

Memory for, and Salience of, the Unique Features of Similar Stimuli in Perceptual Learning

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In two experiments, participants received exposure to complex checkerboards (e.g., AX and BX) that consisted of small distinctive features (A and B) superimposed on a larger common background (X). Subsequent discrimination between AX and BX, assessed by a same-different task, was facilitated when the stimuli were presented on alternate trials in preexposure—a perceptual learning effect (Experiment 1). The hypothesis that this form of exposure results in more accurate representations of the unique features was supported in Experiment 1, which showed that participants were well able to match the color of the feature with its shape. Experiment 2 showed that exposure to A and B in isolation, intermixed with presentations of AX and BX, enhanced the perceptual learning effect, which confirmed that the better encoding of the unique features during intermixed preexposure is a direct cause of the enhanced discrimination observed following preexposure on this schedule.

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It is well established, on the basis of experiments using conditioning procedures with animal subjects, that exposure to similar stimuli reduces generalization between those stimuli. For example, Mackintosh, Kaye, and Bennett (1991) exposed a group of rats to two compound flavors, AX and BX (e.g., sucrose-lemon and saline-lemon) prior to conditioning in which an aversion was established to AX. It was observed that the aversion generalized rather poorly to BX in comparison with the generalization shown by a group given no preexposure (for a review of this effect see Hall, 1991). This effect has been taken to indicate that exposure to similar stimuli enhances the ability to discriminate between them and has been regarded as an instance of perceptual learning.

Explanations of this perceptual learning effect need to accommodate the fact that the effect of preexposure to the stimuli depends on the way in which stimulus presentations are scheduled. For example, Symonds and Hall (1995) gave two groups of rats preexposure to compound flavors AX and BX (e.g., saline-acid and sucrose-acid). One group of rats received intermixed presentations of the two compounds (i.e., the trial sequence: AX, BX, AX, BX . . .) and the remaining group experienced the stimuli in separate blocks of trials (i.e., AX, AX . . . BX, BX . . .). Following

preexposure, all rats underwent conditioning, in which an aversion was established to AX. Generalization of the aversion to BX was found to be less pronounced for rats that had received intermixed preexposure than for rats that had received blocked preexposure. This effect of scheduling, to be referred to as the intermixed-blocked effect, suggests that the process responsible for perceptual learning is more likely to be engaged when the stimuli are experienced in alternation.

The intermixed-blocked effect has been obtained repeatedly in studies of animal conditioning (see, e.g., Blair & Hall, 2003, for a within-subjects demonstration of the effect) and a recent study by Lavis and Mitchell (2006) has also demonstrated the effect in humans. In their procedure, Lavis and Mitchell (2006) preexposed participants to four, complex, multicolored checkerboards, AX, BX, CX, and DX. The four stimuli were all very similar in that the majority of the constituents of each checkerboard were held in common (constituting the X element of the stimuli). The elements unique to each of the four checkerboards (A – D) were small constellations of a single color, superimposed on the X background. All participants received intermixed preexposure to two of the stimuli (AX/BX) and blocked preexposure to the remaining two stimuli (CX/DX). Following preexposure, participants completed a same-different task. On each trial of this task, two stimuli were presented sequentially and the participants were required to indicate whether those stimuli were the same or different. Same-different judgments were more accurate for stimuli given intermixed preexposure than for those given blocked preexposure (for a between-subjects demonstration of this effect, see Mitchell, Kadib, Nash, Lavis, & Hall, 2008). This finding is consistent with those from the animal experiments and suggests that the intermixed-blocked effect is a robust and general phenomenon.

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The results described above are consistent with Gibson's (1969) interpretation of perceptual learning. Gibson (1969) suggested that exposure to a stimulus engages a process called "differentiation." This process causes the mental representation of the stimulus, which is sparse and incomplete when the stimulus is novel, to be expanded and elaborated upon so that more and more of the stimulus features are incorporated. In this way, the representation of the stimulus becomes a more detailed and accurate reflection of the actual stimulus and the features become more perceptually effective. It is easy to see how this differentiation process might improve discrimination between similar stimuli. With exposure, the representations of the stimuli will come to include more of the features that distinguish those stimuli, thus rendering them more discriminable.

In addition, Gibson (1969) suggested that the opportunity to compare stimuli focuses attention on the unique features of these stimuli. Consequently, the process of differentiation becomes biased toward the unique features when comparison is possible, which allows these elements to be extracted from the background. Presumably, the opportunity to compare stimuli is present to a greater extent during intermixed than during blocked preexposure. If the unique elements have higher perceptual effectiveness following intermixed than following blocked preexposure, same-different judgments between intermixed stimuli will be more accurate than those between blocked stimuli—accurate performance on a same-different task depends on participants' ability to perceive the unique elements. The analysis can also be applied to the generalization test results reported for animal subjects (e.g., Symonds & Hall, 1995). Generalization between AX and BX depends on the strength of the conditioned response (CR) governed by the common element, X, after conditioning with AX. When the perceptual effectiveness of A and B is high, perception might be expected to be biased toward these features over X. The presence of the A element during AX conditioning will interfere with the ability of X to gain associative strength and the presence of the B element during test will interfere with the ability of X to retrieve the US. Therefore, if the unique elements have greater perceptual effectiveness following intermixed than following blocked preexposure, generalization should be less pronounced in the former case.

The idea that intermixed preexposure biases attention toward the unique features provides a compelling explanation for the intermixed-blocked effect. What Gibson's proposal fails to provide is a mechanism by which this redistribution of attention might occur. A number of potential mechanisms have been suggested over the past decade or so, but one proposed by Hall (2003), that has received substantial support in the animal learning literature, relies on the process of habituation. It has been demonstrated repeatedly that exposure to a stimulus decreases the unconditioned response to that stimulus. This effect, known as habituation, has been taken to indicate a loss of salience—a decrease in the ability of the stimulus to capture attention as it becomes more familiar. Hall (2003) suggests that habituation of the unique elements proceeds differently, depending on whether preexposure is intermixed or blocked. In the blocked schedule, the unique elements habituate normally; however, in the intermixed schedule, habituation of these elements is prevented or retarded. The result is that the unique features of intermixed stimuli will have higher salience than their blocked counterparts. Thus, the superior discrimination

observed between intermixed stimuli occurs because the unique elements of these stimuli capture attention rather effectively.

A somewhat different mechanism, and one that is perhaps more consistent with Gibson's original notion of the unique elements being extracted from the background and elaborated upon, is that provided by Mitchell, Nash, and Hall (2008). The essence of this account (and Mitchell et al. noted that this outcome can be predicted by several existing theories, e.g., Jacoby's, 1978, theory of memory; Wagner's, 1981, theory of habituation) is that the allocation of attention to a stimulus is affected by how recently the stimulus was last encountered. Recently presented stimuli are easy to process and therefore receive little attention. Less recently presented stimuli require greater effort to process and therefore receive greater attention. In the case in which AX and BX are exposed on an intermixed schedule, X is presented on consecutive trials, whereas A and B are presented only on every second trial. Therefore, for each AX (or each BX) trial, the previous presentation of X will have been more recent than the previous presentation of A (or B). This difference in recency will result in attention being preferentially allocated to the unique element, A (or B), over the common element, X. In the case of blocked preexposure, on the other hand, A (or B) and X are both presented on every consecutive trial. Thus, on a given trial, the unique and common features will have been presented equally recently. Attention will, therefore, not be biased toward the unique features.

It is not this preferential allocation of attention, per se, that is proposed to be responsible for the superior discrimination between intermixed stimuli. Rather, the greater attention to the unique features during intermixed preexposure leads to better encoding in memory. Because the memory traces (representations) of the intermixed unique elements are strong and well-encoded, these representations can be retrieved easily and used effectively to identify these elements (and hence, aid discrimination) on later tasks. In contrast, the weaker representations of the blocked unique elements are less readily retrieved and used and discrimination between blocked stimuli is poorer. Thus, in contrast to Hall (2003), who assumes that salience and discrimination between stimuli is passive and relies entirely on bottom-up processes, Mitchell et al. (2008) propose that, while the process of perceptual learning is passive, the task of discriminating between stimuli involves using the products of perceptual learning in an active, top-down way.

The Mitchell et al. (2008) account of the intermixed-blocked effect generates a clear prediction that will be tested in the experiments to be reported here. It concerns the nature of the representations of the unique features that will result from different schedules of stimulus exposure. According to Mitchell et al. (2008), superior discrimination between intermixed stimuli is a direct result of the unique elements of those stimuli being strongly encoded in memory. Conversely, discrimination between blocked stimuli is comparatively poor because the corresponding unique elements are less well-encoded in memory. The present Experiment 1, therefore, involved a direct test of memory for the unique features after different schedules of preexposure using a human perceptual learning paradigm based on that of Lavis and Mitchell (2006). The design took advantage of the fact that the unique features of the stimuli used in this paradigm each had a distinctive shape and a distinctive color. After preexposure, memory for the unique features could thus be tested by presenting participants with a given shape and asking about the color with which it had

previously been associated. According to Mitchell et al. (2008), memory should be more accurate for features exposed in the intermixed arrangement (i.e., for A and B) than for those exposed in the blocked arrangement (i.e., C and D).

Experiment 1

In a within-subjects design, using visual checkerboard stimuli, Lavis and Mitchell (2006) observed that same-different judgments were more accurate following intermixed than following blocked preexposure. Experiment 1 used stimuli and procedures that were very similar to those of Lavis and Mitchell (2006) in order to investigate memory for the unique features of the stimuli after the different schedules of preexposure. Following preexposure, participants completed a color-matching task (in addition to a same-different task). On each trial of the color-matching task, an unfilled outline of one of the unique elements was presented in the center of the screen and participants were required to select the correct color for that element. Each of the four unique elements had a unique shape and color. According to Mitchell et al. (2008), the unique elements of the intermixed stimuli should be better encoded in memory than should their blocked counterparts. That is, participants should select the correct color more often for the intermixed than for the blocked unique elements.

Method

Participants. The participants were 12 undergraduate psychology students from the University of New South Wales who volunteered for the experiment in return for course credit.

Apparatus and stimuli. The stimuli were five 20×20 cell multicolored checkerboards (AX, BX, CX, DX, and EX), examples of which are shown in Figure 1. Although the pool of stimuli included five checkerboards, any given participant only ever encountered a random selection of four. All five checkerboards had a common background (X) which was created by filling 156 of the 400 squares with one of five colors: red, green, blue, yellow, or purple. The remaining squares were filled gray. The unique elements (A, B, C, D, and E) of the five checkerboards were 4-square blocks of a single color (red, blue, green, yellow, or purple). The

constituent squares of each unique element were all immediately adjacent to one another (i.e., not diagonally adjacent). Each unique element had a unique color, configuration, and location on the checkerboard. During the experiment, the entire checkerboard was surrounded by a thin black border and the checkerboards were presented on an otherwise blank light-gray screen.

The stimuli used in the color-matching task were unfilled outlines of the five unique elements (although, any given participant only saw the outlines of the four unique elements to which they had been preexposed). That is, each stimulus was a thin, black line, in the shape of one of the unique elements, but filled white. These outlines were presented in the center of a gray square, which was the same size as the preexposed grids and the same gray as the noncolored squares of those grids.

The stimuli were presented centrally on a 17" computer monitor and were approximately 8 cm square. Revolution Studio 2.7.2 was used to control stimulus presentation on an IBM-compatible PC.

Procedure. There were three phases in Experiment 1: A preexposure phase and two test phases. In the preexposure phase, all participants received both intermixed and blocked preexposure. At the beginning of the preexposure phase, two stimuli were randomly selected to serve as the intermixed stimuli (AX/BX) and a further two were randomly selected to serve as the blocked stimuli (CX/DX). During the intermixed preexposure subphase (INT), the two stimuli were presented in alternation (AX, BX, AX, BX . . .) and during the blocked preexposure subphase (BLK), all presentations of one stimulus preceded all presentations of the second (CX, CX . . . DX, DX). Preexposure order was counterbalanced across participants, such that blocked preexposure followed intermixed for half of the participants and the reverse was true for the remainder. The test phases were a same-different task and a color-matching task. To ensure that performance on the color-matching task was not affected by completion of the same-different task, the color-matching task preceded the same-different task for all participants.

At the beginning of the preexposure phase, participants were presented with written instructions on the screen. They were told that they would be presented with colored checkerboards and that their task would be to watch the screen, pay attention, and try to

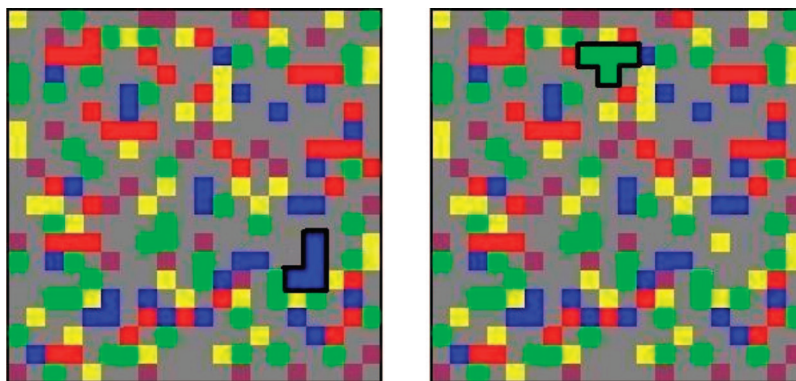


Figure 1. Two examples (e.g., AX and BX) of the stimuli used in Experiments 1 and 2. The common element, X is the majority of each checkerboard. The unique elements, A and B are the 4-square patterns indicated by the heavy black outlines in each stimulus. The outlines are present for the purposes of illustration and were not present in the experiments.

identify any differences between the checkerboards, as any differences they detected would be useful later in the experiment. On each trial, one of the stimuli was presented for 470 ms in the center of the screen and was then removed. Stimulus offset was followed by a 2000-ms intertrial interval (ITI), during which the screen remained blank. In order to maintain attention, participants were asked to press the space bar to proceed from one trial to the next; however, the next trial was initiated immediately following the 2000-ms ITI, regardless of whether the spacebar had been pressed. There were 20 presentations of each of the four stimuli during the preexposure phase, making a total of 80 preexposure trials (40 in the intermixed subphase and 40 in the blocked subphase).

At the end of the preexposure phase, the color-matching task commenced. At the beginning of the color-matching task, participants were presented with instructions on the screen. They were told that they would see some stimuli from the preexposure phase and that, for each stimulus, they would be required to click on a button corresponding to the correct color of that stimulus. At the onset of the first trial, the instructions "Choose the color you think goes with the stimulus" appeared across the top of the screen and five colored buttons appeared at the bottom of the screen. Four of the colored buttons corresponded to the colors of the four unique elements presented during preexposure (A – D) and the fifth button was the same color as the unique element of the one remaining unrepresented stimulus. This fifth color option was included to increase the difficulty of the task. The instructions and the buttons remained on the screen throughout the test phase. On each test trial, the outline of one of the four unique elements (A – D) was presented in the center of the screen and remained until the participant clicked one of the colored buttons. The next trial followed after a 500-ms pause, during which only the instructions and the colored buttons remained on the screen. Each of the four unique element outlines was presented four times during the color-matching task, making a total of 16 trials in this test phase. The order of these trials was randomized.

After completion of the color-matching task, the same-different task commenced. A set of instructions appeared on the screen informing participants that two checkerboards would be presented consecutively and that their task would be to judge whether the two stimuli were the same or different. Participants were asked to press the "a" key if the two stimuli were the same and the "5" key (on the number pad) if the two stimuli were different. A reminder about which keys to press remained on the screen throughout the test phase. On each test trial, two stimuli were presented sequentially, in the center of the screen, for 800 ms each. There was a 2000-ms interval between these two stimulus presentations, during which the screen was blank. At the offset of the second stimulus, a white square (of the same size as the stimuli) was presented in the same position as the stimuli. The white square remained on the screen until the participant pressed one of the two response keys, and for another 1400 ms after this response had been made. At this point, the next trial was initiated.

There were four types of test trial: (1) INT-different, in which AX and BX were presented, (2) INT-same, in which AX and AX (or BX and BX) were presented, (3) BLK-different, in which CX and DX were presented, and (4) BLK-same, in which CX and CX (or DX and DX) were presented. The order of stimulus presentations on the different trials was counterbalanced. There were 10

trials of each type and 40 trials in total. The order of these trials was randomized.

Sets of planned contrasts using a multivariate repeated-measures model (O'Brien & Kaiser, 1985) was used to analyze the data from this and all subsequent experiments. A significance level of $p < .05$ was set for all of the statistical analyses.

Results and Discussion

The mean proportions of correct responses on the color-matching task for the intermixed and blocked conditions are shown in the top panel of Figure 2. It is evident that participants selected the correct color more often in the intermixed than in the blocked condition. To examine this observation (and to reveal any counterbalancing effects), a set of planned contrasts was conducted with preexposure condition (INT vs. BLK) and preexposure order (INT → BLK vs. BLK → INT) as the main factors. This analysis revealed a significant main effect of preexposure condition $F(1, 10) = 6.89$, $MSE = 0.07$. There was also a significant main effect of preexposure order $F(1, 10) = 6.78$, $MSE = 0.06$, with participants who received the order INT → BLK performing better,

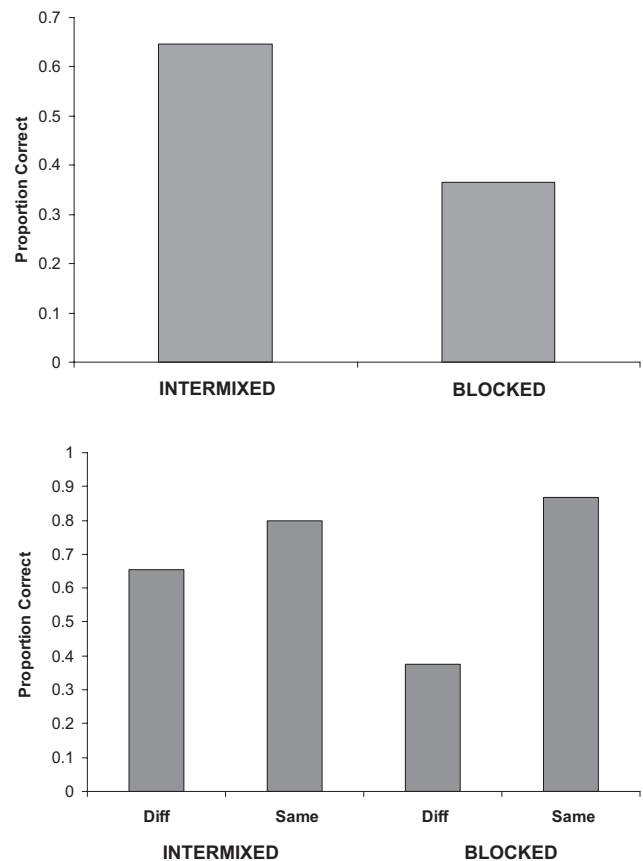


Figure 2. Experiment 1: The top panel shows the mean proportion of correct responses in the intermixed and blocked conditions on the color-matching task for stimuli that had been preexposed on an intermixed (INT) or a blocked (BLK) schedule. The bottom panel shows the mean proportion of correct responses on same and different trials for the intermixed and blocked conditions in the same-different task.

overall, than those who received BLK → INT (the mean proportion of correct responses were, respectively, 0.64 and 0.38). Critically, however, there was no interaction between the two variables ($F < 1$), indicating that the superiority of intermixed over blocked preexposure was not affected by preexposure order. An analysis comparing performance to chance (with chance as 0.2, given that there were five colors to select from) revealed that performance in both the intermixed and blocked conditions was significantly above chance [$F(1, 11) = 23.43, p < .001, MSE = 0.051$; and $F(1, 11) = 5.88, p < .05, MSE = 0.028$, respectively].

The results of the same-different task confirmed that our preexposure procedures produced the standard intermixed-blocked difference in discrimination. The bottom panel of Figure 2 shows the mean proportions of correct responses for same and different trials in the intermixed and blocked conditions. Performance was, in general, better on same trials than on different trials. There was no clear difference between the two conditions on same trials, but performance on different trials was better for the intermixed than for the blocked condition. To investigate these observations (and to examine any counterbalancing effects), a set of planned contrasts was conducted with preexposure condition (INT vs. BLK), trial type (same vs. different), and preexposure order (INT → BLK vs. BLK → INT) as main factors. There was no main effect of preexposure order $F < 1$, no interaction between preexposure order and either of the other two factors $F_s < 1$ and no three-way interaction, $F < 1$. Thus, preexposure order had no effect on same-different performance.

The main effect of preexposure condition approached, but did not reach significance, $F(1, 10) = 3.56, p = .09, MSE = 0.04$. There was, however, a significant difference between same and different trials, $F(1, 10) = 17.25, MSE = 0.07$, and a significant interaction between trial type and preexposure condition, $F(1, 10) = 8.64, MSE = 0.04$. Analysis of simple effects revealed that performance on different trials was significantly better in the intermixed condition than in the blocked condition, $F(1, 10) = 6.38, MSE = 0.07$. The difference between the two preexposure conditions on same trials, fell just short of significance, $F(1, 11) = 4.21, MSE = 0.01$.

Although the preexposure effect observed on same trials was only marginal, the fact that this effect was in the opposite direction to that observed on different trials suggests the possibility that the difference between the intermixed and blocked conditions could be due to a response bias, rather than to a true difference in discriminability. That is, if the elevated number of “hits” (correct responses on different trials) in the intermixed condition was accompanied by an equal elevation in the number of “false alarms” (incorrect responses on same trials), then it may be that performance differences between the intermixed and blocked conditions are due to differences in criterion rather than to differences in stimulus discriminability. To examine this possibility, d' values were calculated and analyzed. The average d' values for the intermixed and blocked conditions were 2.09 and 1.25, respectively. A contrast comparing the two conditions revealed that d' was significantly greater for the intermixed condition than for the blocked condition, $F(1, 11) = 4.90, MSE = 0.87$. This result indicates that differences between the intermixed and blocked conditions are not the result of response biases and confirms that discrimination was superior after intermixed preexposure. Indeed, an earlier pilot experiment, in which the same-different task was

conducted without the color-matching task, confirmed this result: performance was found to be significantly better in the intermixed condition, an effect that the interaction and simple effects revealed to rest almost entirely on responses on different trials.

These results replicate those reported by Lavis and Mitchell (2006), showing that discrimination between two similar stimuli is better following intermixed than following blocked preexposure to those stimuli. As in the previous study the difference between the preexposure conditions was confined to the different trials. Performance on same trials was very good for both the intermixed and blocked conditions. This bias toward “same” responses probably reflects the fact that the stimuli were very difficult to discriminate.

Experiment 2

The results of Experiment 1 demonstrate that the superior discrimination produced by intermixed preexposure is associated with better memory for aspects of the unique features of intermixed stimuli. This finding is consistent with the account of perceptual learning outlined by Mitchell et al. (2008), who suggested that a critical consequence of the intermixed preexposure procedure is that it allows better processing of the unique features of the stimuli so that they become better encoded in memory. These well-encoded representations can be used to discriminate the stimuli presented on test (the perceptual learning effect) and will also support good performance on a task of recognition memory for the unique features.

There is, however, another possible explanation for the results of Experiment 1 that is consistent with Hall's (2003) salience modulation mechanism. According to this account, the greater salience of the intermixed unique elements is the result of a mechanism that prevents the intermixed unique elements from undergoing habituation to the same extent as the blocked unique elements. During intermixed preexposure, therefore, the unique elements will continue to capture attention in the same way as novel stimuli, whereas during blocked preexposure, the unique elements lose their ability to capture attention. One consequence of the sustained ability of the intermixed unique elements to capture attention is better discrimination between intermixed than between blocked stimuli. An additional consequence could be that the unique elements of intermixed stimuli have greater opportunity for encoding than their blocked counterparts. Thus, the better memory for the intermixed than for the blocked unique elements might simply be a correlate of the intermixed-blocked effect, rather than its cause.

The aim of Experiment 2 was to determine whether there is a direct causal link between the extent to which the unique features of the stimuli are encoded and the enhanced discrimination between the stimuli to which those features belong. Participants were preexposed, on a fully intermixed schedule, to six stimuli. Four of the stimuli were checkerboard grids, and the remaining two stimuli were the unique elements of two of those grids. We assumed that the additional exposures to the two unique elements would facilitate the development of a full representation of these elements. Thus, if stronger encoding of the unique elements causes better discrimination, then discrimination between the stimuli with the additional unique element exposures should be superior to that between the stimuli whose unique elements did not receive these additional exposures. In contrast, if the stronger encoding of the

intermixed than of the blocked unique elements is not a cause, but merely a side effect of differences in the salience of these elements produced by the habituation processes postulated by Hall (2003), then the reverse pattern of results would be expected—discrimination between the stimuli with the additional unique feature exposures should be worse than that between the stimuli whose unique features did not receive extra exposures. This is because additional exposure to the unique elements should lead, not only to better encoding (which is not predicted to affect discrimination), but also to greater habituation of these elements. Thus, the exposed unique elements are predicted to be lower in salience than their less-exposed counterparts, leading to poorer discrimination between the stimuli to which the exposed unique elements belong.

Method

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 of the checkerboards used in Experiment 1 (see Figure 1), plus the unique elements from those four checkerboards. The unique elements, when presented alone, appeared on a gray square, which was the same size as the checkerboards and the same gray color as the nonfilled squares within the checkerboards. The location of each unique element on the gray square was the same as its location when it appeared on the background checkerboard. All other details of stimulus presentation were the same as in Experiment 1.

Procedure. There were two phases in Experiment 2: A pre-exposure phase and a test phase. During the preexposure phase, participants received intermixed preexposure to six stimuli: the four checkerboards (AX – DX) and two of the unique elements (e.g., A and B). The two unique elements were randomly selected for each participant at the beginning of the experiment. The checkerboards and the unique features were presented pseudorandomly with the restriction that the same stimulus could not be presented on two consecutive trials. The checkerboards were presented 20 times each during preexposure and the unique elements were presented 10 times each. Thus, there were 100 preexposure trials in total. All remaining details of the procedure during the preexposure phase were identical to those in Experiment 1.

The test phase was a same-different task that commenced at the end of preexposure. There were four types of test trial: (1) unique element exposed (UE-exp) – different, in which the two checkerboards whose unique elements had received additional exposures were presented (e.g., AX and BX); (2) unique element exposed (UE-exp) – same, in which one of the stimuli whose unique elements had received additional exposures was presented twice (e.g., AX and AX); (3) unique element not exposed (UE-non) – different, in which the two stimuli whose unique elements had not received additional exposures were presented (e.g., CX and DX); and (4) unique element not exposed (UE-non) – same, in which one of the stimuli whose unique elements had not received additional exposures was presented twice (e.g., CX and CX). The order of stimulus presentation on the different trials was counterbalanced. There were 10 trials of each type in the test phase, and 40 trials in total. The order of trials was randomized. All other details

of the test procedure were identical to those of the same-different task in Experiment 1.

Results and Discussion

The mean proportions of correct responses on same and different trials for the two exposure conditions (UE-exp and UE-non) are shown in Figure 3. As in the previous experiments, performance for both exposure conditions was good on same trials. On the different trials, however, performance in the UE-exp condition was superior to that seen in the UE-non condition, suggesting that separate exposure to the unique stimulus features enhanced discrimination performance. A set of planned contrasts supported this interpretation. There was a significant main effect of trial type (same vs. different), $F(1, 23) = 65.28$, $MSE = 0.06$, with better performance on same trials than on different trials, and a significant main effect of exposure condition, $F(1, 23) = 4.49$, $MSE = 0.06$, with better performance in the UE-exp than the UE-non condition. However, the interaction between exposure condition and trial type was not significant, $F(1, 23) = 2.51$, $p > .1$, $MSE = 0.05$. Simple effects analysis revealed that, although there was an overall difference between the two preexposure conditions, the differences between the UE-exp and UE-non conditions on same and different trials, individually, did not reach significance, $F(1, 23) = 1.06$, $p > .1$, $MSE = 0.014$ and $F(1, 23) = 3.94$, $p = .059$, $MSE = 0.102$, respectively.

These results show that discrimination between stimuli whose unique elements had received additional exposures was better than that between stimuli whose unique elements did not receive such exposures. There is thus no support for the idea that the encoding differences observed in Experiment 1 are merely a side effect of Hall's (2003) salience modulation mechanism. It was argued that salience may be increased (or maintained) more by intermixed than by blocked preexposure in the way that Hall (2003) suggests and that the resultant differences in attention might be responsible for the stronger encoding of the intermixed than of the blocked

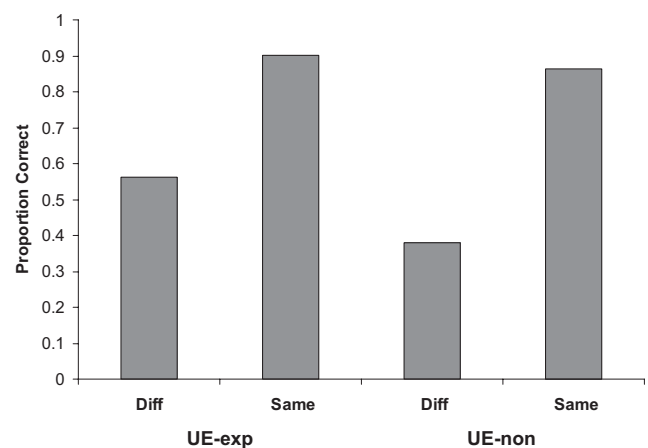


Figure 3. Experiment 2: Mean proportion of correct responses on same and different (Diff) trials for the same-different task. For stimuli used in the UE-exp condition, preexposure included additional trials in which the unique features were presented separately; no such additional trials were given in the UE-non condition. The top panel shows mean scores over the entire test; the lower panel shows means for the first block of test trials.

unique elements. If this were the case, however, discrimination between the stimuli whose unique elements had received additional exposures (UE-exp) should have been poorer than between the stimuli whose unique elements did not receive additional exposures (UE-non). According to Hall (2003; and to many other associative theorists), exposure to a stimulus decreases salience via habituation, and, accordingly, the unique elements that received extra exposures (UE-exp) should have been less salient than the unique elements that did not receive these extra exposures (UE-non). Thus, discrimination is predicted to be poorer in the former condition; the opposite of what was observed.

The results of this experiment are, however, consistent with the proposal advanced by Mitchell et al. (2008). According to this proposal, discrimination is enhanced when the unique features of the stimuli to be discriminated are well encoded. Given the assumption that encoding is likely to be facilitated as a result of additional separate presentations of these elements, the finding that such exposure enhances performance on a same-different task supports the above suggestion that better encoded unique elements leads to better discrimination between stimuli. In addition, this finding lends support to the suggestion that the stronger encoding of the intermixed than of the blocked unique elements observed in Experiment 1 is responsible for the better discrimination between intermixed than between blocked stimuli seen in that experiment.

General Discussion

In order to discriminate two similar stimuli (such as our AX and BX) it is necessary for performance to be controlled by the unique features (A and B), rather than the features they hold in common (X). A preexposure procedure (such as the intermixed schedule) that results in enhanced discrimination may thus be assumed to have its effect because it increases the perceptual effectiveness of the unique features, or reduces that of the common features, or both. Correct responding on, for example, a different trial in a same different task will be rendered more likely if the A component of AX and the B component of BX are perceptually dominant. It is now widely accepted that intermixed preexposure can cause increases in the effective salience of the unique features, with respect to that of the common features, and that these increases in salience are at least partially responsible for the observed perceptual learning effects (although other mechanisms, such as inhibition between unique elements have also been demonstrated under some conditions and may contribute to perceptual learning effects, e.g., McLaren & Mackintosh, 2000). What is at issue is the exact nature of the salience change and the mechanisms responsible for it.

The account proposed by Mitchell et al. (2008) holds that the salience of the unique features depends on the strength with which those elements are represented in memory. On a discrimination task, the ability to recognize and identify the unique features will be facilitated when the memory representations of those elements are strong and well-encoded. That is, the stronger the representation, the higher the salience. Mitchell et al. (2008) proposed a mechanism by which the representations of the unique features strengthen more during intermixed than during blocked preexposure. It is suggested that the processes involved in encoding a stimulus are less effective when that stimulus has been recently presented. Because a given unique element, A, is presented on

consecutive trials during blocked preexposure, but only on alternate trials during intermixed preexposure, the interval between presentations of A during intermixed preexposure is double what it is during blocked preexposure. Encoding of A is therefore predicted to be more effective during intermixed than during blocked preexposure.

This analysis was tested in Experiment 1 by assessing memory for the unique elements following intermixed and blocked preexposure. According to Mitchell et al. (2008), memory for these elements should be better in the intermixed than in the blocked case. The results were consistent with this account—when presented with the unfilled outline of a unique element, participants were better at selecting the correct color if the unique element was from an intermixed, rather than a blocked stimulus. This finding was accompanied by superior discrimination following intermixed than following blocked preexposure. Experiment 2 tested the more general proposal that discrimination between stimuli will be better when the unique elements are strongly represented in memory. It was observed that when intermixed exposure to AX and BX was accompanied by additional exposures to the unique elements, A and B, alone, discrimination was enhanced relative to that between stimuli that had received only intermixed preexposure. Assuming the additional exposures to the unique elements strengthened their corresponding representations, the results of Experiment 2 support the proposal of Mitchell et al. (2008) that discrimination will be better when the unique elements are strongly represented.

The interpretation offered by Hall (2003) makes no assertions about the role of representation strength in salience change. Rather it is simply proposed that exposure to a stimulus produces loss of salience by way of habituation, and that the special conditions of the intermixed procedure engage a process that attenuates the loss suffered by the unique features A and B. This allows it to accommodate the results of Experiment 1: the unique elements of intermixed stimuli become more strongly represented by virtue of their maintained ability to capture attention. Hall's account, however, is challenged by the results of Experiment 2. The additional presentations of the unique elements can be expected, according to Hall's (2003) account, to allow further habituation of A and B, reducing their salience and thus reducing the size of the perceptual learning effect.

The difficulty faced by Hall's analysis in accounting for the results of Experiment 2 lies with its assumption that exposure to the unique elements will necessarily decrease their salience. This difficulty is also encountered by a salience change mechanism provided by the McLaren and Mackintosh (2000) model of associative learning. In contrast to Hall's (2003) account, the McLaren and Mackintosh (2000) model proposes a direct link between representation strength and salience. Decreases in stimulus salience are taken to be the direct result of increases in the strength of the stimulus representation (i.e., in the strength of the associations among the various features of the stimulus). According to the theory, when a stimulus undergoes exposure, the constituent units of that stimulus are activated together and this allows associations to form among them. This process, known as unitization, causes the units, and thus the stimulus, to decrease in salience. The unique elements of intermixed stimuli are predicted to be high in salience because this schedule of presentation is held to prevent them from becoming unitized. When taken at face value, this mechanism appears to require that in order for the intermixed unique elements

to be more salient than their blocked counterparts, they must also have weaker representations: the opposite of the results observed in Experiment 1. However, if it is assumed that the salience of A and C are determined more by within-compound A-X and C-X associations than by within-unit A-A and C-C associations, then the model can be made to predict that A will have a stronger, more unitized representation than C, while simultaneously predicting that A will be more salient than C.

Although the results of Experiment 1 can be accommodated in this way, those of Experiment 2 cannot. The additional exposures to the unique elements, A and B, alone must cause an increase in the degree to which these elements are unitized and must therefore lead to decreases in salience. The enhanced discrimination observed between AX and BX, relative to the stimuli, CX and DX, whose unique elements did not receive additional exposures, is therefore not anticipated by McLaren and Mackintosh's (2000) unitization mechanism.

It might be thought that the reason why theories such as those of Hall (2003) and McLaren and Mackintosh (2000) fail to adequately account for the current data is because human perceptual learning effects are the consequences of mechanisms different from those responsible for the perceptual learning effects in non-human animals that these theories were primarily designed to address. One feature often cited as distinguishing the animal and human procedures is that the former give mere exposure, whereas the latter may involve an element of reinforcement or feedback (e.g., Mackintosh, 2009). Our participants were instructed to look for differences among the stimuli, and it is reasonable to assume that success in finding one would be (mildly) rewarding. It is important to note, however, that no external feedback was given. A self-generated event cannot operate in the way that externally applied feedback might. It is a consequence of detecting differences, rather than a cause of it and does not, in itself, explain why the differences appear to be detected more readily in the intermixed than in the blocked condition.

A related possibility (suggested, among others, by McLaren & Mackintosh, 2000) is that, for human participants, the search for differences among the stimuli generates changes in strategic attention, and that these, rather than changes in the nature of the stimulus representation of the sort we have been discussing are responsible for the effects obtained. For our present stimuli, the most obvious possibility is that participants might be able to detect the spatial location of the unique features, at least with the intermixed schedule. By comparing stimuli across trials, participants might be able to locate the regions that change from trial to trial; by attending to these regions, they could learn about the unique features. They would then be able to discriminate between the stimuli on the final test and perform well on a test requiring information about the shape and color of the features. It is true to say that some of our participants report using a strategy of this sort and that, for these, it may play a role in generating the results obtained. But even for these, this can be only part of the story. A full account needs to explain why the intermixed arrangement makes it possible to detect a distinctive feature (and thus its location) in the first place—to say that alternating AX and BX allows A and B to stand out is simply to restate the phenomenon we wish to explain. Whatever subsidiary mechanisms are brought into play in the human perceptual learning paradigm, the central issue remains, as for studies with animals, the processes by which

certain forms of preexposure enhance the effective salience of distinctive features of the stimuli.

Leaving these theoretical arguments aside, we need to consider a set of experimental results that constitute a direct challenge to our assumption than human and animal perceptual learning effects are underpinned by common mechanisms. In an experiment with rats as subjects, Mackintosh et al. (1991) assessed discrimination between the compound flavors, AX and BX, by establishing an aversion to AX and measuring generalization to BX. Preexposure to AX and BX reduced generalization (i.e., enhanced discrimination), but preexposure to the elements, A and B, alone was much less effective in this regard. On the face of things, the account offered in explanation of the results of the present Experiment 2 predict the opposite—preexposure to distinctive features alone might be expected to allow strong encoding and thus, generate a powerful perceptual learning effect.

Before taking this observation as evidence that the mechanisms underlying perceptual learning in rats are different from those operating in people, we should note some important procedural differences between our Experiment 2 and that of Mackintosh et al. (1991). In the latter, subjects in the critical group received only preexposure to the unique features; in our experiment, this form of preexposure was in addition to intermixed preexposure to the compounds, AX and BX. There is thus, no discrepancy between the results—our experiment shows that extra presentations of A and B enhance the effect produced by exposure to the compounds; that by Mackintosh et al. (1991) shows that exposure to the features alone is not as effective in producing perceptual learning as is exposure to the compounds themselves. The implication is that intermixed preexposure to the compounds engages some other perceptual learning mechanism, in addition to that involved in determining the strength with which the features are encoded. This could be an associatively based salience modulation mechanism of the sort envisaged by Hall (2003) and McLaren and Mackintosh (2000)—and it is one that could be operating in both the human and the animal perceptual learning procedures.

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