Visual Cognition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/pvis20

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To cite this article: Laurent Grégoire, Andy J. Kim & Brian A. Anderson (2021) Semantic generalization of punishment-related attentional priority, Visual Cognition, 29:5, 310-317, DOI: 10.1080/13506285.2021.1914796

To link to this article: https://doi.org/10.1080/13506285.2021.1914796

Published online: 18 Apr 2021.

VISUAL COGNITION
2021, VOL. 29, NO. 5, 310–317
https://doi.org/10.1080/13506285.2021.1914796

Routledge
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Semantic generalization of punishment-related attentional priority

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ABSTRACT
The present study aimed to determine whether attentional prioritization of visual stimuli associated with punishment transfers across conceptual knowledge independently of physical features. Participants performed a Stroop task in which words were presented individually. These stimuli consisted of four pairs of synonyms selected such that the two words of each pair have both a strong semantic association and no perceptual similarity. In the learning phase, two words (from two different pairs) were associated with shock independently of performance; all the other words were never paired with shock. In the subsequent test phase, no shock was delivered. Results are consistent with semantic generalization of punishment-related attentional priority; synonyms of words paired with shock produced a Stroop interference effect (i.e., slower response times) in learning and test phases, relative to synonyms of words not paired with shock, suggesting they were prioritized by attention.

ARTICLE HISTORY
Received 20 January 2021
Accepted 5 April 2021

KEYWORDS
Selective attention; attentional prioritization; associative learning; punishment; semantic generalization

Attention plays a critical role in an organism's survival by prioritizing stimuli that represent a potential danger. The efficiency with which these stimuli are detected indeed tends to promote a more rapid and appropriate behavioural response (LeDoux, 1996). Consistent with this conceptualization, attention is preferentially drawn to punishment-related cues (see e.g., Anderson & Britton, 2020; Nissens et al., 2017).

Attentional biases toward punishment-related stimuli are typically observed in visual search tasks (see Watson et al., 2019, for a review). For example, when presented as a distractor, a stimulus (e.g., a blue diamond) previously conditioned with aversive electrical shock impairs performance compared to a neutral stimulus (e.g., an orange diamond never associated with shock), independent of perceptual salience (Schmidt et al., 2015). Nissens et al. (2017) also reported that punishment-modulated attentional capture occurred even though fixating punishment-related cues increased the probability of receiving punishment (see also Anderson & Britton, 2020). Thus, stimuli associated with punishment alter visual search performance regardless of physical features and current goals, possibly in an automatic way (Watson et al., 2019).

Despite the importance of this process for survival and adaptation (e.g., detect threatening stimuli), the potential generalization of punishment-related attentional biases has been largely ignored in the literature (although see Grégoire, Kim, et al., 2020), especially semantic generalization, although real-world learning situations often entail conceptual knowledge (Dunsmoor & Murphy, 2015). Semantic generalization was shown in Pavlovian conditioning research focusing on the emotional expression of fear (e.g., Dunsmoor et al., 2012; Dunsmoor & Murphy, 2014; Grégoire & Greening, 2020). A convincing demonstration was reported by Boyle et al. (2016) in a two-phase study. First, two words were used as conditioned stimuli (CSs) in a learning phase: one word was paired with shock (CS+) and the other was not (CS−). In a subsequent generalization test phase, synonyms of the CSs (i.e., the generalized conditioned stimuli, GCS+ and GCS−, respectively) were presented in the absence of shock. Skin conductance responses were significantly greater for the GCS+ than for the GCS−, reflecting a semantic generalization of fear conditioning. In the domain of reward learning, a recent study evidenced semantic generalization of value-based attentional priority (Grégoire & Anderson, 2019), but

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no experiment seems to have focused on the semantic generalization of punishment-related attentional priority. This potential process could provide valuable insight into a critical aspect of adaptation and improve the understanding and treatment of anxiety disorders to which attentional biases contribute (Van Bockstaele et al., 2014).

The present study aimed to determine whether attentional prioritization of visual stimuli associated with punishment transfers across conceptual knowledge independently of perceptual features. We devised a colour-word Stroop task in which words were presented individually. In a learning phase, two words were paired with shock (CS+) and two words were not (CS−). Throughout this phase, synonyms of CSs (i.e., GCS+ and GCS−, respectively) were also presented in the absence of shock. In a subsequent test phase, participants performed a similar task, but no shock was delivered. We hypothesized that synonyms of words paired with shock would produce a Stroop interference effect (i.e., would slow down the colour-identifying task), relative to synonyms of words not paired with shock, because they should be prioritized by attention (due to their semantic association with words related to punishment) and thus more difficult to ignore.

Method

Participants

Thirty-four participants were recruited from the Texas A&M University community. All were native English speakers, reported normal or corrected-to-normal visual acuity and normal colour vision. Data from two participants were removed from analyses due to a low proportion of correct responses (below 2.5 SD of the group mean; see, e.g., Grégoire & Anderson, 2019). The final sample included 32 participants (17 females, mean age = 20.00 years, SD = 2.58). All procedures were approved by the Texas A&M University Institutional Review Board and were conducted in accordance with the principles expressed in the Declaration of Helsinki. The sample size was chosen to achieve 0.80 power at $\alpha = 0.05$, based on the effect size ($dz = 0.55$) observed in Schmidt et al. (2015) for attentional capture by punishment-associated stimuli.

Specifically, the power analysis indicated that a sample size of 28 would be sufficient to detect an effect (computed using G*Power 3.1).

Apparatus

A Dell OptiPlex 7040 (Dell, Round Rock, TX, USA) equipped with Matlab software (Mathworks, Natick, MA, USA) and Psychophysics Toolbox extensions (Brainard, 1997) was used to present the stimuli on a Dell P2717H monitor. The participants viewed the monitor from a distance of approximately 70 cm in a dimly lit room. Paired electrodes (EL500, BioPac Systems, Inc., Goleta, CA, USA) were attached to the non-dominant forearm of each participant, and 2-ms mild electric shocks were delivered through an isolated linear stimulator under the constant current setting (STMISOLA, BioPac Systems), which was controlled by custom Matlab scripts. Responses were entered using a 5-button response box (MilliKey MK-5).

Stimuli

Four pairs of synonyms were selected from The University of South Florida Word Association, Rhyme and Word Fragmentation Norms database of free association (Nelson et al., 1998): *clock-time*, *assist-help*, *fuel-gas*, *yolk-egg*. The chosen pairs were all rated highly (i.e., above 65%) for frequency of free association when the first word was provided (see Grégoire & Anderson, 2019). Only the first word of a pair could be associated with shock (in the learning phase); their corresponding synonyms were never reinforced with shock. There was no phonological or orthographic similarity between the two words of each pair. Words were presented in equiluminant red, green, blue, and purple. All possible combinations between words and colours were presented an equal number of times in learning and test phases. If the response was incorrect or not provided within the timeout limit, “incorrect” or “too slow” appeared at the centre of the screen, respectively. Throughout the experiment, the background of the screen was dark grey, while the fixation cross and feedback appeared in white. Written information was presented in 60-point Arial font.

Design

The learning phase and the test phase were split into four and two 96-trial blocks, respectively. Each block comprised an equal number of CS+, CS−, GCS+, and GCS− trials. The first word of two pairs represented the CS+ and the first word of the two other pairs represented the CS−; their corresponding synonyms constituted the GCS+ and GCS−, respectively. The four pairs of words and conditions were fully crossed and counterbalanced across participants (with the restriction that the first word of a pair was always a CS), leading to six possible combinations. In the learning phase, each CS+ was associated with shock independently of performance (i.e., speed and accuracy) with a reinforcement ratio of 66.67%. CS+ trials reinforced with shock were randomly distributed in each block of the learning phase, except for the first block, in which the first four trials consisted of each of the two CS+ reinforced with shock and each of the two CS− (presented in a random order). This manipulation aimed to avoid presenting non-reinforced CS+ trials before reinforced CS+ trials and generalized stimuli before conditioned stimuli in order to increase our chance of getting Stroop effects on both conditioned and generalized stimuli. No shock was delivered in the test phase. For the sake of simplicity, we kept the same terminology for the four conditions in the two phases, though participants did not receive shock in the test phase. In each block of the two phases, each of the eight words was presented three times in each of the four colours; trials were pseudorandomly ordered, excluding immediate repetitions of colours and words.

Procedure

Prior to the experiment, the participant was connected to the isolated linear stimulator and a shock calibration procedure was conducted to achieve a level that was "unpleasant, but not painful" (Grégoire, Britton, et al., 2020; Grégoire, Kim, et al., 2020; Murty et al., 2012; Schmidt et al., 2015, 2017). Then, participants performed twenty-four practice trials with six neutral words (different and not semantically related to the experimental words) presented in each of the four colours, in a random order. Participants were informed that no shock was delivered during the practice.

Each trial began with the presentation of a fixation cross at the centre of the screen for a random duration between 400 and 600 ms. A coloured word then appeared around the centre location for 1000 ms or until the participant reported the colour of the word, followed by a 1000-ms blank screen (Figure 1). We used a trial-to-trial spatial uncertainty of 100 pixels around the centre location (to present words) in order to limit opportunities for employing strategies (e.g., fixating on a small portion of the print to avoid reading words; Ben-Haim et al., 2014). For each incorrect or missed response, a 500-ms blank screen followed by a 1000-ms feedback display were added in the sequence of trial events

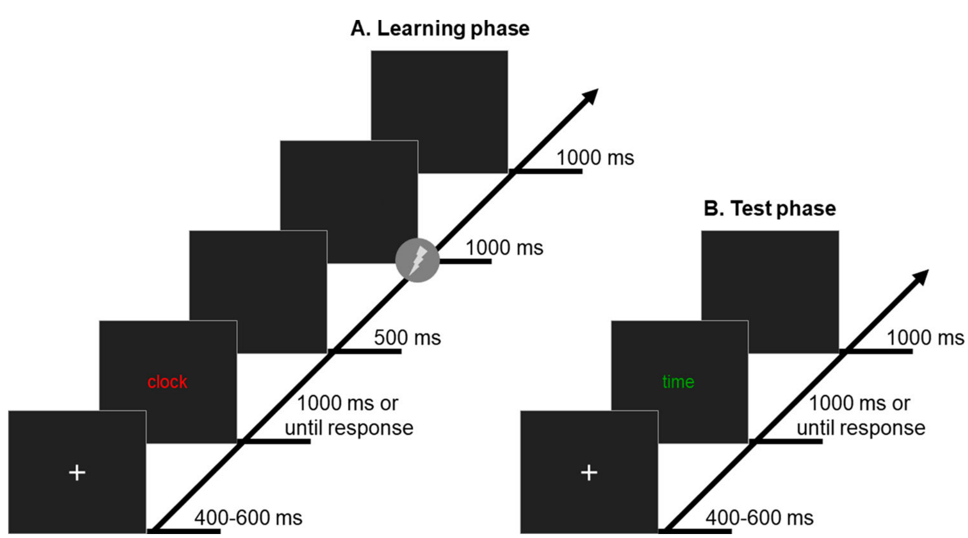

Figure 1. Sequence of trial events in (a) learning and (b) test phases.

after the presentation of the Stroop word. When participants made an error or a miss on a reinforced CS+ trial (learning phase), the shock was delivered just as the feedback display appeared, 500 ms after the presentation of the Stroop word. The sequence of trial events was exactly the same when participants reported the correct response on a reinforced CS+ trial, but the feedback display was replaced by a blank screen.

Participants were instructed to report the ink colour of each word as quickly and accurately as possible, ignoring their meaning, by using the button box with their dominant hand. Two keys of the button box were labelled "left" and "right." Participants had to press the "left" key if the word was coloured in green or purple or the "right" key if the word was coloured in blue or red.

Before the learning phase, we specified that a shock could be delivered on some trials independently of performance (i.e., speed and accuracy), but no information about stimulus-shock contingencies was given. Participants were *not* informed that no shock was delivered in the test phase in order to evaluate the persistence of potential Stroop effects during extinction.

After the test phase, participants provided self-reported evaluations of their contingency awareness between words and shock. Each of the eight words was presented once in each of the four colours, leading to 32 trials. Stimuli were pseudorandomly ordered and displayed around the centre of the screen in the same way as in the experiment. Participants were asked to indicate how likely each trial was to result in shock by clicking on a continuous scale ranging from 0 to 100 (0 meant shock was impossible and 100 meant shock was guaranteed).

Data analyses

Misses and errors represented, respectively, 0.74% and 6.23% of the trials in the learning phase, and 0.99% and 6.14% of the trials in the test phase. Response times (RTs) for correct responses beyond three standard deviations of the mean for each participant (1.29%) were trimmed (Grégoire et al., 2013, 2014, 2015; Grégoire & Anderson, 2019).

Repeated-measures analyses of variance (ANOVAs) were conducted with condition (CS+, CS−, GCS+, GCS−) and phase (learning, test) as within-subject variables, separately for mean RTs and proportion of errors and misses. For each ANOVA, sphericity was tested with Mauchly's test of sphericity, and when the sphericity assumption was violated, degrees of freedom were adjusted using the Greenhouse–Geisser epsilon correction. Additional *t*-tests were performed when appropriate, mainly to analyse Stroop effects for conditioned (CS+ minus CS−) and generalized (GCS+ minus GCS−) stimuli. For each *t*-test, data were checked for normality of distribution with the Kolmogorov–Smirnov test. A Wilcoxon signed-ranks test was used when data were not normally distributed. Note that we calculated Cohen's *dz* using the formula $dz = t/\text{sqrt}(n)$ for paired sample *t*-tests (Lakens, 2013; Rosenthal, 1991).

Results

Stroop task

Proportion of errors and misses. The ANOVA performed on the proportion of errors and misses revealed a significant main effect of condition, $F(3, 93) = 3.11$, $p = 0.030$, $\eta^2 p = 0.091$, no significant main effect of phase, $F(1, 31) = 0.07$, $p = 0.792$, and no significant interaction between condition and phase, $F(3, 93) = 0.32$, $p = 0.811$. In the learning phase, the proportion of errors and misses was significantly greater in the CS+ condition than in the CS− condition, $t(31) = 2.04$, $p = 0.049$, $dz = 0.36$, but no significant difference was observed between GCS+ and GCS− conditions, $t(31) = 1.52$, $p = 0.140$. In the test phase, the proportion of errors and misses was also significantly greater in the CS+ condition than in the CS− condition, $Z = 2.01$, $p = 0.044$, but no significant difference was observed between GCS+ and GCS− conditions, $t(31) = 0.36$, $p = 0.722$ (Table 1).

RTs. The ANOVA performed on mean RTs revealed a significant main effect of condition, $F(3, 93) = 4.65$, $p = 0.004$, $\eta^2 p = 0.130$, no significant main effect of phase, $F(1, 31) = 1.00$, $p = 0.325$, and no significant interaction between condition and phase, F(2.38,

Table 1. Proportion of errors and misses as a function of experimental conditions in learning and test phases.

	CS+	CS−	GCS+	GCS−
Learning phase	8.17 (4.19)	6.80 (4.90)	6.87 (4.39)	6.02 (4.72)
Test phase	8.01 (6.26)	6.58 (5.00)	7.16 (5.77)	6.77 (6.65)

Note: Standard deviations are in parentheses (2005).

73.86) = 0.84, $p = 0.455$. In the learning phase, no significant difference was observed between CS+ and CS− conditions, $t(31) = 1.10$, $p = 0.280$, but RTs were significantly greater in the GCS+ condition than in the GCS− condition, $t(31) = 3.56$, $p = 0.001$, $dz = 0.63$ (Figure 2(a)). Similarly, in the test phase, no significant difference was observed between CS+ and CS− conditions, $t(31) = 1.66$, $p = 0.107$, but RTs were significantly greater in the GCS+ condition than in the GCS− condition, $t(31) = 2.58$, $p = 0.015$, $dz = 0.46$ (Figure 2(b)).

Contingency-awareness questionnaire

Contingency-awareness scores were significantly higher in the CS+ condition ($M = 58.81$, SD = 20.63) than in CS− ($M = 35.83$, SD = 20.21), GCS+ ($M = 37.79$, SD = 19.91), and GCS− ($M = 34.25$, SD = 21.24) conditions, $Zs > 2.44$, $ps < 0.015$. No significant difference was observed between the GCS+ condition and the GCS− condition, $Z = 1.24$, $p = 0.213$.

Discussion

The current study aimed to determine whether punishment-related attentional priority generalizes to semantically related but perceptually unrelated stimuli. RTs to identify the colour of Stroop words were significantly slower for GCS+ trials than for GCS− trials in the learning phase, and this effect persisted into extinction. Thus, in each phase of the experiment, we observed a Stroop effect on generalized stimuli, suggesting that synonyms of words paired with shock were prioritized by attention. Contingency-awareness scores did not differ significantly between the CCS+ and GCS− conditions, which were accurately discriminated from the stimulus actually associated with shock (CS+). Participants, therefore, seem to have explicitly learned that the likelihood to receive a shock was not higher for GCS+ than for GCS−. This outcome excludes the hypothesis that an erroneous explicit learning of the relationship between GCS+ and shock was responsible of the Stroop effects observed with generalized stimuli on RTs. It is worth adding that our experimental design removed the potential confounds that phonological and orthographic similarity between either word of each pair could account for generalization (as in Grégoire & Anderson, 2019).

Our data also revealed an unexpected absence of Stroop effect with conditioned stimuli on RTs. One interpretation of this absence of effect in RT is signal suppression of punishment-related stimuli (Gaspelin & Luck, 2018). According to the signal suppression hypothesis (Sawaki & Luck, 2010), a top-down control mechanism may prevent attentional capture and reduce the processing of salient stimuli. Hickey et al. (2010) suggested that the salience of a stimulus increases after pairing with valent outcomes. Thus, words associated with punishment could be perceptually more salient than words not associated with shock. In order to perform the task more efficiently, participants, who learned the word-punishment relationships (as reflected by contingency-awareness

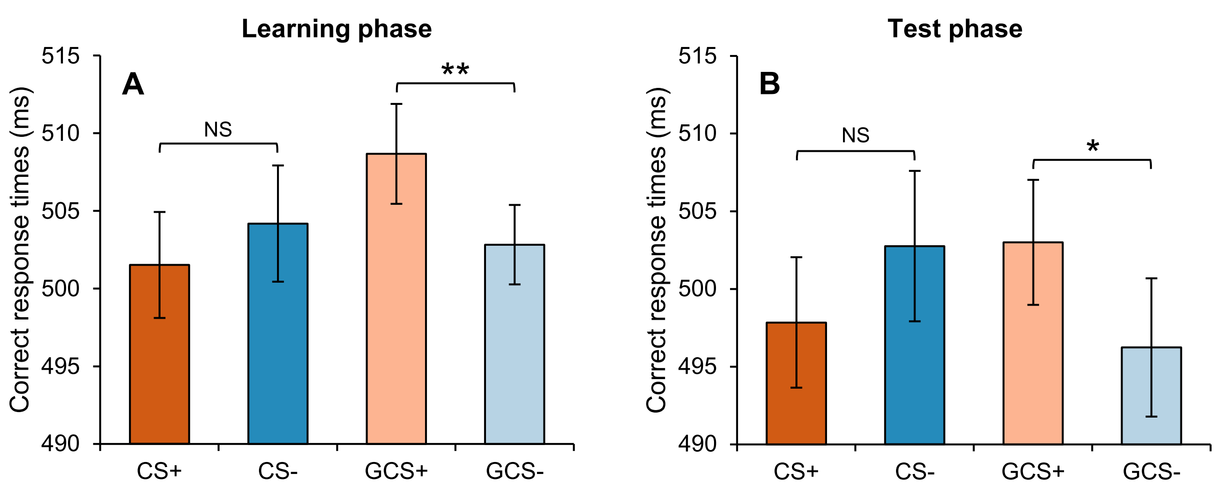

Figure 2. Correct response times as a function of condition (CS+, CS−, GCS+, GCS−) in (a) learning and (b) test phases. Error bars depict within-subjects 95% confidence intervals calculated using the Cousineau method (Cousineau, 2005) with a Morey correction (Morey, 2008). *$p < 0.05$, **$p < 0.01$, NS = non-significant.

data), might have actively suppressed the more perceptually salient punishment-associated words. Suppression of punishment-associated stimuli has been observed in at least one prior study (Grégoire, Britton, et al., 2020). An alternative explanation is that the potential increased salience of words associated with shock might facilitate the colour identification and reduce RTs in the CS+ condition. RTs for words associated with shock could thus result from two opposite influences operating concurrently. On one hand, the word-shock association would render the word more attractive for attention and so more difficult to ignore, which would increase RTs to identify the colour. On the other hand, CS+ as a whole could gain perceptual saliency after repeated pairing with shock or elicit increased arousal, which would facilitate the colour identification. The null effect observed between CS+ and CS− in RT would be the consequence of these two opposite influences. Finally, the absence of Stroop effect with conditioned stimuli on RTs could be explained by a speed-accuracy trade-off. Participants made more errors and misses on CS+ trials than on CS− trials, in each phase. Faster RTs on CS+ trials might therefore result from a decrease of accuracy. In either case, however, both conditioned and generalized stimuli were associated with a decrement in task performance despite their irrelevance to the task, which can only be explained by a bias resulting from learning.

The Stroop effect observed with generalized stimuli can evoke the classic emotional Stroop effect reported in previous studies, but several aspects distinguish the two outcomes. The emotional Stroop effect usually results from longer response times to identify the colour of emotionally charged words compared to neutral words (e.g., Algom et al., 2004). In the current study, only initially neutral words were presented, so the Stroop effect observed with generalized stimuli did not ensue from the intrinsic emotionality of words. Furthermore, the emotional Stroop task does not necessarily include semantically related emotional words (e.g., *abandonment*, *cancer*, *hatred* in Caparos & Blanchette, 2014; *burn*, *choking*, *sabotage* in Chajut et al., 2010). However, studies with patients suffering from psychological disorders reported results that seem similar to those of our experiment. For example, a greater Stroop interference was evidenced in participants with spider phobia than in controls for spider-related words (e.g., *hairy*, *crawl*) when compared to neutral words (Watts et al., 1986). More generally, patients are slower than controls to identify the colour of words specifically related to their psychopathology (see Cisler et al., 2011; Williams et al., 1996, for reviews). A possible interpretation of this result is the practice (or expertise) in the processing of such information. Psychological disorders are strongly associated with ruminations (see e.g., Ehlers & Clark, 2000; Vălenas & Szentagotai, 2014; Wilkinson et al., 2013); patients tend to frequently think about objects and situations related to their problem, which could increase the familiarity (or the idiosyncratic frequency of usage) of such information (Williams et al., 1996). Stroop interference was shown to rise with the familiarity of words (Dalgleish, 1995; Klein, 1964; but see Burt, 2002; Kahan & Hely, 2008). Thus, larger Stroop effects observed in patients with words semantically related to their psychopathology might reflect a greater familiarity for concepts associated with their concerns. Using neutral words in non-clinical participants, the Stroop effect observed with generalized stimuli in the present study is independent of the potential confounding factors mentioned above and straightforwardly highlights the ability of such biases to develop from experience in a controlled learning environment.

It is worth adding that conditioning effects can be specific in some situations. Lee et al. (2009) reported that an angry face previously paired with a shock in a conditioning phase produced a Stroop interference when compared to a neutral face of the same gender, but this interference effect did not generalize to an angry face of the opposite gender (which was not paired with shock in the conditioning phase; see also Grégoire et al., in press, for an example of specific contextual generalization). Although the nature of the relationship between the two angry faces did not seem exclusively semantic, contrary to the relationship between the CS+ and the GCS+ in the present study, this outcome reveals that aversive conditioning effects do not systematically transfer to stimuli related to the CS+.

To conclude, our results are consistent with a semantic generalization of stimulus-punishment associations in the control of attention. Our findings are inconsistent with the idea that the effects of aversive conditioning on the control of attention are restricted to the specific stimulus features previously paired with aversive outcomes. The present study highlights an important role for semantics in punishment-driven attention, providing fundamental insights into its representational basis.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by a grant from the National Institute on Drug Abuse [R01-DA046410] to Brian A. Anderson.

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