Experiencing Extinction Facilitates Subsequent Acquisition of Positive, but not Negative Patterning in Human Predictive Learning

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Abstract

Two experiments evaluated whether the experience of extinction facilitates subsequent acquisition of patterning discriminations in human predictive learning. Both experiments compared acquisition of negative and positive patterning discrimination between a group of participants that had experienced extinction with a nontarget cue, and a group of participants that had not. Experiment 1 found that acquisition of positive (Experiment 1a) and negative (Experiment 1b) patterning discriminations with the target cues, when they were independently trained, took place at the same rate regardless of the extinction experience with the nontarget cue. Experiment 2 found that, when positive and negative patterning discriminations were concurrently trained, experiencing extinction facilitated the acquisition of positive, but not negative patterning. Results suggest the existence of some boundaries for the idea that experiencing uncertainty facilitates subsequent learning because of the activation of the exploratory mechanism of attention as proposed by recent attentional associative learning theories.

Keywords: attention, extinction, facilitation, learning, patterning
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Learning about environmental regularities and being able to update this learning when those regularities change is essential for organisms’ survival. How human and non-human animals react to changes in the regularities of the environment has been the focus of a large number of experimental studies since the seminal study of extinction conducted by Pavlov (1927). During extinction, a stimulus or a response that has been previously conditioned is no longer followed by the outcome. Under the basic assumption that the goal of the organism is to predict its environment as accurately as possible (e.g., Rescorla & Wagner, 1972), when predictors’ value changes, this change generates a situation of associative interference in which the new information competes with the information previously learned. This change triggers a sudden increase in the prediction error that activates the learning mechanism to correct the discrepancy between what the organism expects and what actually the environment provides.

There is a set of theories that goes further, suggesting that uncertainty leads to an arousal increase in the organism that produces an unspecific facilitation of subsequent learning. Anselme (2010) postulated that some degree of uncertainty is needed to activate the cognitive resources as a strategy to obtain information about the environment. Le Pelley et al. (2016) suggest that when environmental conditions are not entirely predictable, the organism engages the attentional exploration mechanism in an attempt to explore all the possible sources of information in the environment. Once the organism is able to predict the regularities of the environment, the organism engages the attentional exploitation mechanism that is driven by the predictiveness of each cue.

Along with these theoretical approaches, several studies have found that human and non-human animals show greater overt attention and spent more time exploring uncertain than predictive stimuli (Beesley et al., 2015; Kaye & Pearce, 1984; Koenig et al., 2017; Luque et al., 2017; Vadillo et al., 2016), although the opposite pattern of results, with more attention being driven by predictive stimuli, has been also reported in the literature (Le Pelley et al., 2011; see...
Le Pelley et al., 2016 for a review). The contradiction between these two types of results can be solved if we take a comprehensive view of the dual-attentional mechanism in which attention is a dynamic process that change across learning (see Le Pelley et al., 2016). Hence, a trade-off between attention being driven by uncertain or certain stimuli will be expected depending on the overall predictability of the learning environment (e.g., Torrents-Rodas et al., 2021a; Walker et al., 2019) on in sudden increases in prediction error (e.g., Easdale et al., 2019; Torrents-Rodas et al., 2021b). Research in recent years have been focused on exploring what variables determine the trade-off between attentional exploration and exploitation mechanisms (e.g., Chao et al., 2020; see Le Pelley et al., 2016 for a review).

Focusing on the studies exploring whether uncertainty increases attention, organisms seem to learn new associations faster when they involve uncertain stimuli. For instance, Hall & Pearce (1982) found that rats acquire a new association about a particular conditioned stimulus (CS) faster when the CS had a history of unpredictable reinforcement than when the same CS was a reliable predictor. In humans, Easdale et al. (2019) showed faster acquisition of new associations in participants experiencing a sudden increase in the prediction error, compared to a control group without such increase. Chao et al. (2020) found that acquisition of new associations was determined by the number of initial uncertain cues. When the environment is too complex, including many uncertain stimuli, uncertainty did not facilitate subsequent learning. However, when the number of uncertain stimuli compounds is relatively low, allowing for a realistic exploration of each combination, uncertainty seems to produce the activation of the exploration mechanism, facilitating subsequent acquisition of new associations.

Recent results suggest that the role of uncertainty facilitating learning may go beyond the stimuli which triggered the uncertainty. Alcalá et al. (2019) trained two groups of rats to discriminate between two different stimuli, one followed by food and the other presented alone. In a second phase, the relationship between the stimuli and the outcome was reversed in half of the animals (interference group), while it was kept the same in the other half (control group). After this experience, in a subsequent test phase rats received the food under a fixed time
program and then all animals were subjected to a temporal discrimination based on the time-interval between reinforcers. Animals that had the reversal experience developed the temporal conditioning faster compared to the control group (and also than an additional control group using naïve animals) (see Nelson et al., 2018 for a similar effect in human learning). A similar pattern of results has been reported in spatial learning. Shanab and Cotton (1970) found that experiencing extinction in a runway facilitated subsequent acquisition of a T-maze discrimination and vice versa. More recently, Alcalá et al. (2020) trained two groups of rats in a water maze. For the control group, the hidden platform always was placed in the same quadrant relative to the landmarks. However, for the experimental group the platform was placed close to the landmarks in the first phase, but moved to the opposite quadrant during the second phase, and then producing interference. In the critical test phase, all rats experienced a new position of the hidden platform and results showed that rats of the experimental group acquired faster the new learning than the control group, suggesting that experiencing of interference facilitated spatial learning. González et al. (2019) also reported an attenuation of the retardation effect that appears when a differential conditioned inhibitor is paired with the outcome in participants that experienced extinction with a different stimulus (Gonzalez et al., 2021; see De la Casa et al., 2018, for a related example using successive negative contrast in rats).

However, this facilitation effect does not always occur, particularly in learning situations either very straightforward to solve (Alcalá et al., 2018; Ogallar et al., 2019; Rosas & Callejas Aguilera, 2006), or contrarily, in a very complex scenarios with a large set size of cues (see Chao, et al., 2020). Regarding the former discriminations, some of the procedures conducted in predictive learning in our laboratory compared learning in a group who experienced extinction with a control group without interference treatment. For the group extinction, the extinguished cue (i.e., E-) is trained concurrently a new cue paired with the outcome (i.e., P+). Importantly, the control group also learned about this new cue (i.e., P+), but concurrent to learn about a non-reinforced cue which does not produce any interference (Filler-). So, both groups experienced the new cue P+ at the same time, but the experimental group concurrently with extinction
treatment. Critically, results showed that the rate of learning about the new cue (P+) is the same in both group and then experiencing of associative interference did not speed learning about the new cue in this simple scenario. Notably, an increase of the contextual processing with this extinction treatment is observed in a subsequent phase testing the contextual dependency of the new cue P+ (Ogallar et al., 2019; Rosas & Callejas Aguilera, 2006). In similar vein, animal’s results also showed that experiencing reversal training facilitated context processing, but it did not facilitate acquisition of a simple CS-US relationship in appetitive conditioning (Alcalá et al., 2018). Hence, interferences treatments boost attentional resources, but this increase is not enough to facilitate a simple acquisition, presumably by the easiness to acquire a single relationship cue-outcome (i.e., a ceiling effect). Taken together, although simple acquisition seems not affected by a concurrent experience of interference, extinction triggers a change in the organism’s attention modulating context processing (Rosas & Nelson, 2019).

Given this background, experiencing interference treatment seems to facilitate subsequent learning, but only under a specific set of circumstance, suggesting that the facilitation effect depends on several factors of the learning situation, such as the difficulty of the new learning or the novelty of the new cue. Hence, to achieve a better understanding of the facilitation effect as product of interference it is necessary to further explore the boundaries under which the facilitation effect might appear or not. The goal of the present study was contextualized in this regard.

We aimed to explore the effect of experiencing extinction of a nontarget cue on subsequent acquisition in a complex learning discrimination (negative and positive patterning) in human predictive learning. In positive patterning discriminations, two cues are followed by no outcome when presented isolated (e.g., M-, N-), while they are followed by the outcome when presented in compound (e.g., MN+). In negative patterning discriminations, the cues are reinforced when presented alone (e.g., M+, N+) and not reinforced when presented in compound (MN-).

Negative patterning seems harder to establish than positive patterning in nonhuman animals (Bellingham et al., 1985; Rescorla, 1972). This is not always the case in human animals (Harris
positive patterning seems to appear with increases in the complexity of the discrimination (Whitlow, 2013), with the use of aversive outcomes (Whitlow, 2010), and when the outcomes are differentially more salient than the absence of outcomes (Livesey et al., 2011).

We decided to conduct a patterning discrimination since it involved a complex discrimination, in which the same cue is presented alone and is paired with the presence and the absence of the outcome, depending on whether is presented alone or accompanied by another cue. As we stated above, if the lack of effect on single acquisition is caused by the simplicity to learn a single relationship between cue-outcome, we believe that patterning may create a better scenario to evaluate the potential facilitation effect of previous extinction, since engaged learn differential associations. Contrarily to other procedures in which the complexity of the discrimination was manipulated by increasing the number of cues (e.g., Chao et al., 2020) or the pre-exposure of the target cue (e.g., González et al., 2019) we produced a scenario that recruit simultaneous associations between the same cue and the presence or absence of the outcome. Hence, the use of patterning seems as a good scenario to explore the boundaries of the effect of extinction on subsequent acquisition (see for instance, Lachnit et al., 2008).

The design of this experimental series is summarized in Table 1. In all cases, we compared performance on a group of participants receiving extinction with a nontarget cue before the critical patterning phase versus a control group without the extinction experience. In Experiment 1, the effect of extinction of the nontarget cue on positive and negative patterning with the target cues was separately explored. In Experiment 2, the difficulty of the discrimination was increased by leading participants to acquiring both discriminations jointly. Based on the rationale detailed above, we expected that experiencing uncertainty may facilitate acquisition of subsequent learning. Hence, we expected group extinction to acquire the patterning discrimination faster than the control group, and that this differential acquisition was modulated by the difficulty of the discrimination.

[Insert here Table 1]
Experiment 1

Experiment 1 included Experiments 1a and 1b differing in the type of patterning used during the test phase (positive patterning in Experiment 1a and negative patterning in Experiment 1b). In both experiments, after an initial acquisition phase with nontarget stimulus E, half of the participants received extinction of E (Ext group) and the other half did not (Con group). Afterwards, each group received training with the positive patterning (Experiment 1a) or the negative patterning (Experiment 1b) discrimination with the two new target cues (M and N). The extinction treatment was used as the way to produce an increase in the prediction error that we expected to facilitate subsequent learning about both, positive and negative patterning discriminations (see Alcalá et al., 2019; 2020; González et al., 2019).

Experiment 1a: Positive patterning

Method

Participants

Thirty-two (5-males) psychology students between 18 and 24 years old from the University of Jaén participated in exchange for credit course. They had no previous experience with this task. Human ethics committee at the University of Jaén approved this study under the protocol number CEIH 250914-2. Sample size was based in Rosas & Callejas-Aguilera (2006). They reported sensitivity using a n= 32 to effects related with the increase on attentional processing using extinction protocol similar to our protocol.

Apparatus

Participants performed the experiment individually in adjacent cubicles. Each cubicle had a desktop computer where the task was presented. The procedure was implemented with E-Prime 2.0 software. Monitors were 22” and set to a resolution of 1920 by 1080. Cues were the same as those used by Rosas and Callejas-Aguilera (2006) with the exception that the name of the food was presented below the image of each cue with green-font Calibri (e.g., “Corn”).
During Acquisition and Extinction phases, *cucumber* and *corn* were counterbalanced as Cues E- and P+. Cues F1- and F2+ were *eggs* and *tuna fish*, respectively. In the patterning phase, *tomato* and *bass* were used as Cues M and N. *Diarrhea* was used as Outcome. Contexts A and B were the images of two fictitious restaurants counterbalanced across participants: “La chocita Canadiense” and “La vaca Suiza” (see Figure 1). Each restaurant has a unique set of elements. “La chocita Canadiense” has a blue ceiling, wood-furniture and wood-floor, intending to create the atmosphere of a traditional restaurant. “La vaca suiza” has a yellow ceiling with white-furniture and white and black tiles as floor, intending to create the atmosphere of a modern restaurant. The label of each restaurant was visible in a blue-screen on the left of the picture in the case of “La chocita canadiense” and in a yellow-screen on the right of the picture in the restaurant “La vaca Suiza”. Each restaurant occupied the center of the screen (1014 x 706 pixels). An image of each food (85 x 134 pixels), appeared centered on the restaurant images, surrounded by a small grey-canvas. In the lower part of the screen, below the picture of the restaurant, appeared a scale from 0 to 100 divided into 21 small green pixels buttons. Each button had a number representing an interval of 5 points in the scale. On top of the scale, beginning at 0 and ending at 100, and equally separated from each other, the words none, little, some, and much were presented. The feedback screen presented the same information as in the previous screen except that the scale was substituted by the presentation of the outcome (either s/he had diarrhea written in red font, or s/he had no diarrhea written in blue font). The remainder area in all screens was white. The demonstration restaurant was a third restaurant different from the ones counterbalanced as contexts A and B and the cue used for demonstration was pasta, a food that was not used afterwards in the experimental procedures.

[Insert here Figure 1]

**Procedure**

Informed consent was obtained from participants before beginning the experiment. Participants sat in front of the computer. The instructions (in Spanish) were presented in successive screens. A grey button with the sentence “Click here to continue” was presented at
the right bottom of the screen. Participants used the mouse to click within the button to continue with the next instructions screen. Instruction screens were sequentially presented immediately afterwards.

First screen: Recent developments in food technology have led to the chemical synthesis of food. This process has great advantages because its cost is very low and it is easy to store and transport. This revolution in the food industry may solve hunger in third-world countries.

Second screen: However, it has been detected that some foods produce gastric problems in some people. For this reason, we are interested in selecting a group of experts to identify the foods that lead to some type of illness and how it appears in each case.

Third screen: You are about to receive a selection test where you will be looking at the files of persons that have ingested different foods in a specific restaurant. You will have to indicate the degree to which you think that a gastric problem will appear. To respond you should click the option that you consider appropriate. Your response will be random at the beginning, but do not worry, little by little you will become an expert.

At this point, participants had to call the experimenter who continued the instructions by demonstration. The demonstration screen was identical to the screens used during training, with the exception that an irrelevant cue (pasta image) was presented without the outcome in a restaurant different from those used for A and B. The experimenter showed participants how to respond on this screen.

A trial consisted of the presentation screen followed by the feedback screen. Participants were requested to make a probability judgment about the relationship between the cue and the outcome by clicking on the button of the scale they considered appropriate during the presentation screen. The duration of the cue presentation depended on the time taken by each participant to respond. Immediately after this screen, and independent of the chosen option, participants received a 1500-ms feedback screen. The intertrial interval was 1000-ms, and it was indicated by a screen with the sentence: Loading the file of [a randomly chosen female/male
name]. Names were always different to keep the impression that each file was from a different person. Before the beginning of the experiment, participants were randomly assigned to one of two groups: Extinction (Ext) and Control (Con). The experiment was conducted in three phases. The overall length of the experiment was 20 minutes.

*Acquisition Phase:* We followed a protocol commonly used in our laboratory with the goal of keeping a situation that we have repeatedly found that leads to reliable extinction, even if the use of two contexts was not necessary for the design of the experiments conducted here (see Ogallar et al., 2019, Rosas & Callejas-Aguilera, 2006). Participants in both groups received 24 trials in each context, separated in 3 blocks. In each block of trials, all participants received 4 trials of each combination E+ and F1– in Context A, or 4 trials of each combination F1- and F2+ in Context B. Trials in each block were randomly intermixed. Thus, experience with cues, outcome, and contexts was equated throughout the acquisition phase within and between groups. Each block of trials within a context was preceded by a screen with the sentence: *Now you are going to analyze the files of the people who ate at this restaurant [restaurant’s image].* The order in which blocks of trials (and contexts) were presented was counterbalanced within and between participants (ABBAAB or BAABBA).

*Extinction Phase:* Extinction phase was identical to Acquisition phase, except for the following. In both groups, a new cue was presented related to the outcome (P+) in Context A. The outcome of E was changed in the extinction group and now it was associated with the absent of outcome (E–). E was not presented in the control group and it was substituted by F1- to equate the experience with the outcomes.

*Patterning phase:* Patterning phase was identical in structure to previous phase, but participants had to make predictive judgments about two new cues according to a positive patterning configuration: M-, N- and MN+ (Garlic, Bass and Garlic-Bass). Four different blocks were conducted during the patterning phase always in the context in which the extinction took place (i.e., Context A). Each block consisted of two presentations of each cue and compound.
The order of the cues and compound inside each block was randomized. One random sequence was generated taken into account this configuration, and it was applied for all participants.

Dependent Variable and Data Analyses

We recorded the rating of each participant in each trial. Test data are presented in 2-trial blocks including the number of cue presentations during each block of the patterning phase. For the sake of coherence, we also report data in 2-trial blocks across all the phases of the experiment. There were no differences in the cues trained individually (i.e., M and N) during the patterning phase, nor interacted with any other factor during the pertinent analysis. Hence, for the sake of simplicity on reporting the results both cues were collapsed during the patterning phase (i.e., M-/N-). Predictive judgments were evaluated with an analysis of variance (ANOVA). The rejection criterion was established at \( p < 0.05 \) and partial eta square (\( \eta^2_p \)) is reported for the effect size. Additionally, confidence intervals on partial-eta squares (95%) were computed using software available in Nelson, (2016) 95% for the analyses conducted during the patterning phase. The data reported in this paper are available at:
http://dx.doi.org/10.17632/hmk63hc686.1

Results

All participants were included in the analyses. Only performance in context A is reported, as it is this context where all the target information is presented throughout the experiment. Performance in context B is not reported as it developed according to the associated contingencies of each cue and without differences between groups in all the experiments reported here, and does not add relevant information to the goals of the study.

Acquisition Phase

The left section of Figure 2a portrays the acquisition phase. Both groups learned the associated contingencies of each cue, without differences between them. A mixed 2 (Group; Ext vs Con) x 2 (Cue; E+ vs F1-) x 6 (Block; 1 – 6) ANOVA revealed significant main effects of Cue, \( F(1, 30) = 1385.37, \ p < .001, \ \eta^2_p = .98 \), Block, \( F(5, 150) = 5.23, \ p < .001, \ \eta^2_p = .15 \), and a
Cue x Block significant interaction, \( F(5, 150) = 44.63, p < .001, \eta_p^2 = .59. \) The main effect of Group was not significant, \( F(1,30) = 1.49, p = .231, \) nor interacted with any other factor.

Subsequent analyses conducted to explore the interaction revealed that the difference between cues appeared in the very first block, \( F(1, 31) = 45.57, p < .001, \eta_p^2 = .59, \) although the size of the effect was rather larger in the last block, \( F(1, 31) = 624.65, p < .001, \eta_p^2 = .95. \)

**Extinction Phase**

The right section of Figure 2a represents the extinction phase. Both groups showed similar learning rate on the new P+ cue. As expected, Ext group decreased their response to cue E- according to extinction treatment, while Con group remained with lower ratings to cue F1- during this phase. A mixed 2 (Group; Ext vs Con) x 2 (Cue; E-|F1- vs P+) x 6 (Block; 1 – 6) ANOVA revealed a significant 3-way interaction, \( F(5, 150) = 17.70, p < .001, \eta_p^2 = .37 \) superseding all other effects. Further analyses of this interaction were conducted. A mixed 2 (Group; Ext vs Con) x 6 (Block; 1 – 6) ANOVA analyzed the rate of learning to the new cue P+, revealing a significant main effect of Block, \( F(5, 150) = 33.44, p < .001, \eta_p^2 = .52, \) but not a significant main effect of Group, neither a significant Group x Block interaction, suggesting that learning about the new cue developed at a similar rate in the two groups, largest \( F(1,30) = 1.21, p = .279 \) for the main effect of Group. The differences between groups come from the differential training received with E- and F1-. A mixed 2 (Group; Ext vs Con) x 6 (Block; 1 – 6) ANOVA with the cues E-|F1 revealed a significant main effect of Group, \( F(1, 30) = 37.23, p < .001, \eta_p^2 = .55, \) Block \( F(5, 150) = 28.70, p < .001, \eta_p^2 = .48, \) and a significant Group x Block interaction, \( F(5, 150) = 30.04, p < .001, \eta_p^2 = .50. \) Further analyses of the interaction showed that the simple effect of Group was significant in Block 1, \( F(1, 30) = 89.55, p < .001, \eta_p^2 = .55. \)

Ext group showed higher ratings in the first block than Con group. Ratings in Ext group decreased as extinction treatment progressed until equating ratings in Con group by the last block of training, \( F < 1. \) As expected, the single effect of Block only was reliable in Ext group, \( F(5, 75) = 29.67, p < .001, \eta_p^2 = .66 \), but not in Con group, \( F < 1. \)
In summary, at the end of extinction phase both groups displayed a similar performance to reinforced and non-reinforced cues, though extinction only took place in group Ext.

[Insert here Figure 2]

Positive Patterning Phase

Figure 3a displays the ratings given by participants to the compound MN+ and to the elemental cues M-/N- (collapsed) in Ext and Con groups during the positive patterning test phase. As the Figure 3a suggests, both groups quickly adjusted their predictive ratings to the contingencies of each cue, without differences between them. This impression was confirmed by a mixed 2 (Group; Ext vs Con) x 2 (Cue; MN+ vs M-/N-) x 4 (Block; 1-4) ANOVA, that revealed a significant main effect of Cue, $F(1, 30) = 1066.66, p < .001, \eta^2_p = .97, 95\% \text{ CI} [.95, .98]$, and a Block x Cue interaction, $F(3,90) = 203.88, p < .001, \eta^2_p = .87, 95\% \text{ CI} [.82, .90]$. No other main effect or interaction was significant, largest $F$ for the main effect of Block, $F(3,90) = 1.43, p = .239$. Critically, the effect of Group was not significant, neither interacted with any other factor, $Fs < 1$. Further analyses exploring the Block x Cue interaction found that the simple effect of Cue was reliable from the first block on, $F(1, 31) = 18.30, p < .001, \eta^2_p = .37, 95\% \text{ CI} [.11, .56]$, though it seemed stronger in the last block, $F(1, 31) = 1383.61, p < .001, \eta^2_p = .98, 95\% \text{ CI} [.96, .99]$.

[Insert here Figure 3]

Ratings to the compound increased while ratings to the elements decreased across trial blocks, reaching quickly the expected performance for a positive patterning discrimination. This discrimination was not modulated by the differential extinction treatment received by each group, suggesting that the experience of extinction did not affect subsequent learning of a positive patterning discrimination under the conditions established in this experiment.

Experiment 1b: Negative Patterning

Method
Participants

Thirty-two (4-males) psychology students between 18 and 26 years old from the University of Jaén participated in the experiment in exchange for credit course.

Procedure

The protocol was identical to the one used in Experiment 1a, excepting than during the Patterning Phase participants had to solve a negative patterning discrimination: M+, N+ and MN- (Garlic, Bass and Garlic-Bass).

Results

Acquisition Phase

Right section of Figure 2b displays learning of groups Ext and Con during the acquisition phase. Performance developed as expected in both groups, without appreciable differences between them. A mixed 2 (Group; Ext vs Con) x 2 (Cue; E+ vs F1-) x 6 (Block; 1–6) ANOVA revealed a significant main effect of Cue, $F(1, 30) = 602.31, p < .001, \eta^2_p = .95$, Block, $F(5, 150) = 5.38, p < .001, \eta^2_p = .15$ and a Cue x Block significant interaction, $F(5, 150) = 51.07, p < .001, \eta^2_p = .63$. No main effect or interaction involving Group as a factor was significant, $Fs < 1$. Subsequent analyses of the Cue x Block interaction revealed that performance in cues E and F1 was different from the first training block on, $F(1, 31) = 56.57, p < .001, \eta^2_p = .64$, though differences were larger in the last block of training, $F(1, 31) = 1240.85, p < .001, \eta^2_p = .97$.

Extinction Phase

Right section of Figure 2b shows performance during the extinction phase. Ext group decreased their ratings to the extinguished cue, while ratings to the filler cue (F1-) in Con group remained low. Both groups showed similar performance to the new trained cue (P+). This impression was confirmed by a mixed 2 (Group; Ext vs Con) x 2 (Cue; E|-F1- vs P+) x 6 (Block; 1–6) ANOVA. The 3-way interaction was significant, $F(5, 150) = 8.13, p < .001, \eta^2_p = .21$, superseding the remaining main effects and interactions. A mixed 2 (Group; Ext vs Con) x
6 (Block; 1 – 6) ANOVA analyzed performance to the new cue P+, found a significant main effect of Block, $F(5, 150) = 70.82, p < .001, \eta^2_p = .70$, but not a main effect of Group neither a Group x Block interaction, suggesting that learning about the new cue developed at similar rate in both groups, $Fs < 1$. Again, the difference between groups comes from the differential training received with E- and F1-. A mixed 2 (Group; Ext vs Con) x 6 (Block; 1 – 6) ANOVA with cues E-|F1 found significant main effects of Group, $F(1, 30) = 6.75, p = .014, \eta^2_p = .18$ and Block, $F(5, 150) = 14.03, p < .001, \eta^2_p = .31$, as well as a significant Group x Block interaction, $F(5, 150) = 11.74, p < .001, \eta^2_p = .28$. As the right section of Figure 2b depicts, there was a significant simple effect of Group in Block 1, $F(1, 30) = 31.23, p < .001, \eta^2_p = .51$, that disappeared by the sixth block of trials, $F < 1$, suggesting that both groups yielded similar ratings to the non-reinforced cues by the end of the extinction phase. Finally, the simple effect of Block only was reliable in Ext group, $F(5, 75) = 14.93, p < .001, \eta^2_p = .50$, but not in Con group, $F < 1$.

**Negative Patterning Phase**

Figure 3b displays the ratings to the compound MN- and to the individual cues collapsed (M+/N+). Predictive ratings to the elemental cues increased, while decreasing to the compound without differences between groups. This impression was confirmed by a mixed 2 (Group; Ext vs Con) x 2 (Cue; MN- vs M+/N+) x 4 (Block; 1-4) ANOVA. These analyses revealed a significant main effect of Cue, $F(1, 30) = 1377.61, p < .001, \eta^2_p = .98$ 95% CI [.96, .99], Block, $F(3,90) = 18.64, p < .001, \eta^2_p = .38, 95\%$ CI [.21, .49] and a significant Block x Cue interaction, $F(3,90) = 275.82, p < .001, \eta^2_p = .90, 95\%$ CI [.86, .92]. No other main effect or interaction were significant, largest $F$ for the main effect of Group, $F(1,30) = 1.41, p = .244, \eta^2_p = .04, 95\%$ CI [.00, .24]. Further analyses of the interaction found that the effect of Cue was reliable from the first block on, $F(1, 31) = 23.94, p < .001, \eta^2_p = .44, 95\%$ CI [.17, .61], increasing by the end of training, $F(1, 31) = 817.51, p < .001, \eta^2_p = .96, 95\%$ CI [.93, .97].

Results of Experiment 1b were quite similar to the results found in Experiment 1a in the sense that the negative patterning discrimination developed quickly and at the same rate.
regardless of the extinction treatment. These results suggest that acquisition of negative patterning discrimination was not modulated by the previous extinction experience when trained under the conditions used in this experiment.

Discussion

In Experiment 1 the extinction experience did not facilitate subsequent learning about positive or negative patterning discriminations. This pattern of results did not support the idea that experiencing interference facilitates acquisition of new learning (see Alcalá et al., 2019; 2020; González et al., 2019). Participants quickly acquired the discrimination during the patterning phase in both experiments, showing an asymptotic level of discrimination by the second block of testing. This pattern of performance suggests that conducting positive and negative patterning discriminations in separate experiments may have made the discrimination easy to solve, something that could have make that any potential benefits of previous extinction would go unnoticed. As alternative explanation, participants also can apply the “opposite rule” to solve the discrimination (e.g, Maes et al., 2015). For example, in the case of positive patterning they can solve the discrimination just knowing that when the cues are alone are not followed by the outcome, but followed by the outcome as a compound. This strategy would make the task very easy to solve and without the need to stablish a particular set of associations between cue(s)-outcome.

One interesting aspect that we replicated in first experiment is the fact that simple acquisition is not affected by a concurrent experience of interference, since both groups learned at equal rate about the relationship of the new cue P and the outcome (P+) during second phase. As we stated in the introduction, this is a common result in our laboratory and clearly support the lack on an effect on single acquisition. It is woth to mention that the design used during acquisition and extinction phases consistently finds that extinction experience affects contextual dependency of cues trained concurrently or sequentially to the extinction experience, (Ogallar et al., 2019; Rosas & Callejas-Aguilera, 2006; also see Alcalá et al., 2018), and then it is a valid procedure to boost attentional processing (see Rosas & Nelson, 2019).
At the same time, the lack of effects of extinction upon simple acquisition suggests that there are boundaries on the effect of extinction upon new learning that are not quite defined yet. As suggested by Alcalá et al. (2018), one of those boundaries may come either from the novelty of the situation itself or from the degree of difficulty of the problem the organism needs to solve. It is reasonable to assume that the beneficial effect of experiencing interference on new learning would depend on the difficulty of the new learning situation, appearing only when such a difficulty is intermediate, and not when the new situation is either too simple or too complex for the effects of subtle changes in the activation of the attentional exploration mechanism to have an effect. In agreement with this idea, González et al. (2019) found that acquisition of a cue-outcome relationship was facilitated by the extinction experience in a situation where such acquisition was made more complex by preexposing the cue without outcome before the extinction treatment (see also González et al., 2021).

Experiment 2 increased the difficulty of the discrimination by training both positive and negative patterning discriminations concurrently, under the expectancy that such an increase in the difficulty of the discrimination would leave room for any effect of extinction upon subsequent acquisition to appear.

Experiment 2

Experiment 2 was conducted with the goal of exploring whether experiencing extinction would facilitate subsequent learning of new discriminations of moderate complexity. Complexity of the task, together with the number of cues used during training, are some of the critical variables that have been shown to affect the engage of exploration versus exploitation mechanisms (Chao et al., 2020; Le Pelley et al., 2016). We anticipated that increasing the difficulty of the discrimination with respect to the one used in Experiment 1 might create a better scenario to evaluate the effect of extinction on new learning. A complex learning discrimination was generated in which people had to solve negative and positive patterning concurrently. Moreover, the use of both patterning at the same time should preclude the use of
the “opposite rule” to solve the discrimination and then the discrimination should be solved by particular set of association between cue(s)-outcome.

In this scenario, experiencing extinction was expected to facilitate discrimination of both, positive and negative patterning. However, it should be noted that potential differences between both types of patterning might emerge as function of the different level of difficulty of each discrimination the literature reports (e.g., Whitlow, 2010).

Method

Participants

Thirty-two (5 males) psychology- students between 18 and 23 years old from the University of Cádiz participated in exchange for credit course.

Apparatus and Procedure

They were similar to the ones used in Experiment 1, except for the patterning phase. In the patterning phase, positive and negative patterning discriminations were concurrently trained (see bottom section of Table 1). Two new cues were included: Tomato and Caviar. Half of the participants concurrently received training on positive patterning with Bass and Garlic, and negative patterning with Tomato and Caviar, while the contrary was true for the other half. Both sets of cues were counterbalanced across participants. Each block of training included two trials with each cue (2M-, 2N-, and 2MN+ for positive patterning, and 2L+, 2H+, and 2HL- for negative patterning). Cues were randomly distributed within each block, creating a unique sequence that was used for all participants. The sequence involved 6 blocks of training (12 presentations of each cue overall).

Data analyses

Data analyses strategy was identical to the one used in Experiment 1, including the separate analysis of each patterning discrimination, with the goal of facilitating detection of
potential subtle differences on the effect of extinction on acquisition of negative or positive patterning.

Results

Acquisition Phase

Left section of Figure 4 displays predictive ratings of Ext and Con groups during the acquisition phase. Both groups adjusted their ratings to the contingencies of each cue, without differences between them. A mixed 2 (Group; Ext vs Con) x 2 (Cue; E+ vs F1-) x 6 (Block; 1–6) ANOVA revealed a significant main effect of Cue, $F(1, 30) = 171.63, p < .001, \eta^2_p = .85$, Block, $F(5, 150) = 2.65, p < .025, \eta^2_p = .08$, and a significant Cue x Block interaction, $F(5, 150) = 29.09, p < .001, \eta^2_p = .49$. The main effect of Group was not significant, $F < 1$, either qualified by any other factor. Subsequent analyses of the interaction revealed that there was no significant difference between cues in Block 1, $F(1, 31) = 3.29, p = .079, \eta^2_p = .10$, but that this difference was reliable in the last block of training, $F(1, 31) = 126.85, p < .001, \eta^2_p = .80$.

Extinction Phase

Right section of Figure 4 depicts the ratings during the Extinction Phase. Ext group decreased their ratings to the extinguished cue E-, while ratings to F1- remained low in Con group. Both groups showed similar performance to the new cue P+. These impressions were confirmed by a mixed 2 (Groups; Ext vs Con) x 2 (Cues; E-|F1- vs P1+) x 6 (Block; 1–6) ANOVA. The 3-way interaction was significant, $F(5, 150) = 3.91, p = .002, \eta^2_p = .11$, superseding all main effects, and 2-way interactions.

A mixed 2 (Groups; Ext vs Con) x 6 (Block; 1–6) ANOVA exploring performance to the new cue P+ only found a significant simple main of Block, $F(5, 150) = 16.65, p < .001, \eta^2_p = .35$, the main effect of Group was not significant, nor the Group x Block interaction, suggesting that responding to the new cue developed at a similar rate in the two groups, $F_s < 1$. As expected, the differences between groups came from the differential history of cues E- and F1-.

A mixed 2 (Group; Ext vs Con) x 6 (Block; 1–6) ANOVA with cues E-|F1- found significant
simple main effects of Group, $F(1, 30) = 8.06, p = .008, \eta^2_p = .21$ and Block, $F(5, 150) = 10.81, p < .001, \eta^2_p = .26$. Most important, the Group x Block interaction was significant, $F(5, 150) = 6.61, p < .001, \eta^2_p = .18$. Subsequent analyses conducted to explore the interaction found a significant simple effect of Group in Block 1, $F(1, 30) = 23.35, p < .001, \eta^2_p = .43$, that disappeared by Block 6, $F < 1$ (see Figure 4), suggesting that at the end of extinction phase, both groups yielded similar ratings to the non-reinforced cues. Finally, the simple effect of Block only was reliable in Ext group, $F(5, 75) = 13.29, p < .001, \eta^2_p = .47$, with lower ratings at the end of the extinction, while no effect of Block was found in Con group in cue F1, $F < 1$.

[Insert here Figure 4]

**Patterning Phase**

Figure 5 shows the ratings across both types of patterning. In general, both groups performed according to the outcome associated with each cue and compound. In the case of Positive Patterning (Figure 5a), it seems like Ext group acquired the discrimination between elemental and compound cues better than Con group. However, in the case of negative patterning (Figure 5b), both groups seem to have a similar performance.

A mixed 2 (Group; Ext vs Con) x 2 (Patterning; Positive vs Negative) x 2 (Type of cue: Element vs Compound) x 6 (Block; 1-6) ANOVA found that neither the main effect of Group, nor any interactions involved group as a factor were significant, largest $F(1, 30) = 2.20, p = .15, \eta^2_p = .07, 95\% \text{ CI} {[.00, .27]}$ for the 3-way Group x Patterning x Type interaction. However, a visual inspection of the figure 5 suggests subtle differences between groups depending on the patterning that may have got diluted in the complex analysis. Aware of this possibility, planned comparisons to separately explore the effect of Group in each patterning discrimination were conducted, following our main hypothesis.

In the case of Positive Patterning, a mixed 2 (Group; Ext vs Con) x 2 (Type of Cue: Element vs Compound) x 6 (Block; 1-6) ANOVA found a significant main effect of Cue, $F(1, 30) = 226.46, p < .001, \eta^2_p = .88, 95\% \text{ CI} {[.78, .92]}$, and a Group x Type significant interaction,
$F(1, 30) = 7.90, p = .009, \eta^2_p = .21, 95\% \text{ CI } [.02, .42]$. No other main effect or interaction were significant, $Fs < 1$. Further analyses conducted to explore the Group x Type interaction found that the simple effect of Group was significant in both, the compound, $F(1, 30) = 5.04, p = .032, \eta^2_p = .14, 95\% \text{ CI } [.00, .36]$, and the elements, $F(1, 30) = 4.70, p = .038, \eta^2_p = .13, 95\% \text{ CI } [.00, .35]$. As Figure 5 shows, these differences were the outcome of a lower responding to the compound and higher responding to the elements in Con group than in Ext group, suggesting that positive patterning discrimination developed better in Ext group.

In the case of negative patterning, a 2 (Group; Ext vs Con) x 2 (Type of Cue: Element vs Compound) x 6 (Block; 1-6) ANOVA found a significant main effect of Type, $F(1, 30) = 88.17, p < .001, \eta^2_p = .75, 95\% \text{ CI } [.56, .83]$, Block, $F(5, 150) = 3.77, p = .003, \eta^2_p = .11, 95\% \text{ CI } [.01, .18]$, and Type x Block interaction, $F(5, 150) = 33.55, p < .001, \eta^2_p = .53, 95\% \text{ CI } [.41, .60]$. No main effects or interactions involving Group as a factor were significant, largest $F F(5, 150) = 1.06, p = .38$ for the 3-way interaction Group x Type x Block. Overall, both groups solved the negative patterning discrimination at the same rate, suggesting that experience of previous extinction did not affect negative patterning in this experiment.

[Insert here Figure 5]

**Discussion**

In Experiment 2, positive and negative patterning discriminations were conducted at the same time during the critical test phase creating a situation that was allegedly more complex than when both discriminations were trained separately in Experiment 1 and prevents the use of “opposite rule”. This change in the design of the experiment lead to differential acquisition of the positive patterning discrimination between groups Ext and Con, unveiling a facilitation effect of extinction on acquisition of complex discriminations that, however, was not observed in the acquisition of a negative patterning discrimination. Results reported in Figure 5 are in agreement with the idea that negative patterning may be harder to acquire both in nonhuman (Bellingham et al., 1985; Rescorla, 1972) and human animals (Whitlow, 2010; but see for
instance Harris & Livesey, 2008), at least under some conditions. Accordingly, the overall data reported here are consistent with the idea that the facilitatory effect of interference on subsequent learning depends on the difficulty of the subsequent discrimination, disappearing when the difficulty of the discrimination is overly increased. Whatever the value of this later speculation is, results of Experiment 2 suggest that experiencing extinction facilitates new learning, in agreement with previous reports of the literature (see Alcalá et al., 2019, 2020; González et al., 2019; 2021), but also that this facilitation has some boundaries that need to be further explored.

**General Discussion**

In two experiments, we explored the role of experiencing extinction on subsequent acquisition of complex discriminations in human predictive learning. Extinction did not facilitate positive or negative patterning discriminations when trained separately in Experiments 1a and 1b. However, when both discriminations were concurrently trained in Experiment 2, positive patterning was facilitated by the previous extinction experience, though this experience did not affect acquisition of negative patterning. This pattern of results supports the idea that unexpected increases in prediction error may facilitate subsequent acquisition of new learning, but that such facilitation is modulated by boundaries that are not yet clearly defined.

Several studies pointed out that experiencing unexpected events facilitates acquisition of subsequent learning, assuming that the experience of uncertainty leads the organism either to engage the attentional exploration mechanism (Le Pelley et al., 2016) or to activate cognitive resources (see Anselme, 2010) that facilitate processing of new information. These mechanisms are assumed to prompt an unspecific increase in the arousal of the organism, leading the organism to engage an exploratory pattern of behaviour. In this experimental series, we found that experiencing extinction facilitates subsequent acquisition of new learning, but only under limited conditions.
When the new situation is straightforward to solve, previous interference did not have any effect on subsequent acquisition (see Alcalá et al. 2018; Ogallar et al., 2019; Rosas & Callejas-Aguilera-2006). However, increasing the difficulty of discrimination by pre-exposure of the cues provided a better scenario to study the effect of previous extinction (see González et al., 2019, 2021). In our case, we only found the effect in the positive patterning (presumably the easiest to solve), which may suggest differences in the potential effect of extinction depending on the type of patterning. Although this pattern of result seems difficult to reconcile with a general activation of the exploratory pattern, it could be the case that negative patterning yield a different processing than the positive patterning did. This asymmetric might be not entirely surprising, since positive patterning is more easily acquired than negative patterning in non-human animals (Bellingham et al., 1985; Rescorla, 1972). Similar results have been obtained in humans using an aversive outcome (Whitlow, 2010) or manipulating the salience of the outcome (Livesey et al., 2011). Similarly, it could be argued that the context of the task (food and gastric illness) also might promote a different processing as function of the patterning. In the positive when the combination of two cues produces the outcome that each event alone does not produce seems more likely to occur than the contrary. That is, the same outcome that two events produced separately disappears when the two events are presented together (i.e., negative patterning). Hence, to learn about negative patterning may trigger a more significant incongruence in participants, because it seems rather unlikely that two different foods that produce a gastric illness alone did not yield the same outcome together. This incongruence may lead to greater attentional processing of the cues involved in the negative patterning and then negate any potential effect of experiencing previous extinction. The idea that uncertainty and violation of the expectative trigger an increase in attention is far from being new in the learning literature (see Pearce & Hall, 1980) and also applies to different domains such as semantic incongruence (Ortiz-Tudela et al., 2018), among others. In this particular case, it could be a potential reason underpinning the lack of effect in negative patterning.
Another alternative account might be related with the use of patterning as the target discrimination during the test. As we stated in the introduction, selection of patterning produced that the same cue is associated with the outcome and with its absence. This configuration is inevitable accompanied by an increase in the ambiguity of the cue. This experience might violate to some extent the overall expectation of the participants, especially in the control group, in which until this stage of the experiment all the relationships were consistent. In this line, the election of patterning may have produced an undesired increase in the ambiguity of the cues and consequently an increase in the attentional resources of the control group (see Callejas-Aguilera & Rosas, 2010), hindering the possibility to observe a clearer difference between groups. Especially, in the case of negative patterning in which it could be a synergistic interaction between the ambiguity produced by patterning discrimination and the potential incongruency discussed above, which may be counteract any subtle increase as product of experiencing extinction.

Although these accounts may serve as speculative at the moment, it opens interesting paths to further explore the role of incongruence or uncertainty in future studies. For instance, the cues used in the patterning are a new type of foods, so it could be the case that attention received by the new cues may already be at the asymptotic level regardless of the previous experience with other stimuli (Schmajuk & Larrauri, 2006). Interestingly, González et al., (2019, 2021) found that experiencing interference facilitates acquisition of the cue-outcome relationship in a pre-exposed cue, which is presumably receiving a lower level of attention (Lubow et al., 1981; Mackintosh, 1975). A future way to disentangle the role of attention may be to conduct the patterning discrimination with pre-exposed cues, controlling this way the attention triggered by the novelty of the new cues.

Torrents-Rodas et al., (2021b) found that experienced a sudden increase on prediction error leads to an increase in the overt attention deploy to irrelevant cues, even when these cues did not provide information to master the learning. Hence, a sudden change triggered the exploration of cues that previously received low attentional processing. As pointed out above,
previous research found that changes in attentional processing may be underpinning the facilitation of subsequent learning by the activation of the exploratory attentional mechanism (e.g., Easdale, et al., 2019). Applied to our results, we inferred the increase in attention through the speed of associability of the new cues during the patterning discrimination (e.g., Mackintosh, 1975; Pearce & Hall, 1980). However, we did not provide a direct measure of attentional processing. Future studies should provide insightful evidence in this regard, identifying whether the increase in attentional exploration underpins the facilitation effect. Critically, this would shed light on how other factors such as cues’ novelty and cues’ pre-exposition impact subsequent attentional processing and their implication in the facilitation effect (see Alcalá et al., 2018; González et al., 2019; 2021).

In summary, there has been a large set of research studying the variables under which humans engage the exploration or the exploitation attentional mechanism during the learning process (Le Pelley et al., 2016). Specifically, some studies have targeted how uncertainty can modulate acquisition of the specific cues that triggered the uncertainty (e.g., Chao et al., 2020; Easdale et al., 2019). However, other studies explored the possibility that such facilitation effect could reflect a general increase in arousal prompted by the experience of uncertainty that may lead to a general facilitation of the acquisition of new learning (Alcalá et al., 2019, 2020; González et al., 2019; 2021). In line with the number of factors that enable the trade-off between exploitation and exploration attentional mechanism (e.g., Chao et al., 2020), the facilitation effect about new cues also seems to depend on several variables. In this study, we identified that the degree of difficulty of new learning and the type of discrimination are important variables determining the facilitation effect. Nevertheless, the influence of complexity determining the presence or absence of the facilitation effect should be taken with caution. Insofar, the differences in difficulty rely on comparison between Experiment 1 (i.e., straightforward discrimination) and Experiment 2 (i.e., complex discrimination). However, task difficulty was not explicitly manipulated within a single experiment. Future experiments should address this issue, providing the design to manipulate different levels of task difficulty in the
same experiment. Having said that, the lack of differences in the speed of conditioning of cue P+ during extinction treatment supports the idea that the facilitation effect is unlikely to occur in easy discriminations (e.g., Alcalá et al., 2018; Rosas & Callejas-Aguilera, 2006). In the same vein, it can be anticipated that in a very complex scenario, the facilitation effect will be neglected (see Chao et al., 2020), leaving a critical spot in which previous uncertainty would positively affect subsequent learning, as we found in Experiment 2 with the positive patterning. Whatever the value of this later speculation is, what seems clear is that experiencing associative interference facilitates new learning under some conditions, in agreement with previous reports of the literature (see Alcalá et al., 2019, 2020; Easdale et al., 2019; González et al., 2019; 2021), but that the boundaries for this facilitation to occur are far from being established.

References


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Table 1. A and B: Two physically different restaurants, counterbalanced between subjects. P+ and E-: cucumber and corn, counterbalanced; F1- and F2+ were fillers represented by eggs and tuna fish, respectively. In Exp1 M and N were garlic and bass; in Exp2 garlic and bass and caviar as tomato were counterbalanced as M and N & L and H. “+” indicated the presence of diarrhea and “-” absent of gastric illness.

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**Figure 1:** Snapshot of experimental contexts “La vaca Suiza” on the left and “La chocita canadiense” on the right. In the center of the restaurant appeared the food “Ajos” (Garlic).
Figure 2: Mean predictive ratings given by participants to cues E+, E-, P+, and F1- during acquisition and extinction phases in Exp1a (left panel) and Exp1b (right panel). “+” refers to the presence of the outcome and “-” represents the absence of the outcome. Numbers represent a 2-trial block. Dark symbols represent performance of the Ext group and open symbols represents performance of the Con group. Error bars denote the Standard Error of the Mean (SEM).
**Figure 3**: Mean predictive ratings given by participants about the relationships between M, N and MN, for Positive Patterning in Exp1a (left panel) and Negative Patterning in Exp1b (right panel). “+” refers to the presence of the outcome and “−” the absence of the outcome. Dashed line depicts performance to the compound. Numbers represent a 2-trial block. Dark symbols represent the Ext group and open symbols represent the Con group. Error bars denote the Standard Error of the Mean (SEM).
**Figure 4:** Mean predictive ratings given by participants about to cues E+, E-, P+, and F1- during acquisition and extinction phase for Exp2. “+” refers to the presence of the outcome and “-” the absence of the outcome. Numbers represent a 2-trial block. Dark symbols represent the Ext group and open symbols represent the Con group. Error bars denote the Standard Error of the Mean (SEM).
Figure 5: Mean predictive ratings given by participants to cues M, N, and MN for Positive Patterning (left panel) and cues L, H, and LH for Negative Patterning (right panel) for Exp2. “+” refers to the presence of the outcome and “−” the absence of the outcome. Dashed depicts performance to the compound. Numbers represent a 2-trial block. Dark symbols represent the Ext group and open symbols represents the Con group. Error bars denote the Standard Error of the Mean (SEM).