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The Opportunity to Compare Similar Stimuli Can Reduce the Effectiveness of Features They Hold in Common

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In three experiments, rats were given experience of flavored solutions AX and BX, where A and B represent distinctive flavors and X a flavor common to both solutions. In one condition, AX and BX were presented on the same trial separated by a 5-min interval (intermixed preexposure). In another condition, each daily trial consisted of presentations of only AX or only BX (blocked preexposure). The properties acquired by stimulus X were then tested. Experiment 1 showed that after intermixed preexposure X was less able to interfere with a conditioned response established to a different flavor. Experiment 2 showed that X was less effective at overshadowing when trained in compound with another flavor. Simple conditioning, with X as the conditioned stimulus, was not sensitive to the form of preexposure (Experiment 3). These results indicate that the opportunity to compare similar stimuli that is provided by presenting them in close succession can change the properties of features they hold in common, making these features less effective when tested in compound with other stimuli. A loss of effectiveness by such features would contribute to the perceptual learning effect, the enhancement of subsequent discrimination, that is generated by prior exposure to closely spaced similar stimuli.

Keywords: perceptual learning, associative learning, flavor aversion, salience, associability

Perceptual learning can be evidenced as the increased ability to discriminate among similar stimuli after mere exposure to them. This effect can be explained by an increase in the subject's ability to detect differences between the stimuli, by a reduction in attention paid to irrelevant features, or both. That is, successful discrimination between two similar stimuli requires that behavior be controlled by the distinctive features of the stimuli, rather than those features that they will hold in common. Representing the stimuli as AX and BX, discrimination requires control by A and B, rather than by the X features. It is well established that exposure to AX and BX, particularly when these are presented in an intermixed fashion (e.g., on alternating trials), can promote discrimination between them, as may be demonstrated by establishing a conditioned response (CR) to one stimulus and assessing the extent to which preexposure to the stimuli limits the degree to which this response generalizes to the other. Reduced generalization after intermixed presentations of AX and BX is well established (for reviews see, e.g., Hall, 2021; Mitchell & Hall, 2014).

As we have noted, one possible source of this perceptual learning effect is that intermixed exposure to AX and BX may be particularly effective in reducing the extent to which the common (the X) features can acquire or exhibit control over behavior. For the most part, however, direct testing of the properties acquired by the common features of the stimuli has revealed only weak evidence for such an effect. The issue has been extensively investigated in experiments with rats trained in the flavor-aversion learning paradigm. These have uniformly found that the properties of X, tested after preexposure consisting of intermixed presentations of the compounds AX and BX, do not differ from those produced by a control preexposure procedure in which AX and BX are presented on separate blocks of trials (Hall, 2020; Mondragón & Hall, 2002; see also Bennett & Mackintosh, 1999; Rodríguez & Alonso, 2004, 2008). An effect has been obtained, however, in experiments using auditory stimuli and an appetitive conditioning procedure.

Mondragón and Murphy (2010) presented their rats with intermixed or blocked exposure to compound auditory cues: high and low tones, each presented in combination with a common element, a white noise. The common noise was then trained as a cue for food and subjects' approach to the food tray was measured. Although there were no differences during the acquisition of the appetitive response, the results of an extinction test showed a lower level of approach to the food tray in the intermixed group than in the blocked group. These results may indicate either that after intermixed exposure to auditory compounds the common

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Isabel de Brugada served as lead for funding acquisition and contributed equally to conceptualization, data curation, formal analysis, methodology, supervision, writing–original draft, and writing–review and editing.

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white noise was less well associated with food during conditioning or that this exposure kept X's associability high and therefore enabled the extinction to proceed more readily (Mondragón & Hall, 2002). However, the results of a similar study by Ballesta et al. (2021) seem to indicate that the common element is indeed less associable after intermixed exposure. In their experiment, in which they increased the amount of pre-exposure to auditory compounds, they specifically found slower learning about the common sound during the conditioning phase.

There are clearly many potentially important procedural differences between flavor aversion learning and appetitive conditioning with auditory cues. We have chosen, however, to concentrate here on the timing of the scheduling of stimulus presentations during preexposure, for the following reasons. It has often been supposed (see, e.g., Hall, 2021, for a brief review) that perceptual learning effects will be sensitive to the extent to which the stimulus preexposure procedure provides an opportunity for comparing the stimuli (Gibson, 1969, pp. 14, 108). Comparison may be taken to be facilitated by presenting the stimuli close together in time so that some representation of the first is still active when the second arrives (see, e.g., Dwyer et al., 2011). It might thus be expected to be of importance in the procedures used by Mondragón and Murphy (2010) and by Ballesta et al. (2021), in which the auditory cues were separated during preexposure by intertrial intervals with means of 315 and 240 s, respectively. It seems less likely that an equivalent comparison process would be of importance for presentations flavor stimuli separated by an interval of several hours. Does the ability of intermixed exposure to modify the properties of the common X element in the appetitive procedure depend on the close spacing of the stimuli during training? If so, it should be possible to obtain similar effects with flavor cues, provided the timing of presentation is arranged so as to allow the possibility of comparison with these.

Demonstrations of the basic perceptual learning effect in rats given closely spaced presentations of compound flavor stimuli have been provided by Recio et al. (2018, 2019). In their typical training procedure, presentation of one flavor (AX) is followed, after an interval of 5 min in which water is made available, by presentation of BX. Control subjects receive the same flavor, before and after the interval; AX on some trial pairs, and BX on others. Recio et al. (2019) demonstrated that, with sufficient training, this procedure produced a standard perceptual learning effect, in that subjects given intermixed trials in preexposure showed better discrimination between AX and BX, as evidenced by relatively poor generalization to BX of an aversion conditioned to AX (see also, Sánchez et al., 2022). Recio et al. (2018) confirmed the effectiveness of this training procedure using a different test procedure. In this external inhibition test the subjects received conditioning with a new flavor (Y) followed by a test with the AY compound. Superimposition of a noticeable cue on the trained Y might be expected to detract from the size of the CR evoked by Y (the phenomenon of external inhibition). Subjects given intermixed training showed a more marked effect (i.e., weaker generalization of the conditioned response to the AY compound) than did the control subjects. Significantly, the difference between the groups was abolished when a novel flavor, rather than water, was presented in the 5-min interval between presentations of the compound cues in initial training. This result was interpreted evidence for the importance of a comparison process in this training procedure. It was suggested that the novel flavor acted as a distractor, capable of disrupting the short-term memory of AX, and thus precluding a comparison process that depends on this representation of AX being active when the next stimulus (BX) arrives.

The aim of the experiments to be reported was to extend the experimental procedure developed by Recio et al. (2018, 2019) to examine the effects of exposure to a pair of similar stimuli on the properties of a feature they hold in common. Although, as we have seen, the perceptual learning effects obtained from widely spaced presentations of flavor stimuli appear to be independent of changes in the effectiveness of common features of the preexposed stimuli, it is possible that such changes do occur and are relevant to the effects obtained when presentations of the stimuli in initial training are closely spaced. In the three experiments to be reported rats were given the preexposure to AX and BX flavors according to the procedures used by Recio et al. (2018, 2019), but with tests of the common feature, X. Experiment 1 used a version of the external inhibition test of Recio et al. (2018), with X being tested for its ability to modulate the response controlled by a separately trained cue. Experiment 2, used an overshadowing test, examining the ability of X to modify learning about another cue when the two are conditioned in the compound. Experiments 3A and 3B looked simply at the effectiveness of X when trained as an excitatory conditioned stimulus.

Experiment 1

Two groups of rats received preexposure to two compound flavor stimuli following the schedule and timing used by Recio et al. (2018, Experiment 1). For one group (labeled INT in Table 1), both of the critical stimuli were presented on a given trial separated by an interval of only 5 min. For the other group (BLK in Table 1) a blocked schedule was used, with the same flavor (i.e., AX or BX) being

Table 1
Experimental Designs

	PREEXP	Cond	Test
	Experiment 1		
INT	AX/W/BX BX/W/AX	Y+	XY
BLK	AX/W/AX BX/W/BX	Y+	XY
	Experiment 2		
INT	AX/W/BX BX/W/AX	XY+	Y
BLK	AX/W/AX BX/W/BX	XY+	Y
	Experiments 3A and 3B		
INT	AX/W/BX BX/W/AX	X+	X
BLK	AX/W/AX BX/W/BX	X+	X

Note. INT refers to intermixed preexposure (PREEXP), BLK refers to blocked preexposure. W means water. A and B are hazelnut and caramel aromas (counterbalanced). X is glutamate solution and Y is raspberry aroma. For Experiment 3B, raspberry aroma replaced caramel aroma as a unique element (A or B). The "+" indicates an intraperitoneal injection of LiCl in conditioning (COND); "/" indicates rapid succession of stimuli within the same session. Note that during preexposure the INT group also experienced trials in which BX preceded AX, and the BLK group experienced trials in which both flavors were BX.

presented on both occasions, all presentations of AX occurring in one block of trials and all of BX in another. For these subjects, the minimum interval between a presentation of AX and one of BX was 24 hr. Preexposure was followed by flavor aversion conditioning, in which a novel flavor (Y in Table 1) was associated with injections of LiCl. The final test consisted of presentation of the XY compound. The addition of another flavor to one trained as a CS has been shown to attenuate the conditioned response, reducing the observed aversion (Recio et al., 2018). If closely spaced intermixed preexposure can reduce the effectiveness of the X stimulus, as suggested by the results of Mondragón and Murphy (2010) and of Ballesta et al. (2021), then the attenuation of the aversion produced by adding X to the CS will be less for the INT group than for the BLK group.

Method

Subjects and Apparatus

Subjects were 16 naïve male Wistar rats with a mean ad libitum weight of 393 g (range 430–367 g). The rats were housed individually in transparent plastic boxes measuring 35 × 22 × 18 cm, with sawdust for the bedding. They were kept on a 12-hr light/dark cycle that began at 8:00 a.m. This sample size has proven adequate in the past to detect changes in common element properties following rapid pre-exposure to compound stimuli with similar procedures and designs (e.g., Ballesta et al., 2021; Mondragón and Murphy, 2010). The sample size in these studies was, as in our case, eight subjects per group.

All the solutions used were prepared with tap water on the same day as the experimental session and were administered in the home boxes using 50-ml inverted centrifuge tubes with stainless steel ball-bearing-tipped spouts. Consumption was determined by weighing the tubes before and after the sessions. Stimuli AX and BX consisted of a glutamate solution (16.9 g/l) as X with hazelnut or caramel aromas counterbalanced as A and B, at 0.05% of the total volume of the solution. Flavor Y was a raspberry aroma, again as a 0.05% solution. The aromas used were from the Manuel Riesgo brand (Madrid, Spain). For conditioning, 0.15 M intraperitoneal injections of LiCl at 1% of the subject's body weight were administered.

Procedure

All the procedures used were approved by the Ethical Committee for Animal Experimentation (CEEA) of the University of Granada, number 06/06/2019/099, and were classified as low severity according to European guidelines. Access to water was restricted to two 30-min sessions per day, at 11:00 and 16:00. The rats received three baseline days in which their water consumption was measured during the morning session, since no relevant manipulations were to be carried out during the afternoon session. They were divided into two groups (INT and BLK) of eight approximately matched for weight (mean INT weight: 394 g; BLK: 392 g) and water consumption.

The preexposure phase lasted 4 days (Days 1–4). During the morning sessions all rats received access to compounds AX and BX. The INT group first received 6 ml of one solution for 10 min, followed by 4 ml of water for 5 min, and finally 6 ml of the other solution for 10 min. The order of presentation of the stimuli was counterbalanced so that all subjects experienced AX first on half the trials and BX first on the other trials. The BLK group received the same presentation scheme, but with only one of the compounds being presented on a given day trial. Half received AX on the first 2 days and BX on the next 2 days; half had the reverse arrangement. During the afternoon session, both groups had free access to water for 30 min. On Day 4, after the afternoon session, the animals were weighed again to calculate the volume of LiCl that was to be injected during the conditioning phase.

On the following 4 days (Days 5–8), the rats received two conditioning trials (Days 5 and 7) and two recovery days (Days 6 and 8). On each conditioning day they had access to 30 ml of Y for 30 min, immediately followed by an intraperitoneal injection of LiCl. On the recovery days, the rats had free access to water for 30 min in the morning sessions. For one rat in the INT group, this procedure failed to establish an aversion, and this subject was henceforth withdrawn from the experiment. Two test days followed (Days 9–10), on which the rats received free access to compound XY for 30 min in the morning session.

Statistical Analysis

A repeated measures analysis of variance (ANOVA) was performed to analyze the data, with group as a between-subjects variable and Trial as a repeated measure. We adopted a critical p-value of .05 and used Greenhouse–Geisser and Welch corrections when necessary. Partial eta squared (η^2p) and Cohen's d were used to measure the effect size. The JASP statistical program was used to carry out the analyses.

Transparency and Openness

This study was not preregistered. The raw data on which study conclusions are based are available in the APA′s repository on the Open Science Framework (OSF) https://osf.io/f4r2t/files/osfstorage/63906c4f8ad0c80717ffa599.

Results and Discussion

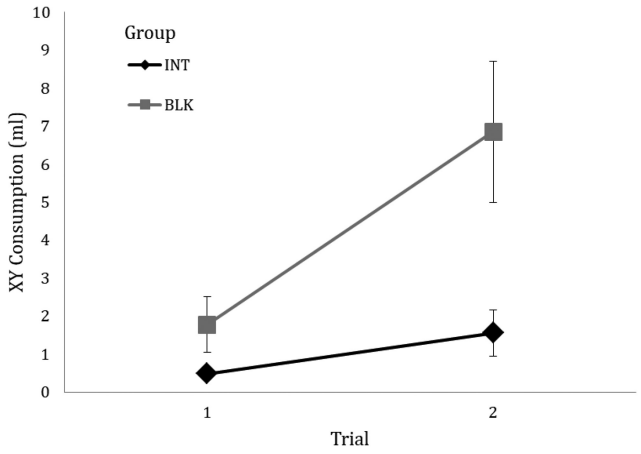
During the preexposure phase, the rats consumed virtually all the liquid available in the tubes. Subjects in groups INT and BLK consumed an average of 4.08 and 4.75 ml, respectively, of the AX solution, and 4.32 and 4.58 ml, respectively, of the BX solution. A repeated measures ANOVA with stimulus (AX and BX) and group (INT and BLK) as variables showed neither significant differences nor interactions in these respects, largest $F(1, 13) = 1.69$, $p = .22$, $\eta^2p = 0.11$, MSE = 3.8 for group factor.

In the conditioning phase, the consumption of Y decreased from the first to the second trial in both groups, consistent with the development of a conditioned aversion. The mean Y consumption for the INT group was 9.1 ml on the first trial and 4.6 ml on the second. For the BLK group, the equivalent Y consumption scores were 11.6 and 4.7 ml. A repeated measures ANOVA with trial and group as variables showed that the decrease in consumption across trials was significant, $F(1, 13) = 43.71$, $p < .05$, $\eta^2p = 0.77$ and MSE = 5.54; neither the group factor nor the interaction of Group × Trial was significant (Fs < 1).

Figure 1 shows the consumption of the XY compound on the two test trials. Consumption was slightly less suppressed in the BLK group than in the INT group on trial 1, a difference that was clearly marked as consumption levels rose on the second test trial.

Figure 1

Experiment 1. Group Means Consumption of XY in the Test Phase



Note. INT refers to the group that received intermixed exposure and BLK refers to the group that received blocked exposure. Error bars show the standard error of the mean.

A repeated measures ANOVA with trial and group as the variables confirmed these impressions showing a significant effect of trial $F(1, 13) = 15.41$, $p < .05$, $\eta^2p = 0.54$, MSE = 4.57 a significant effect of group, $F(1, 13) = 5.79$, $p < .05$, $\eta^2p = 0.31$, MSE = 13.97, and a significant interaction between these variables, $F(1, 13) = 6.54$, $p < .05$, $\eta^2p = 0.33$, MSE = 4.57. The interaction was explored using independent samples *t*-tests. As Levene's test was statistically significant, indicating that the group variances were unequal, we corrected for this violation using the Welch-adjusted *t*-statistic method. This showed a significant difference between the groups on trial 2, adjusted $t(8.48) = 2.7$, $p < .05$, $d = 1.36$.

Consumption of flavor Y was substantially suppressed by the conditioning procedure. The addition of the preexposed flavor X was found to be less effective in attenuating this suppression in subjects that had experienced intermixed presentations of AX and BX during the preexposure than in subjects that had experienced the blocked arrangement. This difference was more evident on the second trial of the test with the XY compound than the first. This may indicate that the presence of X after blocked exposure speeded the development of extinction; alternatively, it may indicate merely that the effect of X was better observed as consumption levels rose with repeated testing. The latter interpretation indicates that X loses properties after intermixed preexposure to AX and BX that prevent it from interfering with the expression of a conditioned response. Alternatively, it may be that X acquires such properties as a result of blocked preexposure (or both of these possibilities). Further discussion will be postponed until other tests of X have been described.

Experiment 2

Experiment 1 tested the properties acquired by stimulus X by assessing the ability of this stimulus to interfere with the expression of a separately acquired CR. In this experiment, we used the same initial training procedure (i.e., intermixed or blocked, closely spaced presentations of AX and BX), but tested the ability of the X stimulus to interfere with acquisition of a CR. Thus, after the initial preexposure phase, the subjects received aversion conditioning with an XY compound (i.e., with X in compound with a novel flavor Y). The presence of X can be expected to overshadow to some extent acquisition by Y. Will the two schedules of preexposure differ in this respect?

Method

The subjects were 16 male Wistar rats with a mean ad libitum weight of 415 g (range 300–460 g). They had had previous experience with tastes and aromas, but these were different from those used in this experiment. The animals were maintained as described for Experiment 1. The apparatus used and the flavors and concentrations of the stimulus solutions were the same as described for Experiment 1.

The design of the experiment is summarized in Table 1. The subjects were divided into two groups (INT and BLK) each of eight rats of equivalent weight (INT mean: 416 g; BLK mean: 414 g). As in Experiment 1, there were four preexposure days, with the flavor used differing within trials for the INT group, but across days for the BLK group. After preexposure, there were two conditioning trials (Days 5 and 7) on each of which access to 30 ml of an XY solution was followed by an injection of LiCl. Each conditioning day was followed by a rest day (Days 6 and 8). Finally, there were four test trials (Days 9–12) on which with free access to the Y solution was given for 30 min. During the procedure, a rat from the INT group became ill and was withdrawn from the experiment. Other details not mentioned here were the same as described for Experiment 1.

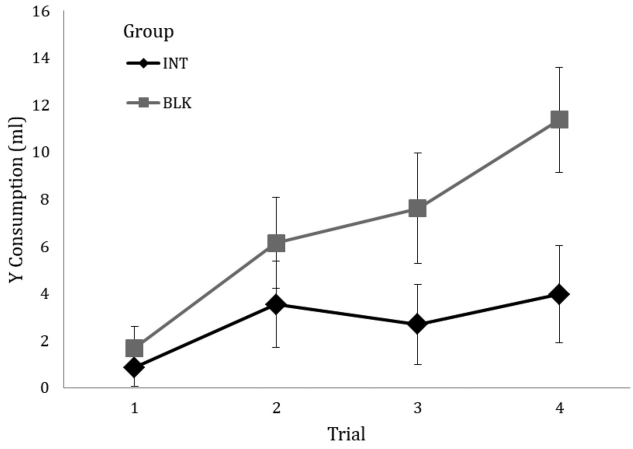
Results and Discussion

During the preexposure phase, the rats consumed virtually all the liquid available. The subjects in groups INT and BLK consumed an average of 5.09 and 4.95 ml, respectively, of the AX solution and 4.43 and 4.78 ml, respectively, of the BX solution. A repeated measures ANOVA with stimulus (AX and BX) and group (INT and BLK) as variables showed neither significant differences nor interaction in these respects, largest $F(1, 13) = 1.84$, $p = .2$, $\eta^2p = 0.12$, MSE = 2.75 for stimulus factor.

The conditioning phase saw a decrease in XY consumption from the first to the second trial. The INT group consumed a mean of 15.7 ml on the first and of 3.5 ml on the second; the scores for the BLK group were 15.7 and 5.4 ml. A repeated measures ANOVA with trial and group as the variables showed a significant effect of trial, $F(1, 13) = 42.24$, $p < .05$, $\eta^2p = 0.76$, MSE = 19.84. Neither the effect of group nor the interaction was significant (Fs < 1). Consumption of flavor Y over the four test trials is shown in Figure 2. Initially, consumption was suppressed in both groups, but with the increase in consumption over the extinction trials of repeated testing, a difference emerged, with the BLK group consuming more than the INT group. A repeated measures ANOVA with trial and group as the variables showed no main effect of group ($F < 1$) but there was a significant effect of trial, $F(3, 39) = 13.61$, $p < .05$, $\eta^2p = 0.51$, MSE = 7.61, and a significant Trial × Group interaction $F(3, 39) = 4.00$, $p < .05$, $\eta^2p = 0.24$, MSE = 7.61. This interaction was explored using independent samples *t*-test, which showed significant differences for both groups on test 4, $t(13) = 2.41$, $p < .05$ and $d = 1.25$.

Figure 2

Experiment 2. Group Means for Consumption of Y in the Test Phase



Note. INT refers to the group that received intermixed exposure and BLK refers to the group that received blocked exposure. Error bars show the standard error of the mean.

The result presented in Figure 2 can be interpreted in terms of overshadowing between separate stimulus elements, with the test of Y alone giving a measure of the extent to which the X element was able to restrict acquisition by Y during conditioning with the compound. The stronger aversion shown by the INT group is consistent with the proposal that after intermixed preexposure stimulus X was less effective in limiting acquisition by Y. The result is also compatible with an interpretation of the overshadowing effect is in terms of the extent to which there is generalization between the XY compound (or configure) used in conditioning and the Y stimulus presented alone on the test. If the X stimulus is particularly noticeable its omission can be expected to reduce such generalization. That the CR remains strong in the INT group despite the omission of X on the test implies that for them X was not an important constituent of the conditioned configure—that the INT preexposure procedure reduced the effectiveness of X in this regard.

Experiments 3A and 3B

The experiments by Mondragón and Murphy (2010) and by Ballesta et al. (2021) tested the properties of the X stimulus after intermixed or blocked preexposure by using it as the CS in a simple excitatory conditioning paradigm. The present Experiment 3A (see Table 1) used the same procedure. That is, after intermixed or blocked preexposure, as in the previous experiments, all subjects received conditioning trials on which X was followed by an injection of LiCl. The strength of the acquired aversion was then assessed by presenting X on a series of extinction trials. Experiment 3B was conducted using the same design, except that in this case the volume of LiCl injected during the conditioning phase was halved. This gave us the opportunity to administer more conditioning trials and to observe the associability of X in more detail. This procedural change resulted in a deeper aversion and thus more extinction trials were given as well.

Method

The subjects were 32 male Wistar rats with previous experimental experience but with stimuli different from those used in this experiment. Their mean ad libitum weight was 492 g (range 432–613 g). They were divided into four groups (two INT and two BLK) of eight, matched for weight. For Experiment 3A, the mean weights were INT: 485 g; BLK: 489 g, while for Experiment 3B, they were INT: 492 g and BLK: 502 g. For Experiment 3B, raspberry odor was used as a unique element instead of caramel odor, as supplies of the latter became unavailable.

As in the previous experiments, there were four preexposure days with AX and BX as the stimuli, the flavor used differing within trials for the INT group, but across days for the BLK group. For Experiment 3A, there were two conditioning trials (on Days 5 and 7) while for Experiment 3B, this phase lasted four trials (on Days 5, 7, 9, and 11). On all of these, 30 ml of the X solution was made available followed by a 0.15 M intraperitoneal injection of LiCl. For Experiment 3A, the dose was administered at 1% of the subject's body weight while for Experiment 3B, this was at 0.5%. Days 6 and 8 were rest days, and also days 10 and 12 for Experiment 3B. On the test trials that followed all subjects were given free access to the X solution for 30 min. For Experiment 3A, test phase lasted four trials (Days 9–12), while for Experiment 3B, this phase lasted ten trials (Days 13–22). Procedural details not specified here was the same as described for Experiment 1.

Experiment 3A Results

During the preexposure phase, the rats consumed virtually all the liquid available. The subjects in groups INT and BLK consumed an average of 4.84 and 4.86 ml, respectively, of the AX solution and 4.93 and 5.14 ml, respectively, of the BX solution. A repeated measures ANOVA with stimulus (AX and BX) and group (INT and BLK) as variables showed neither significant differences nor interactions in these respects, largest $F(1, 14) = 1.35$, $p = .26$, $\eta^2p = 0.088$, MSE = 0.79 for the stimulus factor.

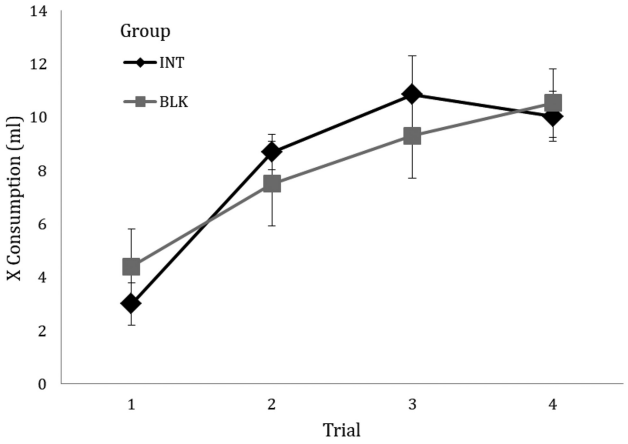
In the conditioning phase, there was a decrease in consumption of X from the first to the second trial in both groups. Group means for the two trials were 16.1 and 13.4 ml for the INT group and 15.6 and 12.6 ml for the BLK group. A repeated measures ANOVA with trial and group as the variables showed a significant effect of trial, $F(1, 14) = 6.4$, $p < .05$, $\eta^2p = 0.3$, MSE = 10.22 (other Fs < 1). Figure 3 shows consumption of X over the 4 test days. Consumption was suppressed on the first trial but was restored with repeated testing. There was no difference between the groups on these tests. A repeated measures ANOVA with trial and group as the variables showed only a significant effect of trial, $F(3, 42) = 28.6$, $p < .05$, $\eta^2p = 0.7$, MSE = 5.22. Neither the effect of group ($F < 1$) nor the interaction, $F(3, 42) = 1.5$, $p > .05$, $\eta^2p < 0.1$, MSE = 5.22, was significant.

Experiment 3B Results

The subjects in groups INT and BLK consumed an average of 4.09 and 4.2 ml, respectively, of the AX solution, and 4.33 and 5.2 ml, respectively, of the BX solution. A repeated measures ANOVA with stimulus (AX and BX) and group (INT and BLK) as variables showed neither significant differences nor interactions in these respects, largest $F(1, 14) = 0.43$, $p = .52$, $\eta^2p = 0.03$, MSE = 0.99 for the Stimulus × Group interaction.

Figure 3

Experiment 3A. Group Means for Consumption of X in the Test Phase

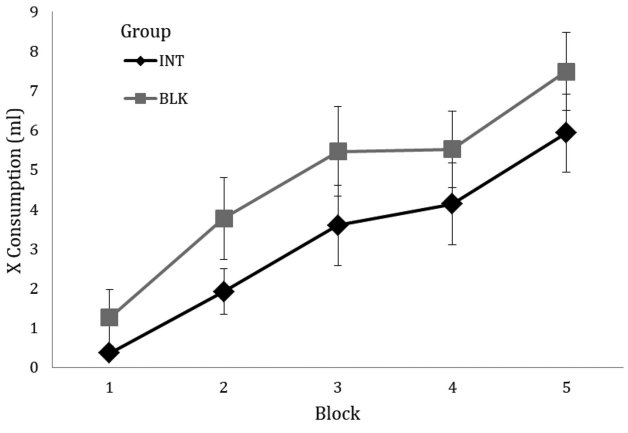


Note. INT refers to the group that received intermixed exposure and BLK refers to the group that received blocked exposure. Error bars show the standard error of the mean.

In the conditioning phase, there was a slow decrease in X consumption from the first to the fourth trial: INT consumed on average: 11.7, 11.1, 5.5, and 1.0 ml and BLK: 10.3, 10.2, 6.6, and 2.2 ml. A repeated measures ANOVA with Trial and Group as factors showed that this decrease in consumption was significant for trial, $F(1.7, 23.9) = 49.7$, $p < .05$, $\eta^2p = 0.8$, MSE = 11. Neither Group factor ($F < 1$) nor the interaction, $F(1.7, 23.9) = 1.2$, $p > .05$, $\eta^2p < 0.1$, MSE = 11, was significant. Figure 4 shows the consumption of X during the 10 test days. The rats increased their consumption at a very slow rate but with similar levels for both groups. A repeated measures ANOVA with trial and group as factors showed that the increase in consumption was significant for trial, $F(9, 126) = 26.5$, $p < .05$, $\eta^2p = 0.7$ and MSE = 3, but neither the group factor, $F(1, 14) = 2.3$, $p > .05$, $\eta^2p = 0.1$, MSE = 40.1 nor the interaction, $F < 1$ was significant.

Figure 4

Experiment 3B. Group Means for Consumption of X in the Test Phase by Blocks of Two Trials



Note. INT refers to the group that received intermixed exposure and BLK refers to the group that received blocked exposure. Error bars show the standard error of the mean.

Discussion

Given the results of Experiments 1 and 2 (and ofBallesta et al., 2021 and Mondragón & Murphy, 2010), the absence of an effect of the preexposure condition in these experiments was unexpected. For Experiment 3A, one possibility is that, after preexposure, the common element suffered sufficient latent inhibition as to preclude acquisition of a conditioned aversion with only two conditioning trials. This is plausible, since on the second conditioning trial the consumption of X for both groups was still quite high. It was for this reason that we modified the parameters for the conditioning and test phases in Experiment 3B in order to make our procedure more sensitive to this variable. But again, with this modified procedure we found no significant differences for X consumption between groups in either the acquisition or extinction phase.

We will not speculate at length on interpretation of these null results, but one possibility may be considered. The preexposure procedure used in these experiments is clearly effective in that it produced a difference between the intermixed and blocked groups in the tests employed in Experiments 1 and 2. Is it possible that the test procedures used in these experiments are more sensitive than simple excitatory conditioning with X as the CS? A feature of the tests used in Experiments 1 and 2 is that they involved presenting the critical X stimulus in compound with another flavor. The preexposure phase of those experiments also involved presenting X in a compound. It is possible that preexposure effects will generalize more readily from training to test in these conditions than when X is presented alone on test, as in the present experiments. We acknowledge that additional assumptions are required in order to explain why Mondragón and Murphy (2010) and Ballesta et al. (2021) obtained effects on conditioning with X in their experiments using auditory stimuli.

General Discussion

The preexposure procedure used in the experiments reported here has been shown to be capable of producing a perceptual learning effect. Experience of closely spaced, intermixed, presentations of the compound stimuli, AX and BX, will promote discrimination between them (Recio et al., 2018, 2019; Sánchez et al., 2022). Moreover, the present experiments demonstrate that this training regime can produce a change in the properties of the common, X, element of the stimuli. Specifically, X is less able to overshadow conditioning to another flavor, and less able to interfere with the CR established to a separately trained CS. Previous experiments using widely spaced presentations of flavored compounds have failed to find any reliable effect of this form of preexposure on X properties (see Hall, 2020). The proposal that the presentation of closely spaced stimuli is key to producing a change on X properties is consistent with the findings reported by Mondragón and Murphy (2010) and Ballesta et al. (2021) who also demonstrated an effect on X (although using a different method of testing) in subjects given closely spaced intermixed presentations of compound auditory stimuli.

A general conclusion that could be drawn from these results is that the mechanisms responsible for the perceptual learning effect

observed after closely spaced stimulus presentations differ from those responsible for the effect observed after widely spaced presentations. However, our designs do not allow us make this claim with confidence. Although, as we have seen above, the literature suggests that these changes in the properties of X with widely spaced presentations are highly elusive, our study did not directly compare long versus short time parameters to test this difference. It remains the case that the effects of preexposure with widely spaced presentations may be better explained in terms of changes in the effectiveness of the distinctive features of the stimuli (e.g., Hall, 2003; McLaren & Mackintosh, 2000). Such changes may also play a role in the effect produced by closely spaced training, but, as our new results suggest, with this procedure, changes in the properties of the X element could also contribute. Specifically, if the common elements of two stimuli are reduced in effectiveness, then discrimination between them, which requires control by the distinctive rather than the common features, will be enhanced (Gibson, 1969).

It is now necessary to attempt to specify more formally what is meant by the "effectiveness" of X, and to consider what learning processes might change it. Mondragón and Murphy (2010) suggested that one aspect of X effectiveness that might be reduced by the intermixed preexposure is its associability (i.e., the readiness with which it will enter into association). According to Mackintosh's attentional theory (1975), when a stimulus is a bad predictor for any consequence its alpha parameter (associability value) decreases, and conversely it increases when that consequence is well predicted. After intermixed preexposure, X could be perceived as a poor predictor of the unique elements because these have been changing on each trial. However, during blocked preexposure X is able (at least) to correctly predict the unique element associated on each block of trials. Such a difference in associability values could explain results of Experiment 2 in which the test involved conditioning of the XY compound. If X loses its associability after intermixed preexposure it would be less effective in establishing associations with the US during the conditioning phase, and competition for associative strength would be "won" by the element Y. After blocked preexposure, by contrast, X would be perceived as a good predictor of the unique elements; this would increase its associability, and promote competition with Y during the conditioning phase, restricting acquisition of aversion by Y. It is a problem for this account, however, that we observed no difference between the groups in Experiments 3A and 3B, where a difference in associability might have been expected to be especially effective in producing a difference in acquisition of the aversion.

Another aspect of the effectiveness of X that may be differentially affected by the form of exposure is its salience. This is a slightly different proposal from that just discussed according to theories (like that of Pearce & Hall, 1980) that make a distinction between the associability of a stimulus and its salience—the former governing the rate of learning whereas the latter also determines the vigor of the response. An account in terms of salience change comes from the analysis offered by Ballesta et al. (2021; see also Artigas & Prados, 2014, 2017). They proposed that during intermixed preexposure, X would form inconsistent and weak associations with the unique elements, which ultimately results in separate representations for each element (A, B, and X), whereas blocked exposure would establish stronger associations in each block of trials, generating configural-like representations (AX, BX). The latter configural-like representations are assumed to be less vulnerable to the effects of exposure than are elemental-like representations, as the strong associations between X and the unique elements reduce the amount of salience lost by each separate element. This account allows an explanation of the results of Experiments 1 and 2. In the test of Experiment 1, a low-salient X, as produced by intermixed preexposure, would be less able to draw attention away from the conditioned Y element, resulting in greater expression of the conditioned aversion to Y on test. The same analysis can apply to explain the results of Experiment 2; a low-salient X produced by the intermixed procedure would be less able to compete for associative strength with a novel Y during conditioning. But again, this account also predicts slower learning about X after intermixed preexposure, the result that was not obtained in Experiments 3A and 3B.

An alternative account of how intermixed preexposure can reduce X salience is found in the theory of habituation offered by Hall and Rodríguez (2019, 2020). This theory postulates that associative learning will change the salience of a stimulus as a function of the consequence that follows it. When a stimulus is followed by no consequence this results in inhibitory learning, characterized as "stimulus-no event" learning. This habituation training progressively negates the initial expectation that some event will follow the stimulus, and, as the expectation declines, the salience goes down. However, this learning process only would be able to operate effectively if X is fully perceived as a separate element, which, as Ballesta et al. (2021) suggest, will be more likely after intermixed preexposure. In any of these cases, the habituation training promoted by the intermixed schedule would reduce the salience of the common element X and this could explain the results presented here in our Experiment 1. Application to the results of Experiments 2 and 3 is more problematic.

The account of Hall and Rodríguez (2019, 2020) proposes that repeated exposure to a stimulus will change not only its effective salience, but also its associability. Specifically, associability is assumed to go down when a stimulus is reliably paired with an associate but will be maintained when its consequences are variable (Pearce & Hall, 1980). This allows, at least with certain parameters, for the possibility that the preexposure procedures used in the present experiments will actually leave X with a higher associability after intermixed than after blocked training. In the latter case, X comes to the test after a block of trials in which its associate has been constant; in the former, the associate of X has changed from trial to trial. A difference between the groups in the level of associability of X will not be relevant in the present Experiment 1 in which there is no further conditioning with X as the CS. In Experiment 2, however, it would tend to work against the effect obtained. That is, enhanced associability in the INT condition would be expected to increase the ability of X to interfere with conditioning to Y, and this would act to reduce the size of an effect generated by a difference in effective salience. And in Experiments 3A and 3B, in which acquisition by X is the sole measure on test, enhancement of the associability of X would act to oppose the effect expected on the basis of salience change, leaving this theoretical account unable to make any clear prediction as to the expected results.

It should be acknowledged that, for the most part, the learning mechanisms considered so far would apply as readily to procedures in which stimulus presentations are widely spaced as to those used here (and also those of Artigas & Prados, 2017; Ballesta et al. 2021; and Mondragón & Murphy, 2010. Although no evidence has been found that the preexposure schedule determines the

properties of the X element when stimulus presentations are widely spaced (see for a review Hall, 2020), this does not necessarily imply that the mechanisms described above are ineffective. Rather, a specification of the reasons why changes in the properties of X are only clearly evident with closely spaced stimulus presentations would be necessary. A crucial step for future research would be to demonstrate differences within the same experiment between the effects of widely spaced and closely spaced presentation of stimuli in perceptual learning.

One final analysis that deals directly with the processes that will be acting when stimulus presentations are closely spaced come from experiments with human subjects by Mundy et al. (2007), and by Dwyer et al. (2011). In these experiments, they obtained a perceptual learning effect (better discrimination after an intermixed preexposure than after blocked) with presentations of the stimuli separated by just 500 ms. They attributed this effect to better encoding of the unique features of the stimuli during intermixed preexposure, as a consequence of short-term habituation of the common element. Thus, for example, when BX follows AX after a short interval, X, which has been previously processed, will free up resources for better processing of B. This short-term habituation of X has some support from the evidence that introducing a distractor in the interstimulus interval attenuates the perceptual learning effect. This short-term habituation account by Mundy et al. (2007) and Dwyer et al. (2011), does not generate predictions about how X will behave when used in a subsequent training or testing procedure. In order to account for our results, it is necessary to assume that the short-term changes in the properties of X postulated by Dwyer et al. (2011) can become sustained and thus influence performance on a test given later.

The interpretations just offered are no more than possibilities, and in the absence of further evidence, it would be fruitless to continue speculation along these lines. We return to the basic finding, which is that the effectiveness of the X element appears to be reduced by closely spaced AX/BX training. Although an effect of this sort seems absent when stimulus presentations are widely spaced, it is likely to be of importance in producing perceptual learning effects when stimuli are presented in a way that allows direct and immediate comparison. It is important to note, therefore, that the bulk of the experimental work on this phenomenon using human subjects (see Mitchell & Hall, 2014 for a review) has used procedures in which presentations of the stimuli have been closely spaced.

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