

The Intermixed–Blocked Effect in Human Perceptual Learning Is Not the Consequence of Trial Spacing

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A robust finding in humans and animals is that intermixed exposure to 2 similar stimuli (AX/BX) results in better discriminability of those stimuli on test than does exposure to 2 equally similar stimuli in 2 separate blocks (CX/DX)—the *intermixed–blocked effect*. This intermixed–blocked effect may be an example of the superiority of spaced over massed practice; in the intermixed, but not the blocked exposure regime, each presentation of a given stimulus (e.g., AX) is separated from the next by the presentation of its partner (BX). Two experiments with human participants replicated the intermixed–blocked effect and showed that the effect was not due to the spacing of exposure trials. A mechanism for the intermixed–blocked effect is proposed, which combines theories from associative learning and memory.

Keywords: perceptual learning, spaced practice, memory, discrimination

Perceptual learning refers to the change in the way that a stimulus is perceived as a consequence of exposure to that stimulus. For example, mere exposure to two very similar stimuli can render those stimuli more distinct (Gibson & Walk, 1956). This phenomenon is particularly interesting to learning theorists because it is not straightforwardly explained in terms of the known principles of associative learning. In fact, Gibson (1969) has argued that this form of learning is the opposite of associative learning. She termed the phenomenon *differentiation*. She argued that differentiation occurs because, during preexposure, the animal has the opportunity to compare the stimuli and extract (or pay greater attention to) the unique features.

Any two similar stimuli can be described as AX and BX; they share common X features but they also possess features that are unique to each stimulus, A and B. Thus, exposure to AX and BX appears to increase the effectiveness of A and B at the expense of X, rendering the two stimuli more distinct. One very important determinant of this perceptual learning effect, first shown in experiments with animals (originally by Honey, Bateson, & Horn, 1994, with chicks; subsequently by Symonds & Hall, 1995, with rats), is that intermixed preexposure (i.e., a trial sequence such as AX BX AX BX . . .) is much more effective than preexposure, in which the stimuli are presented in separate blocks of trials (e.g., AX AX . . . BX BX . . .). This is referred to as the *intermixed–blocked effect*. It has since been shown to occur in human flavor discrimination (Dwyer, Hodder, & Honey, 2004) and in human visual discrimination (Lavis & Mitchell, 2006). A similar effect (termed *contextual interference*) is also seen in the verbal learning (Battig, 1972) and motor learning (Shea & Morgan, 1979) literatures.

The intermixed–blocked effect lends support to Gibson's (1969) argument that stimulus comparison is critical in perceptual learning; there is more opportunity to compare AX and BX in the intermixed condition than there is in the blocked preexposure condition.

The intermixed and blocked preexposure conditions differ, however, not only in terms of the opportunity they allow for participants to compare AX and BX. They also differ with respect to the temporal spacing of trials. On the intermixed schedule, each AX presentation is separated by a presentation of BX. On the blocked schedule, stimulus presentations are consecutive. Thus, the intermixed–blocked effect might not be a consequence of the greater opportunity to compare the two stimuli on the intermixed schedule but might instead be an example of the advantage of spaced over massed practice (Ebbinghaus, 1885/1964). Specifically, intermixed preexposure might allow better discrimination of AX and BX because spaced practice produces better memory for AX and BX. Such a prediction can be derived from standard theories of the *massed–spaced effect*. One prominent theory supposes that when trials are spaced, more time is available for the events to “consolidate” into long-term memory (Wickelgren, 1972). Another possibility is that encoding conditions may vary more when the presentations are distributed across time. This would create a wider range of potential retrieval cues and increase the probability that one of the memory traces will be retrieved on test (e.g., Glenberg, 1979). We aimed to test this general hypothesis in the present experiments by controlling for the effects of spaced practice and specifically for the potential effects of consolidation and encoding variability.

Experiment 1

This experiment takes as a starting point Lavis and Mitchell's (2006) demonstration of the intermixed–blocked effect using visual stimuli in humans. Examples of the stimuli, complex and very similar checkerboards, are presented in Figure 1. Using stimuli of this sort, Lavis and Mitchell showed that discrimination, as assessed by a same–different test procedure, was enhanced after

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preexposure, in which the stimuli were presented on an intermixed schedule (AX/BX). Comparison was made with the performance shown to other stimuli (CX and DX) that were preexposed in separate blocks of trials. In that experiment, the spacing of trials was uniform, which meant that the interval between successive presentations of AX (or of BX) was twice that separating successive presentations of CX (or of DX). In this experiment we repeated the AX/BX preexposure condition and also presented CX in a separate block of trials. In this blocked condition, stimulus presentations were massed. However, presentations of a second blocked stimulus, DX, were separated by an interval corresponding to one stimulus presentation. Thus, the spacing of DX presentations was equivalent to the spacing of AX (and BX) presentations. On the test trials that followed preexposure, the participants were required to discriminate each of the compound cues (AX, BX, CX, and DX) from X. We predicted that if superior performance following intermixed preexposure (AX/BX) is due to temporal spacing alone, then the DX stimulus in the spaced condition would be easily discriminated from the common X cue on test.

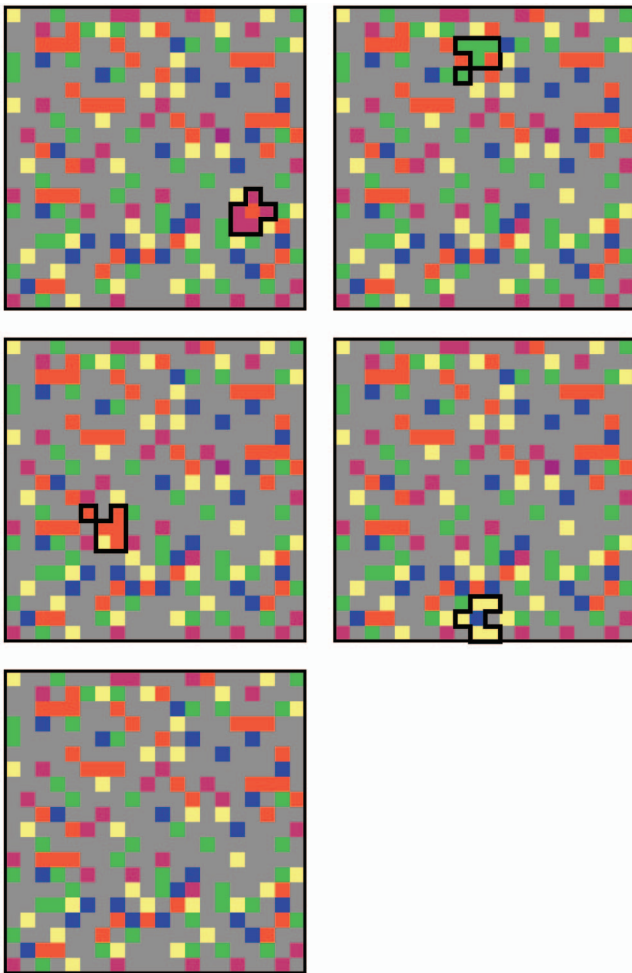


Figure 1. Stimuli AX–DX and X. The lowest checkerboard is X, the common element. In each of the remaining checkerboards appears a unique feature (A–D) surrounded by a heavy black line that distinguishes that checkerboard from X. This outline was not present during the experiment.

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. Stimuli were 20×20 colored checkerboards (see Figure 1). The common X element was created by coloring 156 of the 400 squares green, red, yellow, purple, or blue. The remaining background squares were colored gray. The unique features A, B, C, and D were added by changing groups of six adjacent gray squares to one of the brighter colors. The added unique features differed both in color and in location on the checkerboard. The location of a given unique feature was constant across exposures. The area of the screen around the checkerboard was the same gray color as the gray squares of the checkerboard. A thick black border separated the checkerboard from the background. The individual squares within the checkerboard had no borders. The stimuli were presented on a 17 in. (43.18 cm) computer monitor and were approximately 8-cm square. Inquisit, Version 1.32 (Millisecond Software, Seattle, WA) was used to control stimulus presentation on an IBM-compatible PC.

Design and procedure. There were three phases of preexposure. In the intermixed phase, presentations of AX alternated with presentations of BX. In the blocked phase, all presentations of CX were given consecutively, and in the spaced phase all presentations of DX were given sequentially, but a temporal delay was inserted between each trial. The order of these three phases was counterbalanced across participants. Allocation of the stimuli shown in Figure 1 to conditions was counterbalanced such that each stimulus was presented equally as often in the intermixed, blocked, and spaced conditions.

At the start of the experiment, participants were seated approximately 60 cm from the computer monitor and were presented with the 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 on each occasion. Each individual stimulus presentation, in both the blocked and intermixed phases, was followed by a blank gray screen during which participants made their space bar presses. In fact, the following trial was initiated after 2,000 ms whether a press was made or not. In the spaced condition, the interstimulus interval was increased to 4,470 ms. This is the equivalent of the delay created between each AX presentation by the presentation of BX on alternate trials (and vice versa) in the intermixed condition.

At the completion of the preexposure phase, participants were informed that in a second phase, they would be presented with 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.

There were six types of test trial: (1) intermixed different, in which AX and X (or BX and X) were presented; (2) intermixed same, in which AX and AX (or BX and BX) were presented; (3) blocked different, in which CX and X were presented; (4) blocked same, in which CX and CX were presented; (5) spaced different,

in which DX and X were presented; and (6) spaced same, in which DX and DX were presented. The order of stimulus presentation was randomized across test trials. Each unique feature (A–D) was presented on 12 trials in total, there being 6 different trials and 6 same trials with each.

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. A white square was then presented in place of the checkerboard, and it remained on the screen until the response was made.

Scoring

A set 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 proportions of correct responses on same and different test trials are shown in Figure 2. The scores for AX and BX were combined to produce a mean score for the intermixed condition; the scores for CX represent the massed preexposure condition and those for DX, the spaced preexposure condition. *Different test trials* are those in which the target cue was compared to X alone; *same test trials* are those in which two examples of the target cue were shown. Accuracy on trials in which identical stimuli were presented (same test trials) was higher than that on trials in which different stimuli were presented, $F(1, 23) = 141.08$, $MSE = 0.069$.

Comparison of the three preexposure conditions suggests that on different test trials, accuracy was higher in the intermixed condition (AX/BX) than in the remaining two conditions (CX and DX).

However, there appears to be no difference between the three conditions on the same trials. These observations were tested using three contrasts that compared all combinations of the three conditions. A Bonferroni adjustment was made to the F critical to correct for the fact that these comparisons are nonorthogonal. Performance to AX and BX (the intermixed condition) was better than that to CX (the blocked condition), $F(1, 23) = 7.66$, $MSE = 0.045$. This contrast interacted with the test trial type, $F(1, 23) = 10.33$, $MSE = 0.059$, and simple effects analyses revealed an intermixed–blocked effect on different test trials, $F(1, 23) = 9.65$, $MSE = 0.12$, but not on same test trials ($F < 1$). This result replicates the intermixed–blocked effect shown by Lavis and Mitchell (2006). The intermixed condition also produced better performance than did the spaced condition, $F(1, 47) = 8.20$, $MSE = 0.059$, and this comparison interacted with test trial type, $F(1, 23) = 9.48$, $MSE = 0.49$. Again, simple effects analyses showed that performance was superior for the intermixed condition on the different test trials, $F(1, 23) = 9.83$, $MSE = 0.097$, but not on the same test trials ($F < 1$). Finally, there was no difference between the blocked and spaced conditions, and there was no interaction between these conditions and test trial type ($F < 1$, in both cases).

These findings suggest that discriminability of the stimuli was enhanced by intermixed preexposure, and this was the case even when comparison was made with a blocked control condition in which the stimulus presentations were spaced. On the face of it, this is evidence against the idea that the intermixed–blocked effect is the result of distributed practice in the intermixed condition. In particular, this result implies that the intermixed–blocked effect is not a consequence of the intermixed schedule, allowing a greater opportunity for consolidation of the memory trace. If anything, there appears to be greater scope for consolidation following each

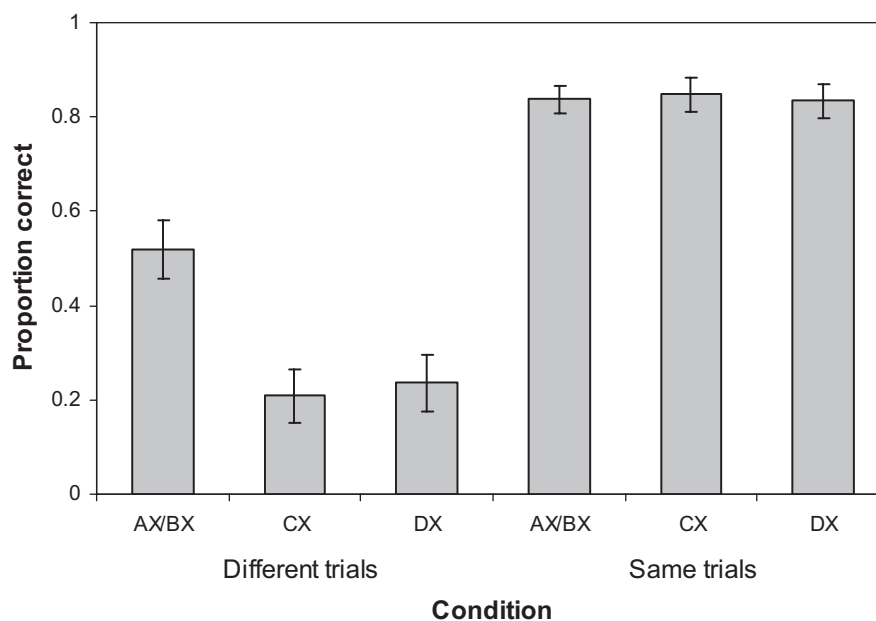


Figure 2. Mean percentage of correct responses on same and different test trials in Experiment 1. Stimuli were preexposed on an intermixed (AX and BX) or blocked (CX and DX) schedule. Presentations of CX were massed, and those of DX were spaced. Error bars indicate standard errors of the mean.

DX presentation than each AX presentation—the BX presentations that immediately followed AX might be expected to interfere with consolidation of the AX memory.

Could the result have been due to greater encoding variability of AX and BX than of DX? Although temporal spacing was equivalent in the intermixed and spaced conditions, the interval between DX presentations was empty, but the interval between AX presentations contained the presentation of BX (and vice versa). Perhaps the presence of BX between AX presentations increased encoding variability for this cue. We designed Experiment 2 to address this possibility.

Experiment 2

In this experiment, we aimed to provide a control for the intermixed condition that equated temporal spacing between stimuli and also presented an event in that interval. In this control condition, CX was intermixed with a quite different cue, DY (schematically, the full design was AX/BX_CX/DY). If the intermixed–blocked effect is due to the temporal spacing of trials, performance in response to AX and CX will be equivalent on test. Furthermore, the events that occur in the interval between stimulus presentations are also (as far as possible) equated. It is only the AX/BX condition that allows comparison of two similar stimuli and therefore the extraction of their unique features according to Gibson (1969).

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 1 with the addition of a further background stimulus, Y. This background had the same pattern of gray and colored squares as was present in the stimulus referred to as X in Experiment 1, allowing the unique features to be located in the same place (replacing the same area of gray) on both backgrounds. However, the color of each of the brighter colored squares of the checkerboard was changed from that used previously. Which of these backgrounds served as X and which as Y was counterbalanced across participants. There were two phases of preexposure. Compounds AX and BX were intermixed in one phase, and CX and DY were intermixed in the other phase (order counterbalanced). Each stimulus was presented 60 times. Across participants, the unique features presented in the stimuli in Figure 1 played the role of features A–D equally often.

As in Experiment 1, the test phase required same–different judgments on pairs of stimuli. In the different test trials, the target stimuli AX, BX, and CX were compared to X alone. On the same test trials, these stimuli were presented twice. To maintain continuity with the conditions that prevailed during training, we presented all possible remaining stimulus combinations on test as filler trials. Thus, overall, each unique feature A–D was presented in compound both with X and with Y. This produced eight types of different trials in total in the test phase: four in which the stimuli AX–DX were compared to X and four in which the stimuli AY–DY were compared to Y. Each of these trial types was presented four times making a total of 32 different test trials. There were 10 types of same test trial on which two of each of the following stimuli were presented: AX–DX, AY–DY, X, and Y.

These trial types were presented once each, making a grand total of 42 trials. In respects not specified here, the procedure was the same as that described for Experiment 1.

Results and Discussion

The results of the critical test trials, those on which AX (or BX) and CX were presented, are shown in Figure 3. Just as in Experiment 1, performance on same test trials was better than it was on different test trials, $F(1, 31) = 70.21$, $MSE = 0.216$. More importantly, performance on trials in which AX (or BX) was presented appears to be better than that on trials in which CX was presented, whether on same or different trials. A contrast comparing overall performance across the two types of test confirmed this observation, $F(1, 31) = 8.38$, $MSE = 0.106$. There was no interaction between the training conditions (AX/BX and CX/DY) and the test trial type (same and different; $F < 1$).

These results support the conclusion that superior performance to AX and BX on the same–different test is due neither to better consolidation of the memory trace during preexposure nor to greater variability in encoding conditions. There is no obvious reason to suppose that either of these mechanisms would have an advantage in the AX/BX preexposure regime relative to the CX/DY regime. In fact, one might argue that variability of CX is greater than that of AX or BX, because the DY cue presented in the interval is very different from all other events experienced during the encoding phases. We further conclude that alternation of trial types is not enough in itself to produce enhancement of discrimination; rather, it is critical that the target cue be presented in alternation with a similar cue. This latter issue has previously been examined in an experiment by Mackintosh, Kaye, and Bennett (1991, Experiment 4), who used rats as subjects, a between-subjects design, and a flavor-conditioning procedure. As in our experiment, they found that perceptual learning (better discrimination of AX and BX on test) was observed when AX and BX were intermixed in preexposure but not when AX was intermixed with BY. Our present results thus constitute a confirmation and extension of this earlier finding, as we used a within-subjects design and a very different procedure and species.

General Discussion

It was shown in two experiments that intermixed presentations of similar checkerboard stimuli, AX and BX, produce very good performance on a same–different test in which discrimination is required between AX and X and between BX and X. In Experiment 1, this performance was superior to that shown to the blocked cues CX and DX, whether those cues were preexposed on a massed (CX) or spaced (DX) schedule. In Experiment 2, performance to AX and BX was also superior to that shown to CX, when CX had been intermixed with presentations of the dissimilar stimulus DY in the preexposure phase. The CX/DY control condition in Experiment 2 controls for every feature of AX/BX preexposure except for the similarity of the cues that are intermixed. Consolidation of the memory trace and encoding variability are, therefore, ruled out as sources of the superior performance to AX and BX on test.

Any theory of the intermixed–blocked effect must, therefore, account for the fact that the similarity of the intermixed stimuli (the presence of many common X elements) is critical in produc-

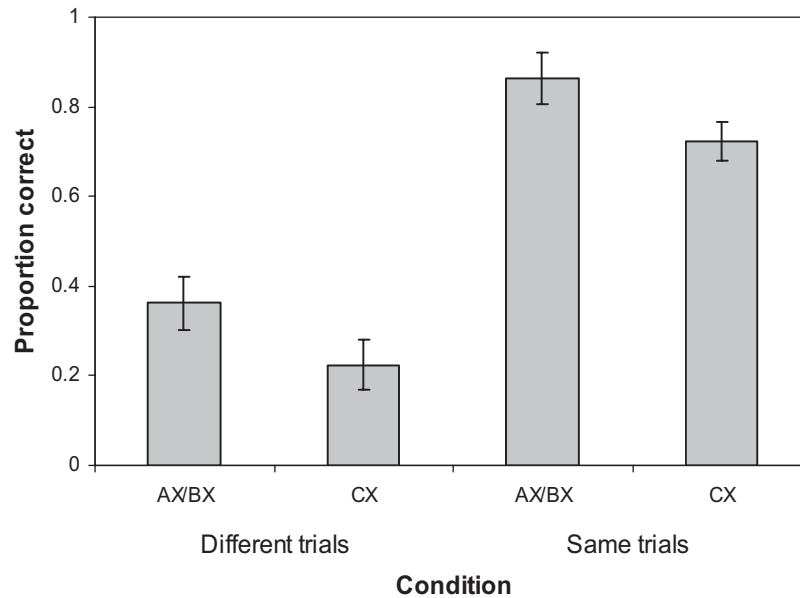


Figure 3. Mean percentage of correct responses on same and different test trials in Experiment 2 when stimuli AX, BX, and CX were compared to the common element X. Presentations of AX and BX were intermixed with one another in preexposure. Stimulus CX was intermixed with DY in preexposure. Error bars indicate standard errors of the mean.

ing the effect. Gibson (1969) argued that the opportunity to compare stimuli allows attention to be focused on the unique features of the stimuli. When AX and BX are intermixed, these unique features are A and B. Increased attention to A and B will produce better performance when AX and X are compared in a same–different test; it is the detection of A that allows a correct response to be made. However, in the CX/DY schedule, there are many unique features (C, X, and Y), and so attention will be diffused across all of these features, including the features (those that make up X and Y) that are not important in the discrimination of CX and X.

Gibson's (1969) proposal does not, however, provide a psychological mechanism to explain how the unique features are identified as a consequence of stimulus comparison. In the following discussion we present two recent theories of the intermixed–blocked effect, both derived from studies of animal learning, which might be seen (to a greater or lesser extent) as providing the mechanism that underlies Gibson's process of comparison. We then also propose a new account that is based on theories of memory, rather than of learning. This new theory is more obviously consistent with Gibson's original ideas and has the great virtue of also providing an explanation for massed–spaced effects when they are observed.

McLaren and Mackintosh (2000) suggested that contemporary associative learning theory can in fact account for the intermixed–blocked effect and therefore perceptual learning more generally. They suggested that intermixed, but not blocked, preexposure to AX and BX promotes the formation of inhibitory links between the unique features A and B. This is because A predicts the absence of the B element on AX trials (and B predicts the absence of A on BX trials). Specifically, the representation of B is activated on AX trials due to the presence of X elements—the X elements are associated with B as a consequence of previous BX trials. How-

ever, the A cue perfectly predicts the absence of this activated B element and so comes to inhibit B. The ability of the common feature X to activate B on AX trials is critical to the operation of this mechanism; A cannot come to inhibit B unless B is expected to appear on AX trials. In other words, the two stimuli must have common elements (they must be similar) for the inhibitory link to form.

An alternative hypothesis, suggested by Hall (2003), is that intermixed, but not blocked, preexposure protects the unique features from the normal habituation process that would otherwise take place across preexposure. This protection from habituation would maintain the salience of the unique features and would, therefore, render AX and BX more distinct. Hall's theory, just like that of McLaren and Mackintosh (2000), relies on activation of B by X on AX trials (and A on BX trials). However, Hall suggested that associative activation of this kind does not lead to inhibition but increases the salience of the unique cues by reversing the normal habituation process. Again, in the case of the CX/DY schedule, because C is not activated on DY trials (nor D on CX trials), this reverse habituation process will not occur, and the salience of C and D will not increase. In postulating a process of salience modulation, Hall's theory is closer to Gibson's (1969) account than is McLaren and Mackintosh's (2000). The theories are similar, however, in that both rely on activation of the B representation on AX trials and A on BX trials for their mechanisms to operate.

There is an account of the effect of spaced practice on human memory that we have not yet considered, which may also provide an explanation for the present results. Jacoby (1978) suggested that when a stimulus is presented on more than one occasion, if prior presentations of a stimulus are remembered, then encoding on later trials will be reduced. If, however, the earlier stimulus presentations are forgotten, then the later pre-

sensation will require greater processing resources and so will be better encoded. This accounts for the massed–spaced effect; when practice is spaced, memory for prior presentations of the stimulus will be poorer, and so encoding will be better on later trials. It can also account for the better performance to AX and BX than to DX that was seen in our Experiment 1. It seems reasonable to suppose that the empty interval interpolated between successive DX presentations would fail to interfere with retrieval of prior DX presentations. Interpolated BX presentations might be expected to result in retrieval interference of prior AX presentations and vice versa. Thus, encoding of AX and BX in memory (and therefore discrimination between these cues and X on test) would be better than that of DX.

With added assumptions, Jacoby's (1978) theory can also account for the findings of Experiment 2. On AX trials, X elements will be more easily processed than A elements, because X elements were presented more recently (on the immediately preceding BX trial). Presentation of the A element will not have occurred on the preceding trial, and so A will not be remembered so well. Because the X elements are easier to process, attentional resources will be directed toward the encoding of A. The consequence will be that A (and B) will receive greater processing resources and be better encoded in memory than the common X elements. These well-encoded representations of A and B can then be used to distinguish between AX and X (or BX and X on test) on test—perceptual learning. This account seems to capture the essence of Gibson's (1969) proposal, in that attention is directed toward the unique features, and those features are extracted from the background and encoded. (It is interesting that an account conceptually similar to that just outlined was put forward by Honey & Bateson, 1996, on the basis of the habituation processes envisaged by Wagner's 1981 learning theory.)

On CX trials in the CX/DY schedule, both C and X elements will be equivalently easy (or difficult) to process, as neither of these elements was presented on the immediately preceding DY trial. As a consequence, processing resources will be distributed across all elements, and the C feature will not be especially well encoded. Thus, CX will not be discriminated from X on test. This analysis also explains the poor performance seen in the blocked condition of the original intermixed–blocked effect (Honey et al., 1994; Symonds & Hall, 1995). When all AX trials appear in a block, both A and X will have been presented on the immediately preceding trial. As a result, both A and X will be easily processed and poorly encoded (and the same is true of BX). Discrimination will, therefore, be poor on test.

In conclusion, our results suggest that the intermixed–blocked effect in perceptual learning is not merely an example of the well-known effect of massed versus spaced practice. However, one account of why spaced practice improves memory (Jacoby, 1978) can, when combined with an elemental approach to stimulus representation, provide an account of the results presented here. It seems then that perceptual learning provides a context in which the areas of learning and memory can become more closely linked than they have been in the past, both at the procedural and at the theoretical level. Perhaps the analysis presented here will also be useful in the interpretation of contextual interference effects observed in verbal learning (Battig, 1972) and motor learning (Shea & Morgan, 1979).

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