

Analysis of the Role of Associative Inhibition in Perceptual Learning by Means of the Same–Different Task

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In Experiment 1a, participants were exposed, over a series of trials, to separate presentations of 2 similar checkerboard stimuli, AX and BX (where X represents a common background). In one group, AX and BX were presented on alternating trials (intermixed), in another, they were presented in separate blocks of trials (blocked). The intermixed group performed to a higher standard than the blocked group on a same–different test. A superiority of intermixed over blocked exposure was also evident in a within-subject design (Experiment 1b) and when the test required discrimination between a preexposed stimulus and the background (e.g., AX vs. X), even if the background changed between preexposure and test (AY vs. Y) (Experiment 2). In Experiment 3, the intermixed/blocked effect was observed when, in preexposure, stimulus presentations were alternated with the background alone (e.g., AX/X). This suggests that the perceptual learning effect is not the consequence of inhibitory associations between unique features but to increased salience of those features. Experiment 4 confirmed this finding and also ruled out an account of the effect in terms of trial spacing.

Keywords: discrimination, preexposure, perceptual learning, inhibition, salience

In recent years, experimental studies of perceptual learning using animal subjects have increasingly made use of versions of the following experimental design (introduced originally by Honey, Bateson, & Horn, 1994; see also Symonds & Hall, 1995). Animals are given exposure, with no explicit training, to separate presentations of two similar stimuli (to be called AX and BX, in which A and B represent distinctive features of the stimuli, and X those features that, being similar, they hold in common). In one condition (intermixed) the stimuli are presented on alternate trials; in another condition, they are presented an equal number of times, but in separate blocks of trials (i.e., with all AX trials preceding all the BX trials, or vice versa). Discrimination between the stimuli is then assessed by establishing a conditioned response to one of them and measuring the degree of generalization to the other. It is reliably found that generalization is less after intermixed exposure than after blocked exposure (e.g., Bennett & Mackintosh, 1999; Mondragon & Hall, 2002; Symonds & Hall, 1995). Equivalent effects have been reliably obtained using a within-subject version of this general design (e.g., Artigas, Sansa, Blair, Hall, & Prados, 2006; Blair & Hall, 2003). This outcome is taken to be an example of a perceptual learning effect, in which the special conditions of preexposure supplied by the intermixed arrangement, enhance the discriminability of the stimuli.

In her classic survey of the topic, Gibson (1969) took perceptual learning to be a process that heightens the perceptual effectiveness of the features that distinguish between similar stimuli, a process that is promoted by exposure in which the subject can compare the stimuli. Reduced generalization after intermixed preexposure appears to match this analysis well: The intermixed arrangement is one that might be thought to foster a comparison process, and generalization between AX and BX would be reduced if the effective salience of the A and B features was enhanced. Generalization will depend on the conditioned response (CR) controlled by the X component of the stimuli, and the presence of a salient cue—such as A and B are assumed to be—can be expected to interfere with both the acquisition and the expression of this CR. Hall (2003; see also Blair & Hall, 2003; Blair, Wilkinson, & Hall, 2004) has offered just such an interpretation of this perceptual learning effect.

It should be noted, however, that the effect of schedule of preexposure on generalization (the intermixed/blocked effect) can be explained in purely associative terms, without any appeal to changes in the effective salience of stimuli. McLaren, Kaye, and Mackintosh (1989; see also McLaren & Mackintosh, 2000) have pointed out that preexposure to AX and BX will allow the formation of associations between the various elements of the compound stimuli. In both the intermixed and the blocked schedules, excitatory within-compound associations (between A and X and between B and X) can be expected to form. Additionally, however, standard principles of associative learning (e.g., McLaren & Mackintosh, 2000; Wagner, 1981) imply that the intermixed procedure should allow the development of inhibitory associations between the unique features (A and B) of the preexposed stimuli, A being present on those trials when B is absent, and vice versa. Following exposure, the compound AX is conditioned, and generalization of the conditioned response to BX is

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measured on test. For subjects that have received blocked preexposure, responding to BX will be partly determined by the ability of X to contact a representation of the unconditioned stimulus by way of an associative chain from X to A and then from A to the unconditioned stimulus. This indirect source of responding will not be available to subjects that have been given intermixed preexposure, for whom the presence of B on test will serve to inhibit activation of the representation of A. The result will be a less vigorous response (i.e., less evidence of generalization) after intermixed preexposure than after blocked preexposure.

According to Gibson (1969; and other more recent authors—see, e.g., Fahle, 2002), an associative mechanism of this sort should not be regarded as being “true” perceptual learning: The proposed associative process indeed reduces generalization in the intermixed condition, but the mechanism proposed does not necessarily involve any change in the perceptual effectiveness of (features of) the stimuli. Given this view, it becomes of interest to ask whether the intermixed/blocked effect can be obtained with a test other than the generalization test, in particular with a test more likely to provide an unambiguous index of changes in effective salience. Blair et al. (2004) have attempted to devise such tests for experimental procedures in which rats are the subjects. An alternative strategy would be to make use of human participants whose discrimination can be tested by procedures that do not involve discrimination training or generalization testing—for instance, they can simply be instructed to report whether or not they can perceive a difference between two stimuli (AX and BX). Better performance after intermixed preexposure than after blocked preexposure would, on the face of things (we shall want to qualify this interpretation later), support the view that the perceptual effectiveness of the cues was different in the two cases.

The experiments to be reported here exploit a procedure shown previously, by Lavis and Mitchell (2006), to be capable of generating the intermixed/blocked effect with human participants given a same-different task as the test. Experiments 1a and 1b demonstrate the basic effect. The possible application of the associative inhibition theory to the results of those experiments is then outlined; in subsequent experiments, variations on the training and test procedure were introduced in order to test implications of the theory.

Experiments 1a and 1b

Previous comparisons of the intermixed and blocked procedures using the same-different task have produced mixed results. Dwyer, Hodder, and Honey (2004; see also Mundy, Dwyer, & Honey, 2006) gave their participants exposure to two compound flavors and found that, although generalization of a conditioned aversion was less after intermixed preexposure than after blocked preexposure, there was no difference between the two conditions in their effect on same-different judgments.¹ Lavis and Mitchell (2006, Experiment 1b), on the other hand, using visual checkerboard patterns as the stimuli, found clear evidence for an intermixed/blocked effect. It is not our intention to attempt to resolve the source of this discrepancy; rather it is to explore the nature of the effect on the same-different task in a procedure in which it can be obtained. Accordingly, in the experiments that follow, we made use of variants of the procedure described by Lavis and Mitchell (2006). These initial experiments were designed to confirm the reliability of the intermixed/blocked

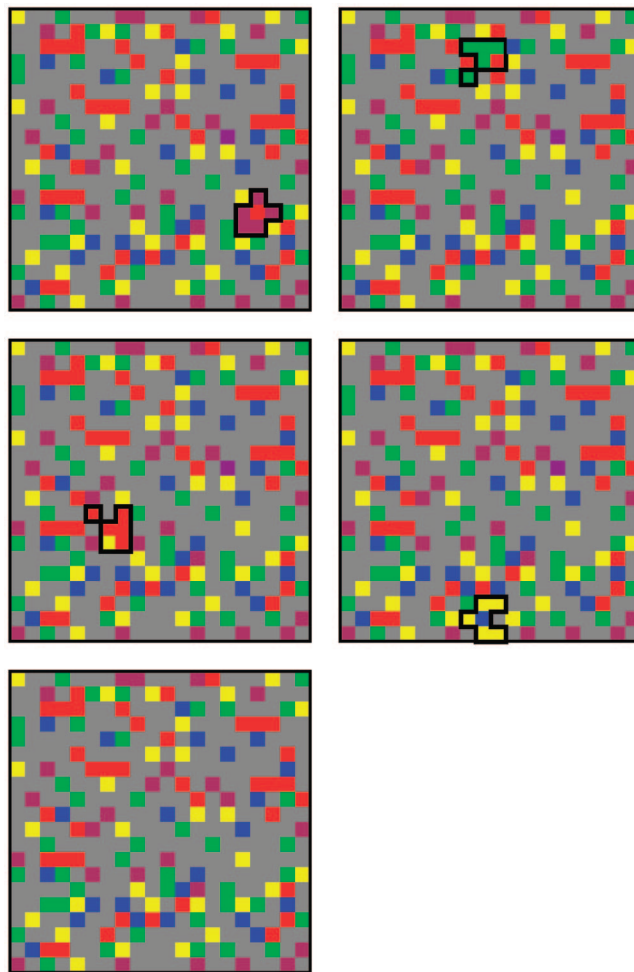


Figure 1. Stimuli AX/DX and X. The lower checkerboard is X, the common element. In each of the remaining checkerboards appears a unique feature (AD) surrounded by a heavy black line that distinguishes that checkerboard from X. This outline was not present during the experiment.

difference. Experiment 1a used a between-subjects design, and Experiment 1b used a within-subject design.

The stimuli were four colored checkerboards of the sort shown in Figure 1. The same background (X; the lowest checkerboard in the figure) was present for all four stimuli, but the addition of unique features (outlined, for purposes of illustration, in black in the figure) created four different compound stimuli. In Experiment 1a, two of those compounds were randomly selected to play the roles of AX and BX. Half of the participants received preexposure consisting of intermixed presentations of AX and BX, and the remainder received a block of trials on which AX was presented and a block on which BX was presented. In Experiment 1b, participants were given intermixed exposure to AX and BX; they also received a block of trials on which CX was presented and a block on which DX was presented. On the

¹ Dwyer, Hodder, and Honey (2004) did see an intermixed/blocked effect on a same-different task after training in which feedback was given on each preexposure trial. Our concern here, however, is with preexposure in which no feedback is given.

test, participants in both experiments were presented with pairs of checkerboards, which had been preexposed either in an intermixed or blocked fashion, and were asked to judge whether the members of the pair were the same or different. A perceptual learning effect would be demonstrated if stimuli preexposed on an intermixed schedule were better discriminated upon testing than those preexposed on a blocked schedule.

Method of Experiment 1a

Participants. The participants were 24 undergraduate students from the University of New South Wales who volunteered for the experiment in return for course credit.

Apparatus and stimuli. The stimuli were four different 20×20 checkerboards (see Figure 1). All had a common background (the X element), created by coloring 156 of the 400 squares green, red, yellow, purple, or blue; the remaining background squares were gray. The common background stimuli are shown at the bottom of Figure 1. Unique features were added by changing six adjacent gray squares to one of the brighter colors. (The stimuli used by Lavis & Mitchell, 2006, were slightly different in that all squares were always brightly colored, so that the addition of a feature changed the background square from one bright color to another.) The added unique features differed from one another in color, shape, and location within the checkerboard. The resulting compounds are shown in Figure 1. The stimuli were presented centrally on a 17-inch computer monitor and were approximately 8 cm square. Revolution Studio 2.7.2 was used to control stimulus presentation on an IBM-compatible PC. The area of the screen around the checkerboard was the same gray as appeared in the noncolored squares of the checkerboard. A thick black border separated the checkerboard from the remainder of the screen. The individual squares within the checkerboard had no border. Although only two compound stimuli were presented to each participant in the present experiment, some subsequent experiments used all four of the stimuli shown in Figure 1. For continuity, all four stimuli shown in Figure 1 were used in this study. Thus, two of the four compound stimuli shown in Figure 1 were randomly chosen to play the role of AX and BX for each participant.

Design and procedure. All participants received a single phase of preexposure in which stimulus compounds AX and BX were presented. For half of the participants, the intermixed group, presentations of AX alternated with presentations of BX. For the blocked group, presentations of AX were given consecutively, followed by presentations of BX.

At the start of the experiment, participants were seated approximately 60 cm from the computer monitor and were presented with instructions on the screen. They were told to pay attention to the stimuli, that any stimulus differences they detected would be useful later in the experiment, and to press the space bar to proceed from one trial to the next. During the preexposure phase, each stimulus was displayed 60 times for a duration of 470 ms. After each presentation, a blank gray screen was presented for 2000 ms during which participants made their bar presses. In fact, the following trial was initiated 2000 ms after the last, whether a press was made or not. This delay was inserted to prevent apparent motion effects that would produce pop-out of the unique features. Such effects are seen with interstimulus intervals of up to around 200 ms.

On completion of the preexposure phase, a second set of instructions was presented on the screen. Participants were informed that they would be presented with a succession of pairs of checkerboards, one pair at a time. They were told to press the A key if these two stimuli appeared to be the same and the 5 key on the number pad if the stimuli appeared to be different. A reminder about which keys to press remained on the screen throughout the test period. Participants were also told not to spend too long on each judgment. Test trials consisted of the presentation of one stimulus for 800 ms, followed by a blank screen for 550 ms and the presentation of the second stimulus for 800 ms. During the interval between trials, a white square was presented in place of the checkerboard, and this remained on the screen until 1400 ms after the response had been made, at which point the next trial was initiated.

There were two types of test trial: (a) *different*, in which AX and BX were presented, and (b) *same*, in which AX and AX (or BX and BX) were presented. The order of stimulus presentation on different trials was counterbalanced across trials. There were 80 test trials in total, divided into two blocks of 40 trials. Within each block, there were 20 trials of each type. After each block, participants were free to rest their eyes if they wished.

To analyze the data, we conducted an analysis of variance with a set of planned contrasts. The repeated measures were analyzed with a multivariate model (O'Brien & Kaiser, 1985), and a significance level of $p < .05$ was set for all of the statistical analyses. This approach was also taken in the analysis of all subsequent experiments.

Results of Experiment 1a

No data were recorded during the preexposure phase. Performance on the same-different test—mean proportion of correct responses on the two trial types for each group—is shown in Figure 2. It is evident that, in both groups, accuracy on *same* trials

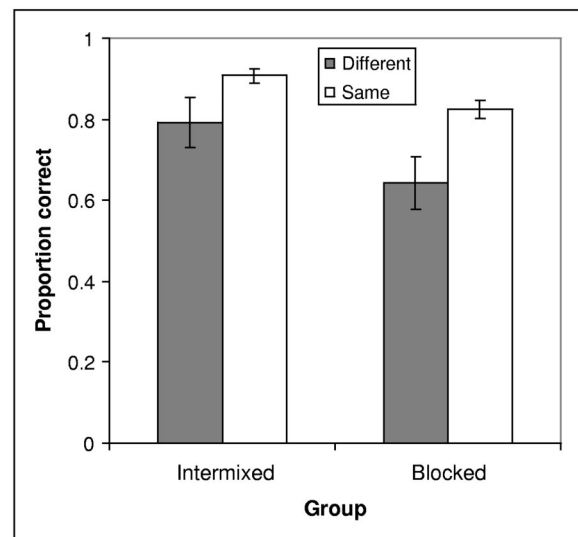


Figure 2. Mean percentage of correct responses on *same* and *different* test trials in Experiment 1a. One group of participants were preexposed to AX and BX on an intermixed schedule, the other on a blocked schedule. Error bars indicate standard errors of the mean.

was higher than that on *different* trials. In addition, overall accuracy appeared to be higher in the intermixed group than in the blocked group. Statistical analysis conducted on the data summarized in Figure 2 confirmed these impressions. The main effects of preexposure condition (intermixed vs. blocked) and of trial type (*different* vs. *same*) were both significant, $F(1, 22) = 4.87$, $MSE = 0.03$, and $F(1, 22) = 13.50$, $MSE = 0.02$, respectively. There was no interaction between these variables ($F < 1$). We also conducted an analysis of participants' sensitivity to the differences by calculating d' for each participant. Hits were defined as proportion of *different* trials on which a correct response ("different") was given. False alarms were defined as the proportion of *same* trials on which an incorrect response was given (also "different"). Mean d' was 3.08 for the intermixed group and 2.12 for the blocked group; this difference was significant, $F(1, 22) = 5.43$, $MSE = 1.02$.

Method of Experiment 1b

The participants were 24 undergraduate students from the University of New South Wales who volunteered for the experiment in return for course credit. Other procedural details were the same as those described for Experiment 1a, with the following exceptions. Inquisit 1.32 by Millisecond was used to control stimulus presentation and record responses. There were two phases of preexposure. In the intermixed phase, presentations of AX alternated with presentations of BX. In the blocked phase, presentations of CX were given consecutively, followed by presentations of DX. The order of these two phases was counterbalanced across participants. Allocation of the compound stimuli shown in Figure 1 to conditions was counterbalanced such that each stimulus was presented equally often in the intermixed and blocked conditions. In addition, the intermixed (and therefore also the blocked) stimulus pairs were made up of all (six) possible combinations of the four stimuli. This, when combined with counterbalancing of the order of intermixed and blocked phases, produced 12 counterbalancing conditions in total.

There were four types of test trial: (a) intermixed *different*, in which AX and BX were presented, (b) intermixed *same*, in which AX and AX (or BX and BX) were presented, (c) blocked *different*, in which CX and DX were presented, and (d) blocked *same*, in which CX and CX (or DX and DX) were presented. There were 160 test trials in total, divided into four blocks of 40 trials. Within each block, there were 10 trials of each type. The mean response time and accuracy was presented on the screen at the end of each block.

Results of Experiment 1b

Performance on the same–different test—mean proportion of correct responses on each of the four trial types—is shown in Figure 3. It is evident that accuracy in responding "same" when identical stimuli were presented was very high, both for stimuli preexposed in the intermixed fashion and also for blocked stimuli. Accuracy in responding "different," however, was much greater for the intermixed stimuli than for the blocked stimuli. Statistical analysis conducted on the data summarized in Figure 3 confirmed these impressions. An analysis of the effect of training order (intermixed followed by blocked, or vice versa) was first conducted on the results of the same–different task. There was no main effect of order ($F < 1$). There was also no interaction

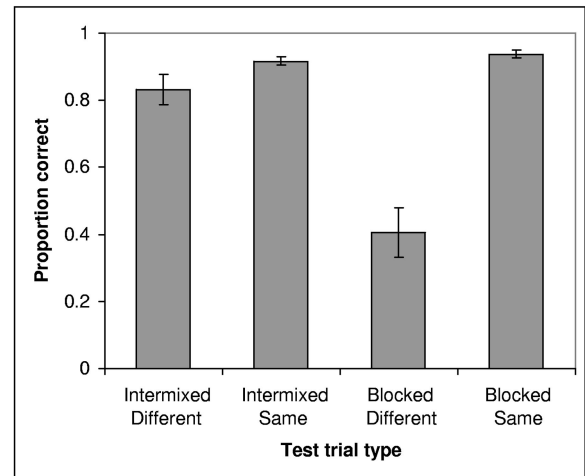


Figure 3. Mean percentage of correct responses on *same* and *different* test trials in Experiment 1b. Stimuli were preexposed on an intermixed schedule (AX and BX) or on a blocked schedule (CX and DX). Error bars indicate standard errors of the mean.

between order and preexposure condition (intermixed vs. blocked) or test trial type (*same* vs. *different*), $F(1, 22) = 1.45$, $MSE = 0.065$, and $F(1, 22) = 1.14$, $MSE = 0.025$, respectively. Finally, there was no significant three-way interaction, $F(1, 22) = 1.33$, $MSE = 0.066$. The two orders were, therefore, collapsed for the purposes of the remaining analyses.

The main effects of preexposure condition and of trial type were both significant, $F(1, 23) = 15.00$, $MSE = 0.066$, and $F(1, 23) = 91.09$, $MSE = 0.025$, respectively. There was also a significant interaction between these variables, $F(1, 23) = 18.01$, $MSE = 0.067$. Simple effects analyses revealed that performance was better after intermixed preexposure than after blocked preexposure on *different* trials, $F(1, 23) = 16.64$, $MSE = 0.132$, and there was no reliable difference between the preexposure conditions on the *same* trials, $F(1, 23) = 4.02$, $MSE = 0.001$. In the analysis of sensitivity, d' was 3.39 for the AX and BX and 1.83 for CX and DX. This difference was significant, $F(1, 23) = 11.77$, $MSE = 2.49$.

Discussion

These data provide clear evidence of an intermixed/blocked effect on a same–different test using a simple, between-subjects design (Experiment 1a) and a more complex within-subject design (Experiment 1b). The results are consistent with Gibson's (1969) idea that only intermixed preexposure allows comparison of the cues and extraction of the unique features. They do not follow straightforwardly from the associative inhibitory mechanism proposed by McLaren and Mackintosh (2000). Indeed, Dwyer et al. (2004) suggested that the formation of inhibitory associations between A and B in the intermixed condition might actually hinder performance on the same–different task. They argued that, when AX and then BX are presented on the same–different task, the memory of AX must be retrieved when BX is being viewed if the subject is to give the correct response of "different." Only in such circumstances can AX and BX be compared with each other and judged to be different. Dwyer et al. went on to argue

that an inhibitory link between A and B would reduce performance on this task: If the presence of B inhibits activation of the representation of A produced by the prior presentation of AX, then that AX presentation would tend to be remembered as an X presentation, and so the difference between AX and BX would be reduced.

It would be premature, however, to reject the inhibitory theory on the basis of this analysis, for as Lavis and Mitchell (2006) have pointed out, an alternative interpretation is possible, and one that generates the result observed. It might be argued that the ability of AX to activate the representation of B (and that of BX to activate A) would act to increase the number of elements common to these two stimuli. In the extreme case, AX and BX would, as a consequence of these associations, be perceived to be the same stimulus, ABX, and discrimination would, of course, be impossible. But if, as a result of intermixed preexposure, A acquires the ability to inhibit the activation of B (and vice versa), this source of similarity would be eliminated or reduced, and performance on the same-different test would be enhanced.

The analysis just offered applies readily to the results of Experiment 1a, but the picture is somewhat more complicated when the inhibition account is applied to the within-subject design of Experiment 1b. In particular, for the case in which experience of the AX/BX trials precedes the CX/DX trials, inhibitory links will form not only between A and B but also between D and all the remaining unique features (A–C), and between C and the features A and B. The pattern of inhibitory links just described implies that discrimination between CX and DX on a test will be better than that between AX and BX, because the associatively activated representation of C would increase generalization between AX and BX but not between CX and DX.

The theory can avoid making this unwelcome prediction by adding the (surely plausible) assumption that the within-compound associations (A–X and B–X) formed in the first phase of preexposure will extinguish during the second phase. In these circumstances, inhibitory links between A and B will form in the first phase, but there will be little opportunity for the C and D features to acquire inhibition. A problem still remains, however. Inhibition between A and B will be effective in influencing test performance only to the extent that AX is able to activate the representation of B and BX of A; that is, it will depend on the existence of within-compound associations, the extinction of which has just been assumed. Probably the simplest way to resolve this contradiction (although not the only one) is suggested by the phenomenon of renewal (e.g., Bouton, 1993), the observation that a conditioned response extinguished in one context can be restored by a change of context. It is possible that our participants viewed the preexposure and test phases as being different contexts. If so, it is possible that extinction of within-compound associations occurred during preexposure, preventing an inhibitory link from forming between C and D, but that these associations became active again on testing, giving AX and BX an advantage due to the inhibitory link between them.

In summary, these experiments have successfully confirmed the reliability of the intermixed/blocked effect when the test involves a same-different judgment. This outcome is not readily predicted by the associative inhibition mechanism proposed by McLaren and Mackintosh (2000). But the difficulties faced by this theory are not

insurmountable, and the simple demonstration of an effect in this situation is not enough to disconfirm the theory. The experiments that follow continue to explore the intermixed/blocked effect using the same-different test, but introduce modifications, both in the training and the test procedures, intended to generate more theoretically decisive results.

Experiment 2

In an experiment that used rats and the taste-aversion procedure, Blair and Hall (2003, Experiment 4a) looked at the effects of preexposure to AX and BX on performance to two new compounds (AY and BY) that were made up of the same unique elements but a new common element. They found that discrimination was better after intermixed preexposure. In Experiment 2 we made use of a version of this experimental design and introduced a new background pattern in the test. As in Experiment 1b, the participants received preexposure to AX and BX on the intermixed schedule and to CX and DX on the blocked schedule. For the test phase, one intermixed feature (A) and one blocked feature (C) were presented against the preexposed, X, background; the others (B and D) were tested against the novel, Y, background. In this way, we were able to make a direct comparison between the condition in which the background element remained the same throughout and the condition in which it changed from X to Y for the test phase. To the extent that the effect of interest depends on the ability of the background cue to activate representations of the unique features on the test, one might expect it to be diminished in size when testing against the Y background.

The test used in this experiment differed in a further way from that used in Experiments 1a and 1b. On *different* test trials the participants were presented with a compound of the common background feature and one unique feature (e.g., AX) to be compared with the background feature alone (e.g., X). This procedure does not in itself constitute a challenge to any theory of the intermixed/blocked effect (see the discussion below), but we needed to establish its effectiveness before using it in Experiments 3 and 4 to examine further the role of inhibition between unique features in generating the effect.

Method

The participants were 48 undergraduate students from the University of New South Wales who volunteered for the experiment in return for course credit. The apparatus was the same as that used in the previous experiments. The unique elements A, B, C, and D were the same as in the previous experiments. For half of the participants, the common element presented in Figure 1 served as the X element, and a newly constructed common element served as the Y element. This background had the same pattern of gray and colored squares as was present in X, allowing the unique features to be located in the same place (replacing the same area of gray) on the Y background as on the X background. However, the color of each of the colored squares of the checkerboard was changed from that used in X.

The preexposure procedure was the same as that used in Experiment 1b. The test consisted of 168 trials, organized as four 42-trial blocks. Each block contained 21 trials using the X common element. These were as follows: 3 intermixed *same* trials, in which

AX and AX were presented; 6 intermixed *different* trials, in which AX and X were presented; 3 blocked *same* trials, in which CX and CX were presented; 6 blocked *different* trials, in which CX and X were presented; and 3 common *same* trials, in which X and X were presented. Each block also included an equivalent set of 21 trials using the Y background element, with B as the intermixed feature and D as the blocked feature. Within each block, trial order was determined at random.

Results and Discussion

Figure 4 shows the proportion of correct responses on the various types of test trial. The solid bars show group mean scores to compounds presented on an intermixed (AX) schedule and on a blocked (CX) schedule in preexposure. The open bars show performance to the unique elements, B (preexposed according to an intermixed schedule) and D (preexposed according to a blocked schedule), when presented in compound with the novel common element Y on the test. *Same* trials are those on which two instances of one of the four compounds were presented; *different* trials required a comparison of AX or CX with the common element X, or of BY or DY with the common element Y. The trials on which X was compared to X, and Y to Y, are not shown; the mean scores (proportion correct responses) for these test trials were high, 0.80 and 0.84, respectively ($SEM = 0.02$ in both cases).

As in our previous experiments, participants performed very well (in responding “same”) when the stimuli presented were identical. Also as in the previous experiments, unique elements presented in an intermixed fashion during preexposure (A and B) produced better performance on *different* trials than did unique elements presented in a blocked fashion (C and D). That the advantage of intermixed over blocked on these test trials is numerically less in this experiment than in the previous studies may reflect the difficulty of detecting a difference when only one of the displays has an added distinctive feature (i.e., when

the discrimination is AX vs. X, say, rather than AX vs. BX). More interestingly, for our present concerns, it is evident from Figure 4 that the same effects were found regardless of whether the unique elements were presented in compound with the common element used during preexposure (X) or with the novel common element (Y).

An analysis of the effect of the order of preexposure schedule (whether intermixed or blocked was presented first) revealed no main effect of order and no interactions involving order (all $F_s < 1$). Accordingly, the data from both orders were combined in the subsequent analyses. The analyses revealed a difference between intermixed and blocked stimuli, $F(1, 47) = 8.71$, $MSE = 0.057$, a difference between *same* and *different* test trials, $F(1, 47) = 171.23$, $MSE = 0.097$, and an interaction between these two variables, $F(1, 47) = 7.31$, $MSE = 0.043$. Simple effects analyses revealed that the difference between blocked and intermixed preexposure conditions was present on *different* test trials, $F(1, 47) = 9.33$, $MSE = 0.086$, but not on *same* test trials ($F < 1$). The nature of the common element had no impact on any of these findings. Contrasts comparing trials on which the element X was presented with those on which the element Y was presented, revealed no effect of this variable, and no interactions between this variable and the comparisons described above (all $F_s < 1$).

An analysis of d' was conducted as described in Experiment 1a. The d' score for AX was 1.61, and that for CX was 1.00. Similar sensitivity was observed for BY and DY; d' for these stimuli was 1.44 and .93, respectively. Contrasts conducted on the d' measure revealed an effect of preexposure schedule, $F(1, 47) = 9.75$, $MSE = 1.525$, but no effect of test background stimulus (X or Y) and no interaction between these two factors (both $F_s < 1$).

In summary, superior performance in *different* trials was seen when the unique feature from an intermixed preexposure schedule was presented either on background X or Y, and this compound stimulus was compared to X or Y alone. The idea that intermixed preexposure to similar stimuli serves to enhance attention to the unique features of those stimuli (Gibson, 1969) provides a straightforward explanation for this effect. When AX is compared to X, or BY to Y, discrimination will be aided if the unique features are more salient. McLaren and Mackintosh's (2000) inhibitory mechanism can also account for the results obtained, at least for those of the test given against the X background. According to this account, discrimination of CX from X will be hindered by the ability of X to excite the representations of all the unique features, A–D. But when it comes to discriminating AX from X, the presence of A in the AX compound will inhibit the activation of B by X, thus reducing the effective similarity of AX and X (the B feature will be activated when X is presented but not when AX is presented). The theory is somewhat less comfortable with the fact that the intermixed/blocked effect was obtained just as well when the test was given with the features on the novel Y background. The mechanism described above depends on the ability of the X background to excite the representations of the features with which it was associated during preexposure. This prompts the conclusion that no effects should be obtained when X is not presented on the test. It is open to us to assume, however, that because X and Y are similar, Y was also able to excite the representations of the unique features A–D on the test. Thus, performance on discriminations involving Y would be expected to be just the same as those involving X.

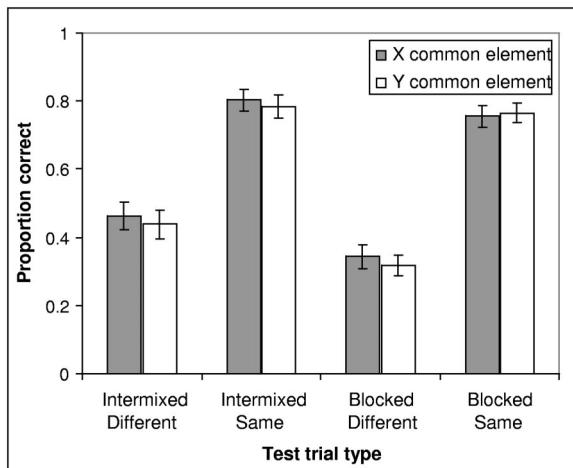


Figure 4. Mean percentage of correct responses on *same* and *different* test trials in Experiment 2. Stimuli were preexposed on an intermixed schedule (AX and BX) or on a blocked schedule (CX and DX). On *different* test trials, cues AX and CX were compared to X (solid bars), cues BY and DY were compared to Y (open bars). Error bars indicate standard errors of the mean.

Although they are not theoretically decisive, these results show that it is possible to obtain a robust intermixed/blocked effect when the test procedure involves the discrimination between a compound of background and feature (e.g., AX) and the background (X). The experiments that follow make use of these same procedures to test other aspects of McLaren and Mackintosh's (2000) account of the intermixed/blocked effect.

Experiment 3

In the previous studies we gave initial training—intermixed presentations of AX and BX—that allowed the possibility that inhibitory links will be formed between A and B. The design of Experiment 3 aims to prevent the possibility of inhibition between unique features. It is based on one previously used in experiments on flavor-aversion conditioning in rats by Rodriguez and Alonso (2004) and by Hall, Blair, and Artigas (2006). In the preexposure phase, participants experienced intermixed presentations of AX and BX and a block of trials with the compound DX. The new feature of the preexposure phase was the introduction of trials in which CX was alternated with X. The results of Experiment 2 indicate that when given a test requiring discrimination between a compound and the background, the participants will be less able to discriminate DX from X than AX from X. According to the associative-inhibition account, this difference arises because the associatively activated representation of B serves as one of the common elements in the comparison of DX and X, rendering discrimination between these more difficult. But the ability of A to inhibit the representation of B eliminates this detrimental factor when the discrimination is between AX and X. (An analogous argument applies to the case in which BX is presented on a test.)

Performance on the remaining discrimination, between CX and X, allows a test of this hypothesis. According to the analysis just presented, the discrimination involving D is (relatively) poor because blocked preexposure does not endow this feature with the power to inhibit some other feature representation. The same will be true of the

C feature; intermixed CX and X trials will not generate inhibition, because there is no second unique feature presented on X trials with which C might form such an association. Accordingly, performance on the discrimination involving CX should be at the same low level as that involving DX. With respect to the Gibsonian notion of changing perceptual effectiveness, it seems reasonable to assume that a preexposure procedure that allows for easy comparison of CX and X should produce an increase in the effective salience of the distinguishing feature, C, and that performance on the test discrimination involving CX will be good.

Method

The participants were 24 undergraduate students from the University of New South Wales who volunteered for the experiment in return for course credit. The apparatus and stimuli were the same as those used in Experiment 1a. The intermixed condition (AX/BX) was organized just as in Experiments 1b and 2, as was the block of trials with DX. However, preexposure to CX was intermixed with presentations of X alone (CX/X). All six possible orders of these three preexposure schedules were given to equal numbers of participants ($n = 4$). The test schedule was the same as that of Experiment 2, except that all presentations used the X common element. There were four blocks of 42 trials (168 trials in total). Each block comprised 3 *same* trials for every compound (AX vs. AX, BX vs. BX, CX vs. CX, and DX vs. DX), 6 *different* trials for each compound (AX vs. X, BX vs. X, CX vs. X, and DX vs. X), and 6 (*same*) X versus X trials. Thus, across the entire test session, there were 12 *same* trials and 24 *different* trials for each compound. Details not specified here were the same as those described for the previous experiments.

Results and Discussion

The group mean proportion of correct responses on various categories of test trial is shown in Figure 5 (as in Experiment 2, the

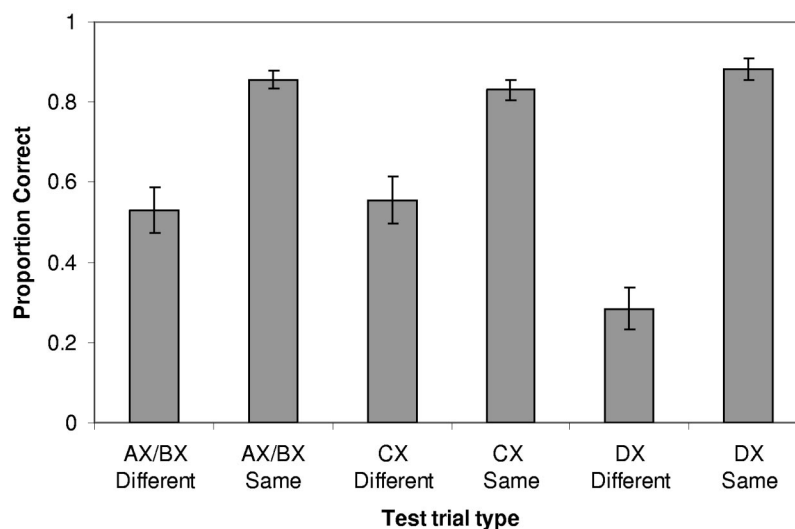


Figure 5. Mean percentage of correct responses on *same* and *different* test trials in Experiment 3. Two stimuli (AX and BX) were preexposed on an intermixed schedule. One cue (CX) was intermixed with the common element X, and a further cue (DX) was presented in a blocked fashion. Error bars indicate standard errors of the mean.

results of trials in which two X stimuli were compared are not shown; on these the group mean proportion of correct responses was 0.85 with $SEM = 0.02$). As usual, participants performed very well (in responding "same") when the two stimuli were identical, regardless of the schedule of presentation used in preexposure. Compounds preexposed on the intermixed schedule during preexposure (AX and BX) produced better performance on *different* trials than did the compound preexposure on the blocked schedule (DX). The new finding is that performance was also good in the condition in which the CX compound was intermixed with the common element X in preexposure, with scores on *different* test trials being much the same as those for AX and BX (see Figure 5).

In contrast to the previous experiments, there were some effects of the order of preexposure schedule, specifically on the difference between performance on *same* and *different* test trials. With six preexposure schedule orders, the number of interactions has the potential to become unmanageable. We therefore limited the number of comparisons analyzed. These showed that overall performance was better when DX preexposure preceded AX/BX preexposure, $F(1, 18) = 12.65$, $MSE = 0.048$. This effect also interacted with test type (*same* vs. *different*), $F(1, 18) = 30.76$, $MSE = 0.025$; specifically, performance on *different* (but not *same*) test trials was better (across all contingencies) when the DX schedule preceded the AX/BX schedule in preexposure. In addition the order of CX and AX/BX contingencies affected accuracy, $F(1, 18) = 4.91$, $MSE = 0.048$, and this comparison interacted with test type, $F(1, 18) = 8.29$, $MSE = 0.025$. Thus, better performance was seen on *different* trials (across all contingencies) when CX preceded AX and BX. The effect of the order of CX and DX schedules relative to each other was not significant, $F(1, 18) = 2.23$, $MSE = 0.048$, and did not interact with any other comparisons (largest $F(1, 23) = 3.50$, $MSE = 0.025$, for the interaction between order of CX and DX and same-different test type).

It is not obvious how to interpret these order effects. For some reason, performance was improved, on *different* test trials only, when the AX/BX trials were presented later in the preexposure phase. Importantly, however, there was no impact of order on which stimulus, AX/DX, was better discriminated on the test; order produced no significant interactions in comparisons involving the variable of stimulus type (AX/DX), largest $F(1, 18) = 2.46$. Because no order effect was observed on this, the primary focus of the article, the data from the different orders were combined for the purposes of the following analysis.

As in the previous experiments, the overall difference between *same* and *different* test trial performance was significant, $F(1, 23) = 100.77$, $MSE = 0.057$. Performance to AX and BX was better than performance to DX, $F(1, 23) = 13.34$, $MSE = 0.021$, and this difference interacted with the same-different test-trial type, $F(1, 23) = 10.96$, $MSE = 0.040$. This intermixed/blocked effect, just as in the previous experiments, was present on *different* test trials, $F(1, 23) = 13.78$, $MSE = 0.052$, but not on *same* test trials ($F < 1$). Performance to CX was also better than that to DX overall, $F(1, 23) = 6.48$, $MSE = 0.044$, and an interaction with test-trial type was again observed, $F(1, 23) = 19.36$, $MSE = 0.032$. Simple effects analyses revealed that the difference between CX and DX on the test was present on *different* trials, $F(1, 23) = 13.07$, $MSE = 0.067$, but not on *same* trials, $F(1, 23) = 3.47$, $MSE = 0.009$. There was no difference between the performance to AX and BX and that to CX ($F < 1$). Finally, d' was 1.87 for the

average of AX and BX, 1.81 for CX, and 0.95 for DX. A contrast comparing AX and BX with DX was significant, $F(1, 23) = 11.45$, $MSE = 0.891$, as was a contrast comparing CX with DX, $F(1, 18) = 6.17$, $MSE = 1.46$. AX and BX did not differ from CX on this measure ($F < 1$).

These results show that the beneficial effects of intermixed preexposure are observed when a compound stimulus is alternated with the background alone (CX/X) in preexposure. In these circumstances it is not possible for a unique stimulus feature to acquire the ability to inhibit another stimulus element (as could happen with the standard intermixed AX/BX procedure). It is not obvious, therefore, how the associative inhibition account might explain this finding. It is better explained by the proposal that the effective salience of the unique feature of the compound is enhanced by intermixed preexposure (or at least maintained at a higher level than is produced by blocked preexposure). It may be assumed that such changes in salience will also take place in the standard AX/BX procedure and are responsible for the test results produced by these stimuli in this and the previous experiments. It is possible that inhibitory links between A and B also play a role, but the fact that performance after this kind of preexposure is no better than that produced by intermixing the compound CX with X alone implies that their contribution must be very slight.

Experiment 4

In the standard intermixed schedule, presentations of AX are separated by presentations of BX and vice versa. Thus, in Experiment 3, the interval between successive presentations of AX (or of BX) was 4940 ms. (The same interval occurred between successive presentations of CX, given the intervening presentations of X alone.) For the blocked schedule, on the other hand, stimulus presentations were not spaced in this way; the interval between successive presentations of DX in Experiment 3 was 2470 ms. This raises the possibility that the intermixed/blocked effect might be a consequence of trial spacing; perhaps stimuli are encoded more effectively when experienced in the spaced arrangement.

We have recently tested this hypothesis using the same stimuli as those used in the experiments described here (Mitchell, Nash, & Hall, in press). We presented two intermixed schedules, AX/BX and CX/DY, in a within-subject design. With this design, all stimulus presentations were equally spaced in time, but only AX and BX were intermixed with a similar stimulus. On the test, discrimination between AX (or BX) and X was better than that between CX and X. Thus, the superiority of intermixed preexposure cannot be attributed solely to the spacing of stimulus presentations. We should acknowledge, however, that inhibition between A and B could have been responsible for the effect seen in Mitchell et al.'s (in press) experiment; this was not tested. It may be the case, therefore, that two mechanisms contribute to the standard intermixed/blocked effect: inhibition between A and B and better encoding of the stimuli due to spaced presentations on the intermixed schedule. Mitchell et al. (in press) controlled for the spacing effect, and Experiment 3, above, controlled for inhibition between unique features. In Experiment 4, therefore, we combined the designs of Mitchell et al. (in press) and the present Experiment 3 to control for both the effect of spaced practice and inhibition.

Participants received two preexposure schedules, AX/X and CX/Y. On the test we assessed the participant's ability to discrim-

inate compound stimuli from the background, testing both AX and CX versus X, and AY and CY versus Y. Of the hypotheses considered here, only Gibson's (1969) predicts that performance on discriminations involving A will be superior to performance on discriminations involving C. The unique feature A should gain salience during preexposure because it uniquely distinguishes AX and X. As a consequence, AX and X, and AY and Y, will be rendered more distinct. During preexposure to CX, attention should be distributed evenly across C and X, because both of these features distinguish CX from Y. Performance when CX and X are compared on the test would, therefore, be expected to be poor. Trial-spacing effects could not be responsible for such an outcome, because the A and C cues are matched in this respect; and as was argued for Experiment 3, the design used here precludes a role for inhibitory associations between unique stimulus features.

Method

The participants were 32 undergraduate students from the University of New South Wales who volunteered for the experiment in return for course credit. The apparatus and stimuli were the same as those used in Experiment 2. There were two phases of preexposure. In one phase, AX and X were intermixed, and in another phase, CX and Y were intermixed. The two unique features shown in the left-hand column of Figure 1 were assigned the roles of A and C (and counterbalanced across participants). Which of the two background patterns served as X and which as Y was counterbalanced across participants. Whether a compound (AX or CY) or an element (X or Y) was the first stimulus to be presented in each phase was counterbalanced. Each of the four stimuli (the two compounds and the two elements) was presented 60 times.

As in Experiment 2, all stimulus combinations were presented on the test. There were thus four types of different trials presented in the test phase (AX vs. X, CX vs. X, AY vs. Y, and CY vs. Y), each presented six times, resulting in a total of 24 trials. There were six types of same trial at test, on which two identical stimuli were presented (AX, CX, AY, CY, X, and Y). These same test-trial types were presented three times each, making a grand total of 42 trials.

Results and Discussion

The results of the test trials involving AX, CX, AY, and CY are shown in Figure 6. The trials on which X was compared to X, and Y to Y, are not shown; the mean scores for these trials, proportion of correct responses, were 0.88 for X and 0.91 for Y. The standard errors of the mean for these test trials were 0.04 and 0.03, respectively.

As in previous experiments, performance on *same* test trials was superior to that on *different* test trials. More importantly, performance on *different* test trials appeared to be better for test stimuli AX and AY than for CX and CY. An initial analysis revealed no main effect of the order of presentation of the two preexposure schedules, $F(1, 30) = 1.84$, $MSE = 0.085$. There was also no interaction between order and test type (*same* or *different*), $F(1, 30) = 1.89$, $MSE = 0.167$, or any other factor (all other F s < 1). Therefore, the data from the two orders of preexposure were combined for further analysis.

Performance on *same* test trials was better than that on *different* test trials, $F(1, 31) = 141.62$, $MSE = 0.172$. Performance on trials

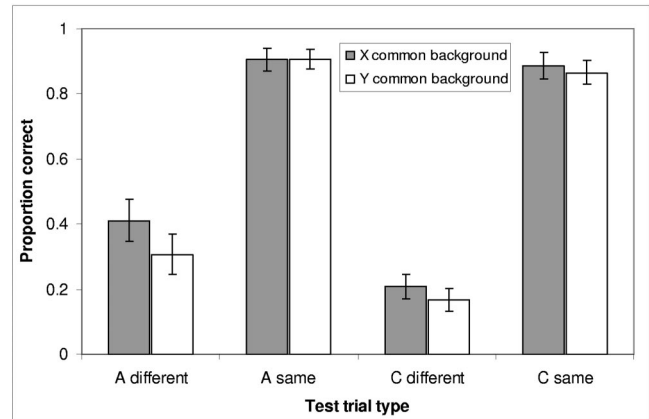


Figure 6. Mean percentage of correct responses on *same* and *different* test trials in Experiment 4. Stimuli AX and CX were compared to the common element X. Stimuli AY and CY were compared to the common element Y. In preexposure, AX was intermixed with X, and CX was intermixed with Y. Error bars indicate standard errors of the mean.

in which A was presented (*same* or *different*, on an X or Y background) was better than that in which C was presented, $F(1, 31) = 11.98$, $MSE = 0.05$. This effect was modulated by an interaction between stimulus type (A or C) and test type (*same* or *different*), $F(1, 31) = 4.78$, $MSE = 0.066$. Simple effect analyses revealed that performance was better to A than to C on *different* test trials, $F(1, 31) = 10.30$, $MSE = 0.092$, but not on *same* test trials, $F(1, 31) = 1.06$, $MSE = 0.029$. Finally, there was no main effect of the background (X or Y) on test performance, $F(1, 31) = 3.01$, $MSE = 0.037$, and the background did not interact with test type (*same* or *different*), $F(1, 31) = 2.11$, $MSE = 0.030$, or stimulus type (A or C; $F < 1$). There was no three-way interaction, $F(1, 31) = 1.57$, $MSE = 0.018$.

In the analysis of sensitivity, d' on the test was 1.03 for A presented on the X background and 0.47 for C presented on the X background. When presented on the Y background, d' for A was 0.80 and for C was 0.23. Contrast analyses revealed a significant effect of stimulus type, $F(1, 31) = 10.22$, $MSE = 1.017$, and of background, $F(1, 31) = 4.67$, $MSE = 0.380$, but no interaction between these factors ($F < 1$).

In summary, preexposure to intermixed presentations of AX and X facilitated discrimination performance both when AX and X and when AY and Y were compared. For the former case it might be argued that the effect is, in some way, a consequence of the similarity between the arrangements used in preexposure and those experienced on the test (essentially alternation of AX and X in both cases). But no such explanation can be offered for the results obtained on the discrimination between AY and Y (in this case the test procedure is more similar to the preexposure given to the control stimulus, C). We conclude, then, that our results are what would be expected if the opportunity to compare AX and X provided by the intermixed schedule enhanced the effective salience of A. Neither better encoding of AX than of CX because of spacing of practice (spacing is equated), nor inhibition between unique features (there is no unique feature for A to inhibit), provides a ready explanation for these results. These results appear to provide unique support for a mechanism of perceptual learning based on modulation of salience.

General Discussion

Experiments 1a and 1b replicated the effect of intermixed and blocked preexposure on performance on a same–different task demonstrated by Lavis and Mitchell (2006). Performance was found to be superior after intermixed preexposure, whether preexposure was manipulated between subjects (Experiment 1a) or within subjects (Experiment 1b). In Experiment 2, after intermixed preexposure to AX and BX and blocked preexposure to CX and DX, discrimination of AX from X was superior to discrimination of CX from X. This replicates the intermixed/blocked effect seen in Experiment 1b and shows that only a single unique feature is required on test. In addition, discrimination of BY from Y was superior to discrimination of DY and Y; the intermixed/blocked effect transferred to a novel Y background. Experiment 3 showed that preexposure to CX intermixed with X was sufficient to improve discrimination on test. It was argued that, because there is no second unique feature with which C can form an inhibitory link in this design, the high performance seen on test trials involving CX must have some alternative source. Participants in Experiment 4 received preexposure to AX/X and to CX/Y. On the test, AX was better discriminated from X (and AY from Y) than was CX (and CY). It was argued that this rules out trial spacing as an explanation for the intermixed/blocked effect. Overall, the results are consistent with the idea, first proposed by Gibson (1969), that when similar stimuli can be compared, the unique features can be extracted and become more salient.

How can these results be reconciled with the evidence for inhibition between unique features seen in other studies of perceptual learning in both rats and humans (e.g., Dwyer, Bennett, & Mackintosh, 2001; Mundy et al., 2006)? It may be relevant that most of the evidence for inhibitory mechanisms in perceptual learning comes from studies using generalization tests. In these tasks, AX is usually paired with some biologically significant outcome (although, see Lavis & Mitchell, 2006; Mundy, Honey, & Dwyer, 2007), and generalization to BX of the resulting CR is tested. The extent of this generalization will be determined by two things. First, responding to BX will be strong if AX and BX are perceptually indistinguishable. We assume that this source of generalization also determines responding on the same–different task used in the present experiments. Second, if AX and BX can be distinguished, then generalization may be determined by other factors, such as the associative relationship between the two compound cues. For example, if AX and BX have been paired in training, BX might produce a strong (CR) because it is associated with AX. Perhaps it is the associative relationship between AX and BX, not the discriminability of these cues, that determines the extent of generalization seen in previous experiments. If so, an inhibitory association between A and B would naturally be expected to have an impact on the extent of generalization from AX to BX, even if it has no impact on their discriminability.

If we accept that perceptual learning as measured with a same–different task is determined by modulations of salience, then what is the mechanism by which this modulation takes place? One possibility has been outlined by Hall (2003), who proposed a reverse habituation mechanism. When a stimulus is presented without reinforcement, a common observation is that the response initially evoked (e.g., an orienting response) declines in vigor—that is, habituation occurs. Hall equated habituation with a reduc-

tion in the effective salience of the stimulus (in essence, familiar stimuli are less salient than are novel stimuli). Hall suggested that the activation of a stimulus representation by the presentation of an associate of that stimulus (rather than the stimulus itself) reverses the habituation process and restores salience. Thus, in the intermixed preexposure schedule (AX/BX), the A feature is activated on BX trials because it is associated with X. Similarly, feature B is activated on AX trials. In Hall's (2003) account, associative activation of A and B, by X, will serve to reverse the normal habituation process and maintain (or even increase) the salience of A and B, despite repeated exposure to these cues. Little associative activation of the unique features occurs on the blocked schedule (CX/DX) because the X–C association formed on CX trials quickly extinguishes across DX trials. Only in the intermixed schedule are the necessary within-compound associations maintained to produce significant associative activation of the unique features and therefore reversal of the habituation process.

This proposal has gained some support from studies of perceptual learning and habituation in rats (e.g., Artigas et al., 2006; Hall et al., 2006), but it should be noted that some features of the results described here constitute a difficulty for it. Although the associative activation necessary for reverse habituation of unique stimulus features will be obtained best with the intermixed procedure, it could still occur to some extent with the blocked arrangement. As Blair et al. (2004) discussed in detail, the effect will be more substantial when, in the within-subject design, the intermixed phase of preexposure precedes the blocked phase. As we have seen, the experiments reported here produce no evidence for such an order effect.

Mitchell et al. (in press) proposed another mechanism of salience modulation that is much closer to Gibson's (1969) original analysis. They suggested (see also Honey & Bateson, 1996; Mundy et al., 2007) that the presentations of the unique features A and B may be more effective when AX and BX are intermixed in preexposure than when they are blocked. Short-term habituation of X (the reduction in effectiveness of presentations of X across consecutive trials) might allow greater attention to be paid to features A and B, which appear only on alternate trials. This may then result in better encoding of the representations of these unique features in memory. In the blocked condition, both unique and common features appear on consecutive trials, and so all features will suffer from short-term habituation and their representations will be poorly encoded. The same processes will operate in the case in which the events alternated in preexposure are a compound (e.g., AX) and a background (X). This theory can also account for the results of the present Experiment 4. Again, A will be well-encoded on AX trials; attention to X will be reduced because of its presentation on the immediately preceding X trial. In the CX/Y condition, however, X will compete with C for attentional resources on CX trials, because it was not presented on the preceding trial. This reduced attention to C will mean that the representation of C will be poorly encoded relative to A.

According to this interpretation, what distinguishes the intermixed from the blocked schedules is the extent to which the participants are able to detect and remember the distinctive features of the stimuli, just as Gibson (1969) suggested. Of course, standard learning theory does not predict that well-encoded features will be highly salient. In fact, the unique features A and B might be expected to be especially low in salience if their representations are well encoded: Familiar stimuli, those for which the participant has a strong mental representation, are generally

thought to be less salient than novel stimuli, for which no representations exist. It is necessary to assume therefore, that, once a detailed and stable representation of A and B has formed (in the intermixed, but not in the blocked, case), a top-down attentional process uses these representations to discriminate AX from BX (see Mundy et al., 2007, for a similar point). Perhaps, as Gibson suggested, the detection of these unique features is reinforcing, and this is why participants pay attention to them.

It may be felt that the instructions given to our participants (to pay attention to the differences between the stimuli) are the source of the attentional bias toward the unique features of the intermixed stimuli observed in our experiments. If so, the perceptual learning effect investigated here may be quite different from the effects observed in nonhuman animals. It may be noted, however, that our results are very similar to those of some recent animal studies (e.g., Rodriguez & Alonso, 2004). Furthermore, prior to preexposure, participants were unaware of the differences between the stimuli; whatever resulted in the detection of the intermixed unique features, but not the blocked unique features, must have taken place prior to participants' awareness of those differences. Thus, although the instructions may well have helped to maintain general vigilance, and certainly would have increased attention to the features once they were detected, it is not obvious how they might have increased the salience of intermixed (but not blocked) features of which participants were not yet aware.

Although the mechanism remains to be fully specified, we may conclude that intermixed preexposure enhances stimulus discriminability as assessed by a same-different test task, under conditions in which associative inhibition between the unique features of the stimuli could not be responsible. It is possible, of course, that associative inhibition plays a role in other versions of the perceptual learning task, in particular those in which discrimination is assessed by means of a generalization test (e.g., Mundy et al., 2006). Some (perhaps Gibson, 1969) might regard the latter as not involving "true" perceptual learning. But if we are prepared to accept a more inclusive definition, we must conclude that there are likely to be multiple determining mechanisms, one of which could be inhibition between unique features and another the modulation of salience of those features.

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