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Experiencing extinction with a non-target cue facilitates reversal of a target conditioned inhibitor in human predictive learning

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ABSTRACT

Three experiments tested the effect of experiencing extinction on learning about a differential conditioned inhibitor that was trained as an excitor. A human predictive learning task was used in which participants had to evaluate the probability of different colored fertilizers (Cues) leading plants to flourish or not (Outcome). Experiment 1 found that presenting the target cue without outcome while other cues were followed by the outcome made the target cue a conditioned inhibitor, passing both, retardation (Experiment 1a) and summation (Experiment 1b) tests of conditioned inhibition. Subsequent extinction of a different cue facilitated reversing the relationship between the conditioned inhibitor and the outcome regardless of whether the situation could be solved by using simple rules (Experiment 2) or not (Experiment 3). Results are discussed in terms of attentional theories that suggest extinction produces a nonspecific increase in attention that facilitates learning.

1. Introduction

An essential role of learning is allowing organisms to make their environment more predictable by using past experiences to predict future events (Kareev, 1995). Thus, learning may be understood as reduction of the uncertainty that produces the prediction error by detecting the regularities of the environment (e.g., Rescorla and Wagner, 1972). Prediction error is defined as the discrepancy between what the organism expects and what the organism receives, and it is assumed to decrease as learning progresses. The learning process is captured within Pavlovian associative learning models by the delta rule, as the mechanism that reduces the prediction error by updating the expected relationship between a given cue and a given outcome (e.g., Mackintosh, 1975; Pearce and Hall, 1980; Rescorla and Wagner, 1972; Sutton and Barto, 1981).

However, regularities in the environment sometimes change, and the organism should be able to adapt to those changes by updating its information about the environment. For instance, in associative interference, the meaning of the cue changes, so that either it is no longer followed by the outcome (extinction), or it is followed by a different outcome, leading to a sudden increase in the prediction error that reactivates the learning mechanism (e.g., Miller and Escobar, 2002). According to theoretical perspectives, prediction errors are assumed to increase the attention received by the cues involved, affecting subsequent learning about those cues (e.g., Pearce and Hall, 1980). For instance, it has been shown that animals learn faster about a conditioned stimulus (CS) that was an inaccurate predictor in a previous stage of learning than about a CS that was an accurate predictor of the unconditioned stimulus (Swan and Pearce, 1988; Wilson et al., 1992). Experiencing extinction also seems to facilitate subsequent learning about the extinguished cue. Hall and Pearce (1982) reported an attenuation of the negative transfer that is found when a CS is sequentially paired with a weak and a strong shock if the CS is presented in extinction before the final conditioning (see also Griffiths et al., 2011 for a replication of this effect in humans). This attenuation was stimulus specific; that is, extinction of a different CS did not attenuate the negative transfer effect on the target cue (Hall and Pearce, 1982, Experiment 2).

Notwithstanding the result reported by Hall and Pearce (1982), some suggest that prediction error increases learning about CSs that are not involved in generating the error (Larrauri and Schmajuk, 2008). In a related idea, Le Pelley et al. (2016), suggest that uncertainty engages an attentional exploratory mechanism, leading to a general search in the environmental resources that facilitates new learning. In line with the idea that prediction error may increase an organism's attention and, facilitate new learning, recent reports from our laboratory have shown that new learning may be promoted by the experience of associative interference. For instance, Alcalá et al. (2019a) trained two groups of

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rats with a simple discrimination between two CSs: one followed by food and the other presented alone. In a second stage of training, the relationship of each CS with the food was reversed in the experimental group (discrimination reversal), while it was kept the same in the control group. All the animals then received temporal conditioning training in which food was presented under a fixed time schedule in the absence of stimuli. Rats that had the reversal experience learned faster about the fixed time schedule than rats that did not have the experience of interference (see Nelson et al., 2018, for an analogous study in humans). Similar results have been reported within the spatial learning domain (Alcalá et al., 2019b; Shanab and Cotton, 1970).

Studies conducted with humans using memory tasks make a similar point. Potts and Shanks (2014) examined the possible benefit of experiencing errors during learning. Participants learned definitions of unfamiliar English words, or translations for foreign vocabulary. Participants in the Generate condition gave a definition of the word and they received corrective feedback. Participants in group Read had to read the word and the correct definition or translation; and participants in group Choice had to select from a choice of definitions receiving feedback afterwards. In the test phase, participants in the Generate condition showed better performance, even when information was novel. Authors pointed out that the discrepancy that occurs between the response participants gave and the correct one leads to surprise, and in turn to an increase in attention that facilitated coding of the correct response (see also Seabrooke et al., 2019).

However, facilitation of learning by the experience of interference is not ubiquitous. Using rats' appetitive conditioning, Alcalá et al. (2018), did not find facilitation of learning about a simple relationship between a conditioned stimulus and food following associative interference (discrimination reversal), though they found that associative interference did facilitate context conditioning.

Given this background, the goal of this study was to explore the generality of the effects of interference upon new learning by testing whether associative interference facilitates excitatory learning within a human predictive learning situation. Specifically, our interest was to test whether the experience of extinction with a cue would attenuate retardation of learning about a different cue that had been pre-exposed. Note that the study by Alcalá et al. (2018) failed to find a beneficial effect of reversal training upon learning about a new CS that, because of its novelty, may have been already highly attended. In this experimental series, the effect of extinction upon learning was tested using a cue that had been previously pre-exposed, under the assumption that facilitation of learning would be easier to detect in a situation in which learning is known to proceed more slowly (Lubow and Moore, 1959).

To explore whether extinction facilitates learning about a pre-exposed cue, we conducted three experiments. Experiment 1 was conducted to characterize the task, trying to determine whether pre-exposing a cue in this specific procedure rendered the cue as a latent inhibitor or as a conditioned inhibitor. A within-subject design was used in which learning about the relationship between the pre-exposed cue and the outcome was compared with learning about a new cue (Experiment 1a); and in which the ability of the pre-exposed cue to reduce responding to a positive predictor was compared with a new cue (Experiment 1b), in the typical retardation and summation tests of conditioned inhibition, respectively (Rescorla, 1969b, 1971). Once shown that pre-exposing a cue in this task renders the cue as a conditioned inhibitor, rather than a latent inhibitor, Experiment 2 was conducted with the goal of evaluating whether experiencing extinction with a different cue attenuated the retardation of learning that was observed in Experiment 1 when the conditioned inhibitor was paired with the outcome. Finally, Experiment 3 was conducted with the goal of testing whether results of Experiment 2 could be replicated in a situation designed to prevent the use of rules by participants.

2. Experiment 1

The goal of Experiment 1 was to characterize the basic phenomenon upon which the influence of the extinction manipulation on new learning was going to be subsequently evaluated in Experiments 2 and 3. Simple exposure to a stimulus without outcomes typically leads to latent inhibition, operationalized as a retardation of subsequent learning about the relationship between the pre-exposed cue and a given outcome (e.g., Lubow and Moore, 1959; see also Pineño et al., 2006). However, when simple exposure to a cue takes place at the same time as a different cue is paired with the outcome, the nonreinforced cue may become a conditioned inhibitor. For instance, Rescorla (1969a) found that establishing a negative contingency between a CS and a shock makes the CS a conditioned inhibitor, inhibition that was greater the greater was the negative contingency (see also Rescorla, 1966, 1968). In similar lines, a standard result in human predictive learning in our laboratory is that the first predictive judgment participants make about the relationship between a cue that has not been presented before and an outcome is located around the middle of the predictive judgments scale (around 40–50 in a scale from 0 to 100). In subsequent trials, participants rapidly tend to give judgments close to 100 when the cue is followed by the outcome, and close to 0 when the cue is not followed by the outcome (e.g., Nelson and Callejas-Aguilera, 2007). This pattern of responding to the nonreinforced cues further suggests the idea that simple exposure to a cue may render it as a differential conditioned inhibitor, instead of a latent inhibitor.

Experiment 1 dealt with these two potential consequences of presenting the cue without the outcome. The design of the experiment is presented in the top two sections of Table 1. Three different cues (Ci, the pre-exposed and then conditioned cue; P, a cue consistently paired with the outcome, and F1, a filler) were either followed, or not followed by the outcome within a human predictive learning situation in which participants had to predict whether watering a garden with a given product (cue) would make flowers grow or not (outcome). In Experiment 1a, the pre-exposed cue Ci was followed by the outcome at testing, comparing its performance with learning about a new cue, N. During the test of Experiment 1b, cues Ci and N were presented paired with cue P, in a summation test. Note that this design controls for the potential effects of a generalization decrement caused by presenting together two stimuli that were previously trained separately, as the generalization decrement would be expected to be at least as high when the pre-exposed stimulus is presented together with the excitor than when the stimulus paired with the excitor is a new one. If the pre-exposed cue becomes a latent inhibitor then it will pass the retardation test (Experiment 1a), but not the summation test (Experiment 1b). Alternatively, if pre-exposing a cue in this task renders the cue as a conditioned inhibitor it will pass both, the retardation and the summation

Table 1
Experimental designs.

Experiment	Group	Phase 1	Phase 2	Test Phase
1a	–	12Ci-, 12P+, 3F1-	–	8Ci+, 8N+, 16F1-
1b	–	12Ci-, 12P+, 3F1-	–	1CiP-, 1NP-, 1F2+,
2	Extinction	12Ci-, 12E+, 3F1-	4E-	8Ci+, 8F1-
	Control	12Ci-, 12E+, 3F1-	4F1-	8Ci+, 8F1-
3	Extinction	12Ci-, 12E+, 3F1-, 4F2+	4E-, 4F1-, 4F2+	8Ci+, 8F1-
	Control	12Ci-, 12E+, 3F1-, 4F2+	2E+, 8F1-, 2F2+	8Ci+, 8F1-

Note: Yellow Gold, Blue Natural, Red Protector, Green Gardener and Pink Purifier fertilizers were counterbalanced as cues Ci, E, P, N, F1 and F2 across participants; "–" and "+" represent the presence and the absence of the outcome, respectively (growth or not of the plants). Numbers represent the amount of trials with each cue-outcome combination.

tests of conditioned inhibition.

2.1. Method

2.1.1. Participants

Fifty students' volunteers from the Universidad de Jaén participated in the study (24 in Experiment 1a and 26 in Experiment 1b). Their age ranged between 17 and 43 years old (Mean = 20.18; SD = 4.03); In Experiment 1a, there were 16 women and 8 men. In Experiment 1b, there were 22 women and 4 men. Participants were rewarded with course credit for their participation and they had no experience with the used task. The participants gave informed consent before starting the task.

2.1.2. Apparatus

Participants performed the experiments in a room that had a total of 12 personal computers with 27″ LCD monitors at 1366 × 730 resolution, distributed in different cabins.

The task used in this experimental series was described by Rosas and Callejas-Aguilera (2006; see also Nelson and Callejas-Aguilera, 2007)). The task was programmed using SuperLab Pro 4.06 and was conducted in Spanish, participants' mother tongue. Participants had to evaluate the effectiveness of a series of colored fertilizers (cues) to favor plants' growing (outcome). The fertilizers consisted of colored watering cans used as cues: Yellow Gold, Blue Natural, Red Protector, Green Gardener and Pink Purifier. These colored fertilizers were counterbalanced as cues Ci, P, N, F1 (and F2 in Experiment 1b) between-subjects. The outcomes (represented as + or -) were flowers growing or not.

Cues and outcomes were presented through a series of videos and photographs prepared for the task. In the animation, there were four different elements: A pink country house was presented in the top left side of the screen, with its label, *Vivero de la Casona*, presented in white font within a pink rectangle at the top right side of the screen. The fertilizer presentation was made through his spill in a garden plot during 2000 ms. Garden plot appeared below the *Vivero de la Casona* label, near the middle of the screen. The animation consisted of filling the watering can with the proper fertilizer. Once full, it spilled into the planter. On the left side, there was a label *Soil treated with*, and the name of the fertilizer used in the correspondent trial.

After the fertilizer animation, a scale at the bottom appeared together with the question: *What do you think is the probability of the plants flourishing?* This scale was placed under the garden plot and the fertilizer that had been used in the trial. In turn, it contained 21 possible response buttons. The scale ranged from 0 to 100 divided into units of 5 to 5. Also, the scale had some labels that helped the valuation: None (above 0 score), Little (around the score 30–35), Quite (around the score 60–70) and Great (over the scores 95–100). The program saves the response immediately after it was emitted with the text panel *Registered Response* on the scale for 1500 ms. The outcome was presented immediately afterwards.

The outcome was the flourishing or non-flourishing of the plants depending of the role that the cue plays in the design. The screen was identical to the previous one, with the difference that, in the feedback screen, an empty gardener appeared. If the fertilizer made the plants flourish, two red flowers emerged from the garden plot with the following message: *The flowers grow*. In the case that fertilizer had no effect, the same planter remains empty with the message *No effect*. In both cases, the duration of the animation was 2000 ms length.

The intertrial interval (ITI) consisted of a blank screen with a yellow button in the lower left message with the following message *Click here to continue*. Thus, ITI duration was controlled by the participant.

2.1.3. Procedure

Participants entered the room in small groups (8–10 participants at a time) being randomly assigned to each experimental condition. Each sat in front of a computer screen where the task was located. Before starting the task, the student had to read, complete and sign the informed consent with no further details of the task. Once the participant signed the informed consent, task began. Instructions were presented in Spanish:

Instructions were presented in three different screens. The transition between screens was controlled by participants by using the button "*Continue*" at the bottom of each screen. Screen 1 presented the coloured fertilizers that were going to be used in the task and the following message: "*We are studying the effect of new products on the treatment of the soil. At the moment we do not know their effect.*" In Screen 2 there were two garden plots, one with flowers and the other without them, with the sentence: *Throughout the task, you will see what happens to the soil when it is treated with each of the new products*. Screen 3 presented an image of the response scale with the following sentence: *First, you will see the colored fertilizer used and then you will have to indicate if, because of the treatment, the flowers grow or not. To make your prediction you must click on the value that you consider most appropriate. When you do that, the message Registered Response will appear. At first you will respond randomly, but do not worry, you will become an expert soon.* Instructions were followed by a practice trial that used a fertilizer and a background different from the ones used during the actual task, which began immediately afterwards.

2.1.3.1. Training. Training trials were identical to the practice trial with the exception that they were followed by feedback. Each cue played a distinctive role: Ci was the pre-exposed cue; N was a new cue; P was the cue with a positive relationship with the outcome; and F1 and F2 were fillers; + and - represented the presence or absence of the consequence, respectively. Participants received a total of 27 trials during Phase 1 (12 for Ci-, 12 for P + and 3 trials for F1) separated in 3 identical blocks. In each block of trials, all participants received 4 trials of each combination Ci- and P+, and 1 trial of F1-. Trials in each block were randomly intermixed.

2.1.3.2. Test. In Experiment 1a participants received 32 trials separated in 4 identical blocks. In each block of trials, all participants received 2 trials of each combination Ci + and N+, and 4 trials of F1- in cycles as follows: Ci+, F1-, N+, F1-, F1-, N+, Ci+, F1-. In Experiment 1b, participants received one trial with each compound: CiP- and NP-. Filler F2+ was included so that participants could not solve the task by assuming that no stimulus was reinforced at testing. The order was counterbalanced: NP-, F2+, and CiP- for half of the participants, and CiP-, F2+, NP- for the other half.

2.1.4. Dependent variable and statistical analysis

Response in the predictive judgments scale was recorded in all the trials (training and testing). For the sake of simplicity, responding to the fillers is not reported here, except where responding to the fillers adds support to the test of the hypothesis. Predictive judgments were evaluated with an analysis of variance (ANOVA). The rejection criterion was established at $p < 0.05$. Additionally, 95% confidence intervals for the effect sizes are reported in the critical analyses conducted during the test phase.

2.2. Results and discussion

2.2.1. Experiment 1a

Performance throughout the different phases of Experiment 1 is presented in Fig. 1. Panel a) of Fig. 1 presents mean predictive judgments to cues Ci and P across the twelve trials of Phase 1 in Experiment 1a. Mean ratings decreased quickly to Ci and increased quickly to P after the first training trial. A 2 Cue (Ci vs. P) x 12 Trial ANOVA found a significant main effect of Cue, $F(1, 22) = 485.13$, Mean Square error (MSe) = 1933.55, $p < .001$, but not of Trial, $F < 1$. There was a significant interaction of Cue x Trial, $F(11, 242) = 54.76$, MSe = 148.57, $p < .001$. Subsequent analyses conducted to explore the interaction

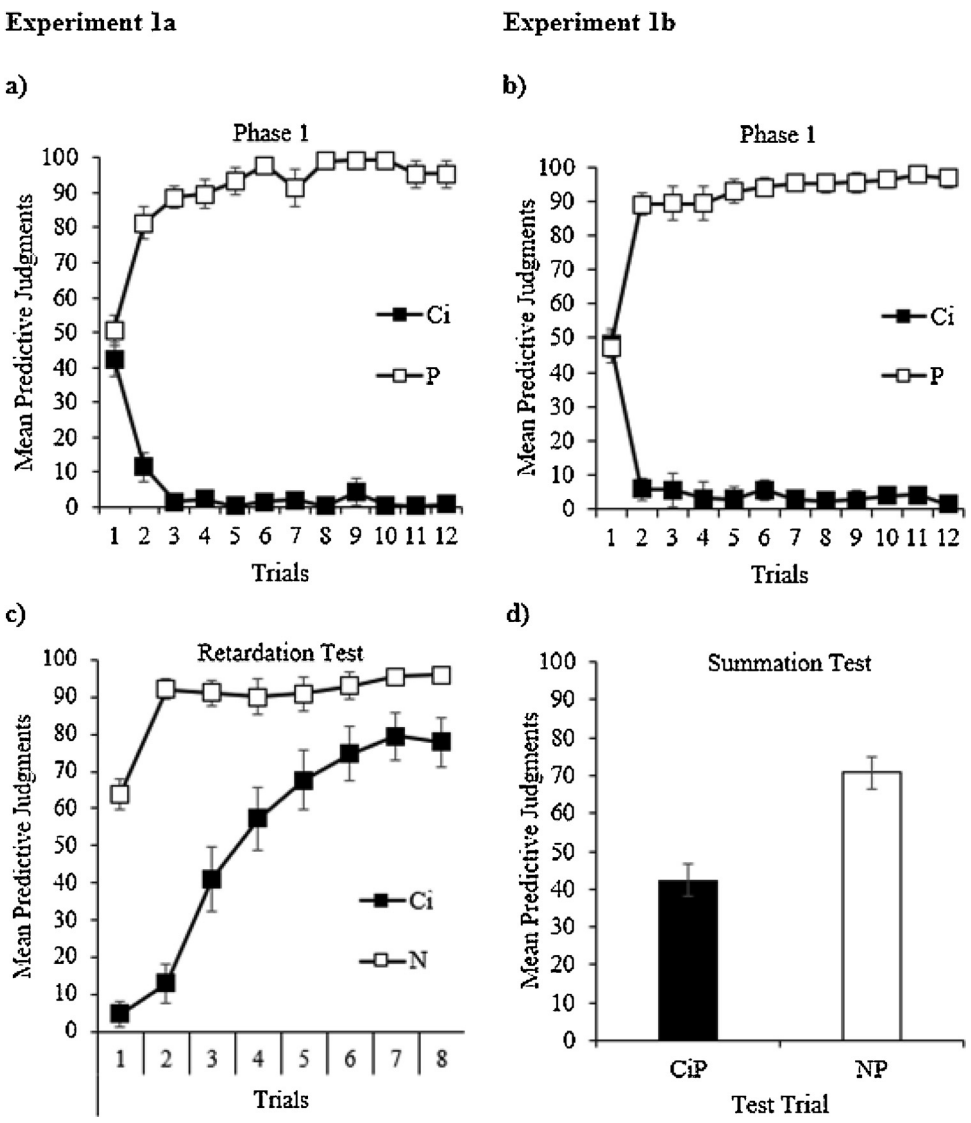

Fig. 1. Mean predictive ratings about the relationship between cues Ci and P and the outcome throughout the 12 trials of training (Phase 1) of Experiment 1a (panel a) and Experiment 1b (panel b). Panels c and d present testing performance. Panel c presents mean ratings to cues Ci and N throughout the 8 trials during the retardation test of Experiment 1a. Panel d presents ratings to the CiP and NP compounds during the summation test of Experiment 1b (below right). Error bars denote standard errors of the mean.

found that the simple effect of Cue was statistically significant in the second and subsequent trials, $F(1, 22) = 107.37$, MSe = 750.25, $p < .001$, for the largest p value found in Trial 3.

Panel c) of Fig. 1 presents mean predictive judgments to cues Ci and N during the retardation test of Experiment 1a. Judgments about Ci increased more slowly than judgments about N. A 2 Cue (Ci vs. N) x 8 Trial ANOVA found significant main effects of Cue $F(1, 22) = 71.90$, MSe = 1755.43, $p < .001$, $\eta p^2 = .77$, 95% CI [.97, .99] and Trial, $F(7, 154) = 38.41$, MSe = 422.52, $p < .001$, $\eta p^2 = .64$, 95% CI [.53, .69]. Most important, the Cue x Trial interaction was significant, $F(7, 154) = 15.58$, MSe = 400.65, $p < .001$, $\eta p^2 = .42$, 95% CI [.27, .49]. Subsequent analyses conducted to explore the interaction found a simple effect of Cue in all the trials, $F(1, 22) = 8.34$, MSe = 347.33, $p = .009$, $\eta p^2 = .28$, 95% CI [.02, .51], for the largest p value corresponding to Trial 7.

These results show that the task used here is sensitive to detect the effects of pre-exposing a cue upon subsequent learning about the relationship between the cue and the outcome, a result that was expected regardless of whether pre-exposure made cue Ci a conditioned inhibitor or a latent inhibitor. However, the initial assessments for cue Ci at testing fell below those observed for the new cue, suggesting that cue Ci might be acting as a conditioned inhibitor if the scale detected a bi-directional relationship with the neutral point placed around the middle section of the scale.

The interaction suggests that acquisition of cues Ci and N differed. However, cue N reached the asymptote of the dependent variable scale quite fast, and judgments were still different between cues at the end of training. Consequently, the difference in the rate of learning observed in this experiment could be an artifact of a ceiling on judgments, leaving open the possibility that pre-exposing a cue in this procedure would affect either or both, the rate, and the asymptote of learning.

In any case, the results do not suggest that pre-exposing the cue results in latent or conditioned inhibition.

2.2.2. Experiment 1b

Mean ratings to Ci and P during Phase 1 of Experiment 1b are presented in panel b) of Fig. 1. Judgments to P increased while those to Ci decreased throughout training similarly to what it was found in Experiment 1a. A 2 Cue (Ci vs. P) x 12 Trial ANOVA found a significant main effect of Cue, $F(1, 25) = 2805.08$, MSe = 395.77, $p < .001$, but

not of Trial, $F < 1$. The Cue x Trial interaction was statistically significant, $F(11, 275) = 38.91$, MSe = 212.38, $p < .001$. Subsequent analyses found a significant simple effect of cue in the second and following trials, $F(1, 25) = 97.69$, MSe = 648.48, $p < .000$, $\eta p^2 = .56$, for the largest p value, corresponding to Trial 2.

Panel d) of Fig. 1 shows the results of the summation test comparing responding to CiP and NP compounds in Experiment 1b. Mean responding to compound CiP was lower than mean responding to compound NP, $F(1, 25) = 23.78$, MSe = 442.77, $p < .001$, $\eta p^2 = .49$, 95% CI [.18, .66], suggesting that cue Ci passed the summation test of conditioned inhibition. That is, judgments to a cue that was previously paired with the outcome (P) were lower when it was presented paired with the pre-exposed cue (CiP), than when it was presented paired with a new cue (NP). The results suggest that pre-exposure resulted in pre-exposing cue Ci renders this cue as a conditioned inhibitor, rather than a latent inhibitor.

3. Experiment 2

Previous research has shown that experiencing a prediction error may facilitate subsequent learning about stimuli that are not among the ones that generate the prediction error (e.g., Alcalá et al., 2019a; 2019b; Nelson et al., 2018; Shanab and Cotton, 1970; but see Alcalá et al., 2018). The goal of Experiment 2 was to test the generality of the effect of extinction experience on subsequent to human predictive learning.

3.1. Method

3.1.1. Participants

Thirty-six students from the Universidad de Jaén participated in this experiment. Their age ranged between 18 and 43 years old (Mean = 19.36; SD = 4.21); 30 of the participants were women and 6 were men.

3.1.2. Apparatus and procedure

Apparatus and procedure were the same described above for Experiment 1 except where noted. The design of the experiment is presented in Table 1. Participants were randomly assigned to group Extinction or group Control upon their arrival to the laboratory. The acquisition phase for both groups was identical to the one described in Experiment 1, with the exception that cue P was labeled as cue E here, as it was the cue that received the extinction treatment in group Extinction (see third section of Table 1). Groups differ in the treatment they received during Phase 2. Group Extinction received 4 extinction trials with cue E while group Control received 4 nonreinforced trials with cue F1. Finally, during the test phase, both groups received a discrimination training in which cue Ci was followed by the outcome while F1 was presented without outcome. The test phase involved 8 trials with each cue. Those trials were grouped in 4 blocks so that there were two trials of Ci + and F1- per block. All participants received the test trials in a fixed sequence that was as follows: Ci+, F1-, Ci+, F1-, F1-, Ci+, F1-, Ci+, Ci+, F1-, Ci+, F1-, F1-, Ci+, F1-, Ci+. Faster learning about the relationship between cue Ci and the outcome in group Extinction group than in group Control would suggest extinction facilitated new learning.

3.2. Results and discussion

Fig. 2 presents mean predictive ratings across the 12 trials with cues Ci and E of Phase 1, the 4 extinction trials with E of Phase 2, and the 8 trials with Ci during the retardation test in groups Extinction and Control of Experiment 2. During Phase 1 (left section of Fig. 2), participants increased responding to E and decreased responding to Ci regardless of the group. A 2 Group (Extinction vs. Control) x 2 Cue (Ci vs. E) x 12 Trial ANOVA found a significant main effect of Cue $F(1, 33) = 438.03$, MSe = 2653.53, $p < .001$, and a Cue x Trial significant interaction, $F(11, 363) = 32.78$, MSe = 267.77, $p < .001$. No other effects or interactions were statistically significant, $F(11, 363) = 1.46$, MSe = 237.77, $p < .143$ for the largest p value for the main effect of Trial. During Phase 2 (middle panel), responding to E decreased progressively, $F(3, 51) = 10.45$, MSe = 684.10, $p < .001$, showing that the extinction treatment was effective on reducing responding to cue E.

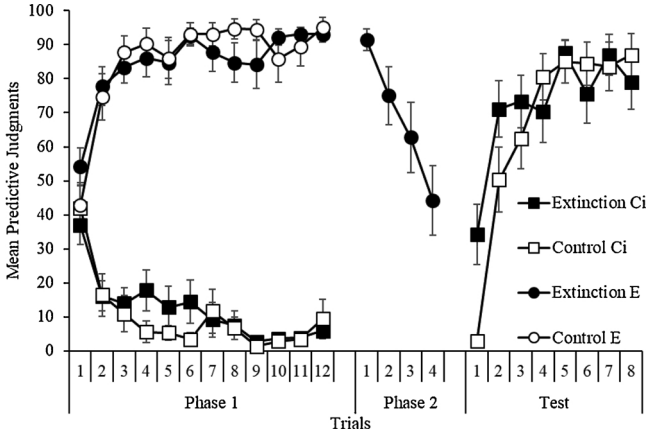

Fig. 2. Mean predictive ratings across the 12 trials with cues Ci and E of Phase 1 (left), the 4 extinction trials with cue E of Phase 2 (middle), and the 8 trials with cue Ci during the retardation test (right) of Experiment 2. Error bars denote standard errors of the mean.

The critical result is presented in the right section of Fig. 2. Ratings to Ci developed faster in group Extinction than in group Control. A 2 Group (Extinction vs. Control) x 8 Trial ANOVA found a significant main effect of Trial, $F(7, 238) = 32.31$, MSe = 563.25, $p < .001$, $\eta p^2 = .49$, 95% CI [.39, .55], and a Group x Trial significant interaction, $F(7, 238) = 3.62$, MSe = 563.25, $p < .001$, $\eta p^2 = .10$, 95% CI [.02, .15]. The main effect of group was not significant, $F < 1$. Subsequent analyses conducted to explore the Group x Trial interaction found a significant simple effect of Group in Trial 1, $F(1, 34) = 12.00$, MSe = 738.93, $p < .001$, $\eta p^2 = .26$, 95% CI [.05, .46]. The simple effect of Group was not significant in the rest of trials, $F(1, 34) = 2.73$, MSe = 738.93, $p < .108$, for the largest p value corresponding to Trial 2.

A Group x Trial interaction seems to favor the idea that the experience of extinction facilitates learning about cue Ci in group Extinction relative to group Control. However, note that the differences between groups were only reliable in the first training trial, a trial where no differences were expected, as participants could not have experienced that the meaning of cue Ci had changed. This pattern of results suggests that the facilitation effect of interference upon learning in this experiment may be based on a mechanism that allows participants to anticipate that the meaning of Ci has changed before even experiencing that change. Note that the design was arranged so that only cue E was presented during Phase 2 in group Extinction. The change in the meaning of cue E between Phases 1 and 2 could have led participants in group Extinction to think that the meaning of all the cues had also changed, solving the test by a simple rule that would be confirmed in the very first test trial, as every participant started the test with a change in the meaning of the conditioned inhibitor. The use of rules is a common mechanism to solve discriminative learning tasks in human predictive learning (see for instance, Matute et al., 2002; Shanks and Darby, 1998), and it is not usually found with other species (Maes et al., 2015).

Whether participants were using rules or not to solve the task could be further confirmed by evaluating responding to the first F1 trial during the test. Responding to the filler cue F1 during the first testing trial was 30.83 (SE = 9.64) in group Extinction and 9.72 (SD = 8.89) in group Control, suggesting that extinction of E led participants to

anticipate that the outcome of cue F1 had also changed. A 2 Group (Extinction vs. Control) x 2 Cue (Ci vs. F1) ANOVA conducted with data from the first training trial of testing found a significant main effect of Group, $F(1, 34) = 28.53$, MSe = 12403.13, $p < .001$, $\eta p^2 = .46$, 95% CI [.20, .62], with no significant interaction between Group and Cue, $F < 1$.

In summary, Experiment 2 found that extinction of a cue facilitated anticipation of a change in the outcomes of different cues. This is consistent with the possibility that participants used some kind of rule at the time of testing. As the extinguished stimulus E, and stimuli Ci and F1 changed in opposite directions, the rule could states that "all stimuli have changed their relationship with the outcome." At any rate, exploring the type of rule participants applied to this situation was not examined in this experimental series. The goal of this series was to test whether the increase in the prediction error that experiencing interference produces may facilitate subsequent new learning. Accordingly, Experiment 3 was designed to prevent the use of simple rules by participants. The goal was to test whether an effect of the interference experience on new learning could be detected in the absence of rule learning (e.g. Alcalá et al., 2019a).

4. Experiment 3

Experiment 3 aimed to test whether reversing the relationship with the outcome of a conditioned inhibitor could be facilitated by extinction of a different cue in a design that precludes the use of general rules to solve the task.

The design of Experiment 3 is presented in the bottom section of Table 1. The key aspects of the design are identical to the design used in Experiment 2, with the exception that additional fillers were presented across Phases 1 and 2. Group Control had a similar treatment with the exception that no cue was extinguished during Phase 2.

4.1. Method

4.1.1. Participants

Thirty-two students from the Universidad de Jaén participated in this experiment. Their age ranged between 17 and 28 years old (Mean = 19.25; SD = 2.16); 24 of the participants were women and 8 were men.

4.1.2. Apparatus and procedure

Apparatus and design of Experiment 3 were identical to the ones used in Experiment 2 with the following exceptions: Four trials with F2 followed by the outcome were included in Phase 1; three stimuli (E, F1 and F2) were presented during Phase 2 in both groups (see fourth section of Table 1). Only stimulus E, and only in group Extinction, reversed its relationship with the outcome in this phase. The design was arranged so that the experience with stimuli and the outcome was equated across groups. During Phase 2, participants received a total of 12 trials grouped in two blocks of 6 trials each. For the Extinction group, each 6-Trial block included 2 presentations of E-, F1- and F2. For the Control group, each block included 1 presentation of E+, 1 of F2+, and 4 of F1-. Trials in each block were randomly intermixed. Note that cues F1 and F2 did not change their relationship with the outcome during Phase 2 in group Extinction. This arrangement was expected to prevent participants anticipating the change in Ci without experiencing that change at testing. Test was identical to the one used in Experiment 2.

4.2. Results and discussion

Fig. 3 presents mean predictive ratings across the 12 trials with cues Ci and E of Phase 1, the 4 extinction trials with E of Phase 2, and the 8 trials with Ci during the retardation test in groups Extinction and Control of Experiment 3. During Phase 1 (left section of Fig. 3), participants' judgments to pre-exposed cue Ci decreased, while judgments to cue E increased. A 2 Group (Extinction vs. Control) x 2 Cue (Ci vs. E) x 12 Trial ANOVA found significant main effects of Cue, $F(1, 30) = 346.33$, MSe = 3413.09, $p < .001$, and Trial, $F(11, 330) = 2.61$, MSe = 231.63, $p < .003$. The Cue x Trial interaction was significant, $F(11, 330) = 40.59$, MSe = 228.28, $p < .001$. No other main effects or interaction were statistically significant, $Fs < 1$. During Phase 2 (middle panel) predictive judgments to E cue decreased in group Extinction, $F(3, 45) = 6.93$, MSe = 956.57, $p < .001$.

The critical results are presented in the right section of Fig. 3. Learning about the relationship between the conditioned inhibitor (Ci) and the outcome was faster in group Extinction than in group Control. A 2 Group (Extinction vs. Control) x 8 Trial ANOVA found a significant main effect of Trial, $F(7, 210) = 36.74$, MSe = 550.73, $p < .001$, $\eta p^2 = .55$, 95% CI [.45, .61], and a significant Group x Trial interaction, $F(7, 210) = 2.31$, MSe = 550.73, $p < .027$, $\eta p^2 = .07$, 95% CI [< .001, .12]. The main effect of Group was not significant, $F(1, 30) = 2.15$, MSe = 5783.51, $p < .153$. Subsequent analyses conducted to explore the Group x Trial interaction found that the simple effect of Group was significant only in Trial 2, $F(1, 30) = 7.90$, MSe = 1645.78, $p < .009$, $\eta p^2 = .21$, 95% CI [.01, .43].

A complementary analysis was conducted in Trial 1 to test the hypothesis of rule learning. In this case, ratings to the filler cue F1 during the first testing trial were 16.18 (SD = 33.29) in group Extinction and 9.67 (SD = 27.55) in group Control. In contrast to what it was found in Experiment 2, there were no differences between groups in the first test trial. A 2 (Extinction vs. Control) x 2 Cues (Ci vs F1) ANOVA found that neither the main effects, nor the interaction, were significant, largest $F(1, 30) = 1.93$, MSe = 853.52, $p < .175$, for the main effect of Group.

In summary, results of Experiment 3 were somewhat similar to the results of Experiment 2, with the exception that facilitation of learning was reliable only after Trial 1 in Experiment 3. This difference may seem subtle, but it is essential for the interpretation of the results. The lack of differences in Trial 1 in this experiment suggests that the design manipulation, including stimuli that kept their meaning stable between Phases 1 and 2, prevented participants from using a simple rule to anticipate the change in the meaning of the conditioned inhibitor during the test phase. Participants could have used a general rule to solve the test by assuming that some stimuli change its meaning while some others do not. That hypothetical rule would be applied only after the first experience with the change. Discarding the use of a general rule of that type is not easy, as the expected performance of using that rule is isomorphic to the one expected if the experience of interference produces a nonspecific increase in attention. At any rate, the results suggest that the experience of extinction attenuates the retardation effect that appears when a conditioned inhibitor is paired with the outcome.

5. General discussion

The main goal of this experimental series was to explore whether extinction of a nontarget cue facilitates excitatory conditioning of a conditioned inhibitor. Experiment 1 established that pre-exposure to a stimulus while other stimuli were paired with the outcome, rendered the stimulus as a conditioned inhibitor. The pre-exposed stimulus passed both, retardation (Experiment 1a) and summation (Experiment 1b) tests of conditioned inhibition. Experiments 2 and 3 analyzed the effect of extinction on new learning about conditioned inhibition. We expected that extinction with a different cue would produce a nonspecific increase in attention that would enhance subsequent excitatory training of the conditioned inhibitor (e.g., Alcalá et al., 2019b; see Le Pelley et al., 2016; Schmajuk et al., 1996; c.f. Hall and Pearce, 1982). The results of Experiments 2 and 3 were consistent with this prediction.

The results support the idea that the increase in prediction error that accompanies an extinction treatment facilitates subsequent learning. In this experimental series, extinction of a cue enhanced subsequent

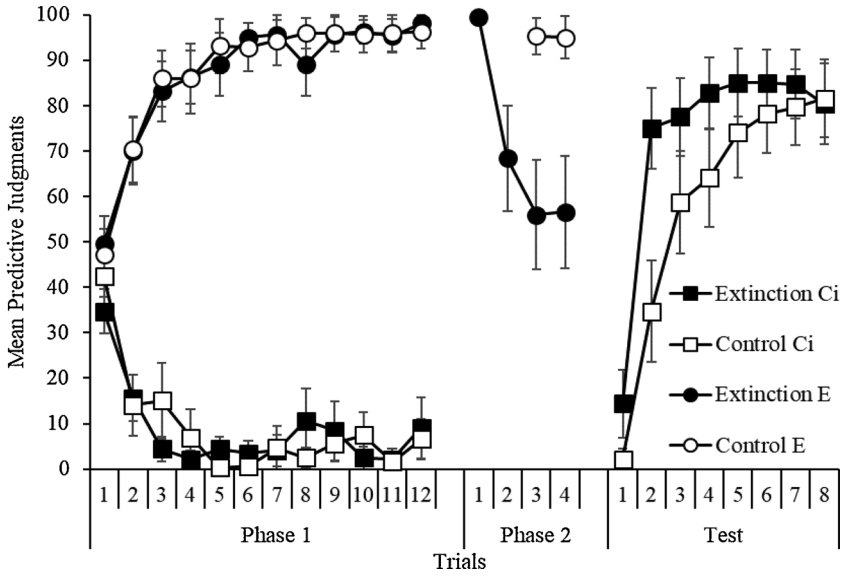

Fig. 3. Mean predictive ratings across the 12 trials with cues Ci and E of Phase 1 (left), the 4 extinction trials with cue E of Phase 2 (middle), and the 8 trials with cue Ci during the retardation test (right) of Experiment 3. Error bars denote standard errors of the mean.

excitatory learning of a different cue. This facilitation of learning appeared in the first test trial of Experiment 2, suggesting that the extinction experience may have allowed participants to anticipate the change in the outcomes of the conditioned inhibitor at testing before having experienced it. This result is easily explained by assuming that participants in group Extinction established a simple rule, generalizing the change in the outcomes of stimulus E during Phase 2 to all the stimuli presented during Phase 1, so that participants anticipate a change in the outcome of any stimulus presented at testing (see Matute et al., 2002; Shanks and Darby, 1998). This idea receives further support by the results obtained with F1, the filler stimulus that was presented without outcome throughout training and testing. Similar to what was found with the target stimulus Ci, participants in group Extinction increased judgments in the first trial of testing when compared to the control group, a result consistent with the idea that participants that experience the change in the outcomes of E during Phase 2 generalized the change in the outcomes to all the stimuli trained in Phase 1.

Extinction also enhanced learning in Experiment 3. The design prevented the solution of the task by simple rules. In this case, facilitation appeared after experiencing the change in the outcomes in the first training trial. Therefore, potential mechanisms of facilitation may have been the interference experience. A potential candidate as the mechanism of learning facilitation by the interference experience is the increase in general attention (Schmajuk et al., 1996) or in the engagement of the attentional exploratory mechanism (Le Pelley et al., 2016). According to these ideas, extinction leads the organism to increase the use of its attentional resources in order to establish new regularities in the environment. This increase in attention would facilitate learning about any stimulus present in the situation, regardless of whether that stimulus is involved in the interference experience or not. Within the specific designs used in this study, facilitation of learning could occur because the experience of extinction restored attention to Ci, that might have been reduced during training because Ci is a consistent predictor of the absence of outcomes (e.g., Pearce and Hall, 1980). However, the use of an eye-tracking device in a predictive learning task similar to the one used here has shown that participants pay attention to both, cues that predict the presence and cues that predict the absence of the outcome regardless of the length of training (see Aristizabal et al., 2016). Thus, facilitation of learning in this situation seems more likely to occur because of an activation of the attentional exploratory mechanism facilitating detection of the change in the cue-outcome relationship (see Le Pelley et al., 2016).

Although the present results do not ensure unequivocally that the increase in attention is the mechanism underlying the facilitation effect on learning by the interference experience obtained in Experiment 3. They are consistent with recent reports suggesting that experiencing different types of interference may facilitate subsequent learning about time (Alcalá et al., 2019a; Nelson et al., 2018) and space (Alcalá et al., 2019b). They are also consistent with the idea, that finding the beneficial effect of associative interference on subsequent learning will be detected in situations where learning is somewhat difficult, either because the stimulus has been previously pre-exposed (see also Bonardi et al., 2016) or because the conditioned stimuli are not self-evident (e.g., Alcalá et al., 2019a; Nelson et al., 2018).

In sum, interference may facilitate acquisition of new learning. However, the range of tasks, procedures, and types of interference that have been used to explore the effect of associative interference upon new learning is quite limited, and future research would be needed to determine the scope and relevance of this effects.

Declaration of Competing Interest

None declared.

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