually based threat signals do not modulate

455 the early detection or vigilance process. One possible explanation for this result is the rather
456 weak US used in the current research. Pavlov and Kotchoubey (2019) compared two different
457 conditioning paradigms (aversive conditioning and name conditioning) using ERP. In
458 aversive conditioning, the US was an aversive painful shock, whereas in name conditioning,
459 the US was the name of the corresponding participant. The results revealed that when US
460 conditioning is strong (i.e., aversive conditioning), learned fear induced P3a and LPP effects.
461 Conversely, when it was weak (i.e., the name conditioning), conditioned stimuli were only
462 able to enhance LPP. The aversive painful shock in that study was set to the level of
463 “moderately painful, but not too strong”. However, in the current study, we set the
464 shock-intensity level to “unpleasant, but not painful.” Furthermore, in classical fear
465 conditioning paradigms, electric shock durations have typically ranged between 50 ms and
466 500 ms (Dou et al., 2020; Ginat-Frolich et al., 2019; Torrents-Rodas et al., 2013; Lange et
467 al., 2019; Bos et al., 2012; Drexler et al., 2018). Considering the use of a compound US
468 (shock with fearful image), we selected a 50-ms duration for the shock to ensure that it was
469 safe and acceptable. Thus, compared to the US in previous research, the US used in the
470 present study might not have been strong enough to modulate earlier, perceptual stages of
471 processing.

472 N400 amplitude was higher for C+ stimuli (C+P+, C+P-) than for C- stimuli (C-P+,
473 C-P-), and for C-P+ stimuli compared with C-P- stimuli. The enhanced N400 effect might
474 be an electrophysiological index of fear generalization. Further, when the conceptually
475 related signal was safe, the threat value of the perceptual signal could elicit an attentional bias
476 toward emotional stimuli. Additionally, N400 amplitude might be modulated by the

477 inconsistent value of the stimuli. In an EEG study, Deveney et al. (2008) employed
478 electroencephalography to investigate the effect of cognitive reassessment strategies on
479 information post-processing. They reported that two stimuli with different properties
480 appearing at the same time triggered the N400 effect. Similar N400 modulations have been
481 found in the current study: a higher amplitude N400 in response to C-P+ and C+P- stimuli
482 compared with C-P- stimuli. In the C-P+ and C+P- conditions, the conceptual and
483 perceptual signal values (threat vs. safety) were opposite, which led to inconsistency of
484 information when the individual processed the stimulus.

485 We further asked whether fear-generalization effects can be indexed by LPP amplitude
486 and how different signal values (safety vs. threat) of the different pathways (perceptual vs.
487 conceptual) impact the later sustained attention processes. Contrary to what we expected,
488 LPP amplitude was lower for trials with generalized C+ exemplars than for trials with
489 generalized C- exemplars. Nelson et al. (2015) investigated the role of LPP in the process of
490 fear generalization, and reported that LPP was higher in response to CS+ stimuli than to GSs,
491 but did not differ among GSs, which suggested that LPP may not be sensitive to the
492 processing of fear generalization. It is worth noting that, unlike the CS+ (directly associated
493 with the US) or GSs (20%, 40%, or 60% similarity to the CS+) that are used in classic fear
494 generalization paradigms, the current research used compound value signals as the
495 generalized stimuli. The test phase might thus have involved both fear and safety
496 generalization. In a study by Seligowski et al. (2021), LPP latencies for CS+ and CS-
497 conditions did not significantly differ, whereas LPP CS- latencies showed a significantly
498 negatively startle response to the CS-. They concluded that LPP may be an ERP-based

499 marker of safety-signal learning. In the current study, one possible explanation for this
500 enhanced LPP effect for conceptually based safety GSs is that LPP might indicate a later
501 inhibitory control process, which could be used to examine safety learning. Nevertheless, as
502 evidence is weak, these interpretations need to be taken with caution, and further research is
503 needed.

504 This study had several limitations. First, when an organism encounters an emergency,
505 the autonomic nervous system (ANS) is stimulated, which leads to a series of physiological
506 changes such as accelerated heartbeat and sweat gland secretion (Cohen & Randall, 1984).
507 The SCR is a valuable physiological tool for indexing human fear conditioning; fear can
508 accurately be reflected by changes in skin conductance or sweating response, which avoids
509 the bias of subjective reports (Glover et al., 2011). Future research can use EEG in
510 conjunction with SCRs to investigate the simultaneous effect of perceptual and conceptual
511 cues on human fear learning. Second, a previous study showed that the LPP component of
512 EEGs is sensitive to fear learning (Baas et al., 2002); however, we did not record EEG data
513 during the acquisition phase because the signal-to-noise ratio was insufficient for EEG.
514 Previous fear-conditioning paradigms usually used one or only a few stimuli to serve as the
515 CS, which allows for enough trials of the same condition to maximize the signal-to-noise
516 ratio. However, it also could lead to habituation. In multi-CS conditioning, several different
517 stimuli were paired with an aversive US (Steinberg et al. (2013), using a total of 208 face
518 images as the CSs. Multiple CS conditional stimuli can be used in future studies to better
519 utilize EEG and SCR data at the same time, to increase the number of experimental trials, and
520 to reduce the number of repeated occurrences of each CS. In addition, the time interval

521 required for EEG and SCR is different. To ensure the accuracy of data recording and control
522 the time required for the experiment, different time intervals can be used to record different
523 emotional indicators (some trials would use short intervals, and some would use long
524 intervals). Finally, the methodological limitations of the study should be noted. Perceptual
525 cues used in the acquisition phase were different meaningless shapes, which separated them
526 from conceptual categories and led to a simple perceptually related color-aversive US
527 association. In the generalization phase, the colors of the GSs were physically similar to those
528 of the perceptually conditioned stimuli (P+; P-), whereas the GS categories (not physical
529 characteristics) were the same as those of the conceptually conditioned stimuli (C+; C-).
530 However, compared with perceptually based fear learning, conceptually based learning
531 involved more stimuli; therefore, fear generalization might be influenced by category vs.
532 perception or one vs. multiple stimuli. Moreover, the arousal ratings for the “black and white”
533 category (M = 5.20; SD = 0.19) used in the present research was significantly greater than
534 those for the “color” category (M = 5.05; SD = 0.17; $p = 0.002$). Future studies are necessary
535 to investigate this by using more appropriate experimental stimuli, such as words, to clarify
536 how physical and verbal stimulus characteristics might influence fear generalization.

537

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543

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545

546 **Ethics approval:** The experimental protocol was established, according to the ethical
547 guidelines of the Helsinki Declaration and was approved the Ethical Committee of Shenzhen
548 University.

549

550 **Consent to participate:** Written informed consent was obtained from participants.

551

552 **Consent for publication:** The authors agree to publication in the Journal.

553

554 **Availability of data and materials:** All data are fully available without restriction.

555

556 **Authors' contributions:**

557 Conceived and designed the experiments: Yi Lei, Jinxia Wang, Haoran Dou

558 Performed the experiments: Jinxia Wang, Mei E, Qi Wu, Tao Xie

559 Analyzed the data: Jinxia Wang

560 Wrote the paper: Yi Lei, Jinxia Wang, Haoran Dou

561

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