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Memory encoding of stimulus features in human perceptual learning

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Memory encoding of stimulus features in human perceptual learning

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Two experiments analysed memory encoding in human perceptual learning. Both experiments started with preexposure without feedback to four checkerboards composed by a unique feature each and sharing a common feature (AX, BX, CX, and DX). Elements of one pair were presented intermixed and elements of the other pair were presented in separate blocks. Immediately after preexposure participants completed a memory recognition task in which the characteristics of the distractors were manipulated. Experiment 1 showed that only intermixed presentation results in good encoding of the unique features of the stimuli. Experiment 2 demonstrated that intermixed preexposure results in different encoding of unique versus common features of the stimuli: Participants are able to remember A and B better than they remember X, whereas for the blocked condition memory for C, D, and X does not differ. Overall, the results presented here support the proposal that intermixing stimuli results in differential memory traces for unique versus common features and that this contributes to the intermixed/blocked effect.

Keywords: Discrimination; Memory encoding; Perceptual learning.

Imagine a biology teacher who presents information about the recognition of two different cell types: Type AX and Type BX. All the cells share similar X characteristics and differ only in some minor feature (A or B). The teacher is faced with the question: For better recognition of the two types of cells, should I present all exemplars of one type first and only then start presentations of the other type (e.g., AX AX AX BX BX BX)? Or should I intermix them (e.g., AX BX AX BX AX BX)?

Research in perceptual learning has long shown that intermixed presentations result in improved ability to discriminate stimuli when compared to blocking different stimuli separately. For instance, using coloured checkerboards Mitchell, Nash, and Hall (2008) demonstrated that preexposing stimuli intermixed resulted in improved discrimination accuracy in a same/different task, when compared to blocked preexposure. Mundy, Honey, and Dwyer (2007) obtained analogous results using morphed pictures of human faces. Moreover, these authors included a nonpreexposure group that resulted in worse performance than both the groups with blocked and intermixed preexposure (for similar results using checkerboards see Mundy, Honey, & Dwyer, 2009).

One simple explanation for this advantage might be that intermixing directs attention to the relevant features of the stimuli. Indeed, in her influential theory of perceptual learning, Eleanor

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Gibson (1969) proposed that preexposure enhances discrimination through a process of differentiation. This mechanism involved the abstraction of the relevant features of the stimuli and filtering, or ignoring, the irrelevant features. Moreover, the process would be enhanced by situations that allowed for greater opportunity for comparison, as the intermixed schedule of presentation.

In accordance with Gibson's proposal, using coloured checkerboards and a same/different task, Mitchell, Kadib, Nash, Lavis, and Hall (2008) demonstrated that changing the stimuli's common features (X) between preexposure and test (i.e., preexposure with AX/BX and test with AZ and BZ) still resulted in better performance after intermixed preexposure, pointing to an attentional bias towards the unique features of the stimuli. Nonetheless, the question remained: How is attention directed towards the unique features of the stimuli?

Mitchell, Nash, and Hall (2008) propose a framework involving memory mechanisms. In general terms, their proposal is that attention is a function of ease of processing, similar to the mechanism proposed by Jacoby (1978) for the spacing effect observed in memory tasks. More precisely, processing difficulty decreases with every successive presentation of the same stimulus. In this sense, recently presented stimuli are easier to process and so will receive less attention. In the case of the A, B, and X features in the intermixed schedule, it would result that because X is presented in every trial it will be easier to process and thus receive less attention. A and B, on the other hand, are not presented in every trial and thus ease of processing will not increase and more attention will be devoted to these features. In the case of blocked presentation of AX, both A and X will be presented in every successive trial and attention will not be biased towards any feature since all are equally easy to process. This ease of processing will result in worse encoding for both A and X features when AX is presented in a single block.

Additionally, the direction of attention will result in better processing of the unique features of the stimuli (A and B) during intermixed presentation and consequently better encoding and a stronger memory trace for these features compared to X. During the same/different task, memory for A and B will be better and more readily available, allowing for better discrimination. Conversely, in the course of blocked presentations, the memory trace for both the unique and common features of the stimuli will be poor and these characteristics will be harder to retrieve, ultimately resulting in worse discrimination.

However, one potentially important point that research using same/different tasks leaves unanswered is the exact nature and quality of the memory recollection for both the unique (A, B, C, and D) and common features (X) of the presented stimuli. Indeed, one prediction directly derived from the account proposed by Mitchell, Nash, and Hall (2008) is that intermixed presentation will result in good, probably detailed, memory for the unique features of the stimuli (see Lavis, Kadib, Mitchell, & Hall, 2011) and poor memory for the common features. Blocked presentation, on the other hand, will result in equally good (or poor) memory for both the unique and common features of the stimuli.

The work presented here tries to approach this question using recognition memory tasks instead of same/different tasks. Although, as we previously stated, most research in perceptual learning makes use of same/different tasks, recognition memory tasks have been used in the past in studies of perceptual learning with experts (Myles-Worsley, Johnston, & Simons, 1988). In recognition tasks, after initial exposure, participants are presented with a series of stimuli, one at a time, that they should classify as new or old, based on their recollection of that stimulus. This kind of tasks involves the same type of stimuli discrimination as the previously described same/different task—in this case between stimuli already seen (“targets”), and stimuli never seen (“distractors”). Thereby, recognition memory tasks might be expected to be equally effective in eliciting the intermixed-blocked effect.

To be more precise, take as an example the case of participants preexposed to AX and BX intermixed and CX and DX blocked. In a subsequent recognition memory task, participants would be presented with AX, BX, CX, and DX (targets) but also distractors such as EX and FX, for example. This new task allows us to more directly test the memory participants have for the stimuli features by manipulating the similarity between targets and distractors: the more similar they are, the more difficult the discrimination is and the more information the participants need to retrieve to achieve good performance. More precisely, in Experiment 1 we manipulated the colour and shape of the unique features of the distractors relative to targets. In Experiment 2 we manipulated both the properties of the common feature of the distractors relative to the targets or the properties of both the common and unique features of the distractors relative to targets.

The account proposed by Mitchell, Nash, and Hall (2008) predicts that, following intermixed preexposure, participants will be highly accurate at identifying the unique feature in the recognition memory task as well as highly accurate at identifying as distractors stimuli with different unique features. Moreover, it also predicts that accuracy at identifying the unique features of the stimuli will be low following blocked preexposure. However, distractors that share the unique features with targets will be hard to discriminate following intermixed preexosure.

EXPERIMENT 1

All the experiments reported here used visual stimuli similar to the ones used in previous studies (Mitchell, Kadib, et al., 2008; Mitchell, Nash, & Hall, 2008). These stimuli are checkerboards composed of several squares of various colours and were created for this very purpose. Besides their proven ability to elicit perceptual learning, these stimuli are completely unfamiliar, difficult to discriminate, and their degree of similarity is easily manipulated (see also, Hall, 2009).

In Experiment 1, participants completed a preexposure phase in which two pairs of stimuli were presented: one pair intermixed (AX/BX) and another pair blocked (CX_DX). Immediately after the preexposure phase, participants completed a recognition memory task in which studied and novel stimuli were presented. Given the particularities of this task, only four stimuli were used during preexposure and 12 stimuli during the recognition task (four targets and eight distractors).

In the recognition task, along with the four preexposed stimuli (AX, BX, CX, and DX) we presented eight stimuli that differed from the targets only in the characteristics of the unique features (A, B, C, or D), but not in the common features (X). A total of four stimuli differed from targets only in the shape of the unique features and another four only in the colour of the target's unique features.

The theory provided by Mitchell, Nash, and Hall (2008) predicts that the memory trace for A and B (i.e., the unique features) will be improved during intermixed preexposure, thus resulting in better memory for these features. In this sense, we expect participants to be better at identifying the correct stimuli as targets, even among other stimuli that differ only in colour or shape relative to A and B. This will be a very hard task for stimuli preexposed in a blocked fashion because the memory trace for the entire stimulus is poor and thus the characteristics of C and D will not be so readily available in memory.

Method

Participants. Eighteen undergraduate Psychology students from the University of Minho (three men, $M_{age} = 22$ years, $SD = 5.6$ years, age range: 18–37) took part in this experiment in return for course credit. All participants had normal or corrected-to-normal vision and were not aware of any colour-vision deficiency. Participants were tested individually in the same room and none had experience with this kind of experiment or stimuli.

Apparatus and stimuli. Stimuli were 20×20 coloured checkerboards. Twelve different stimuli were used in this experiment. All stimuli were identical except for their possession of one unique feature each (see Figure 1 for an illustration of the stimuli used during preexposure).

The stimuli used during preexposure phase were created by colouring a 400-square grid in grey. Additionally, 150 of the squares were randomly changed to one of five brighter colours: yellow, green, red, purple, or blue (30 squares each). This was the background X, the common feature across all stimuli used (top right image in Figure 1). Each of the other four stimuli was created by adding a unique feature (A, B, C, or D) to the common X background. For this purpose, six adjacent grey squares were changed to one of the brighter colours. These unique features differed from each other in colour and position in the grid; distance from the unique features to the centre and corners of the checkerboards was kept constant (see Figure 1). Eight more checkerboards were created for use as novel stimuli during the recognition task. These novel stimuli were created by changing either the colour or the shape of the unique features A, B, C, and D. There were four stimuli (EX, FX, GX, and HX) that differed from AX, BX, CX, and DX

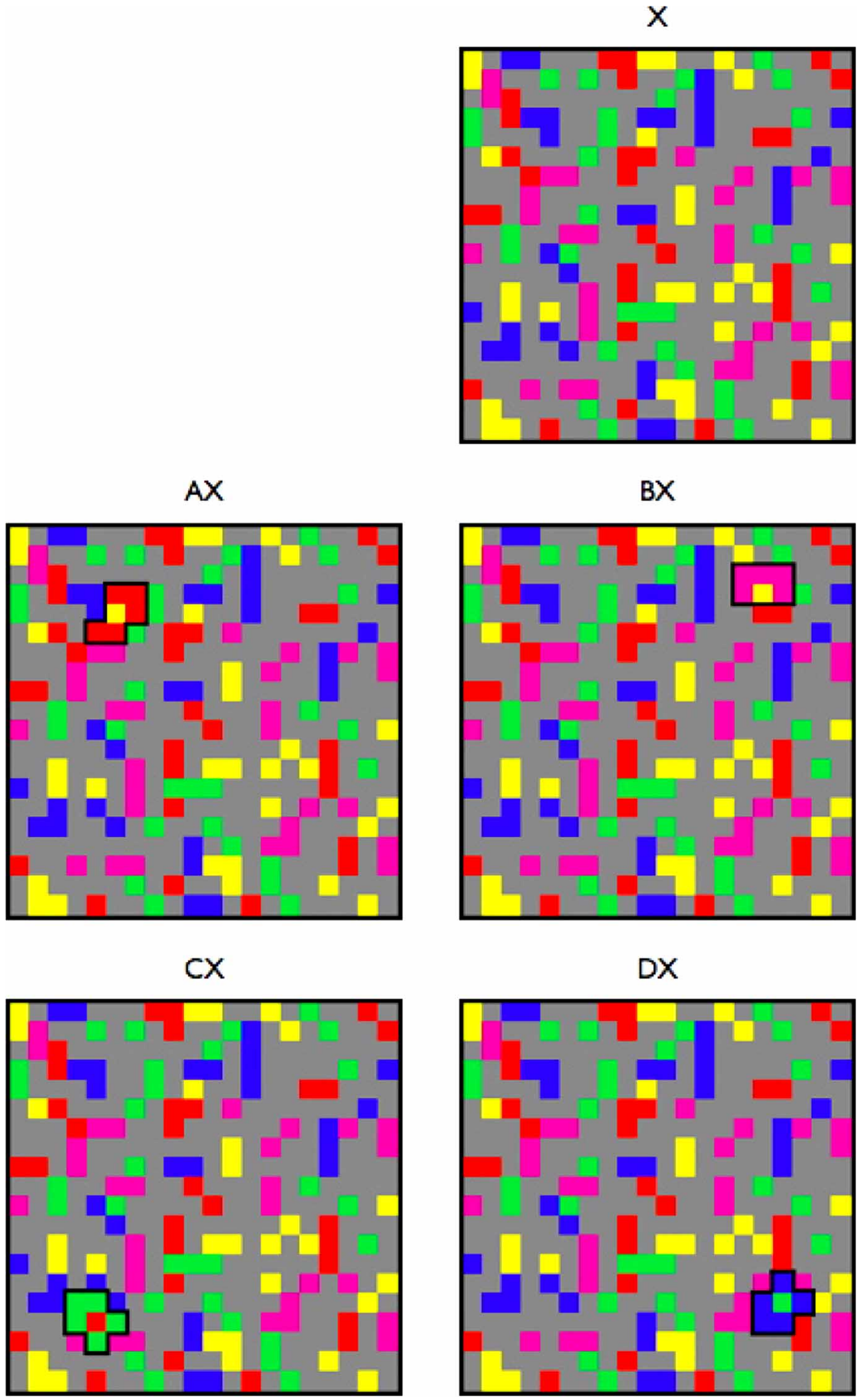

Figure 1. Stimuli used during the preexposure phases of Experiments 1 and 2. The top right stimulus is X, the common feature. Each of the other stimuli has a unique feature delimited by a heavy black border. This outline is for illustration purposes only and was not presented to participants. These stimuli were created following indications by Mitchell, Kadib, et al. (2008) and are similar to the ones used in that and other studies (Mitchell, Nash, & Hall, 2008). [To view this figure in colour, please visit the online version of this Journal.]

only in the shape of the unique feature (shape distractors), and another four stimuli (IX, JX, KX, LX) that differed from AX, BX, CX, and DX only in the colour of the unique feature (colour distractors). In all distractors, the unique features were in the same locations as in the target stimuli.

Participant responses were recorded using a Series RB Response Pad device (RB-730; Cedrus Corporation, San Pedro, CA).

Design and procedure. This experiment had two phases: a preexposure phase and a test phase. The preexposure phase had two conditions, manipulated within-subjects: intermixed presentation of a pair of stimuli and blocked presentation of another pair of stimuli. The order of the two conditions was counterbalanced across participants, as was the allocation of the stimuli to each condition.

At the beginning of the experiment participants were seated approximately 60 cm from the computer monitor and read the initial instructions on screen. Participants were told to pay attention to the stimuli that would be presented next, that all checkerboards were very similar but some had a few small differences, and that any differences found during this phase would contribute to a good performance during the next phase of the experiment. They were also told they should press a key (always the same, unlabelled, central key in the response pad) as quickly as possible every time " <Response> " was presented on screen in order for the experiment to continue.

The preexposure phase began with a brief grey screen followed by the first trial. Each trial started with a 470 ms stimulus presentation, followed by a grey screen for 700 ms, and a choice screen in which " <Response> " was presented on the monitor (although participants were told that they should press a key at this time for the experiment to continue, this screen disappeared after 1500 ms, whether or not a press was made). The trial ended with another 700 ms grey screen. Each condition consisted of 60 trials of each stimulus (intermixed or blocked, depending on the condition). In the case of intermixed presentation, after each trial with a stimulus a trial with the other stimulus of the pair would follow. On the contrary, in the blocked condition all trials with a stimulus were presented before the start of trials with the other stimulus (order counterbalanced across participants for both conditions).

After completing the preexposure phase, a new set of instructions was presented to participants before the test phase. Participants were told they would see various stimuli, one at a time, and for each stimulus they should decide if they had already seen it or not, as well as how sure they were of that response by pressing one of four numbered keys, ranging from 1 ("sure old") to 4 ("sure new"). Participants were also told there was no time limit for this decision and that accuracy was important.

The test phase was composed of 12 trials, each one consisted of a stimulus being presented in the centre of the screen, and remaining there until the participant made the recognition decision. Each one of the 12 stimuli was presented only once in random order.

Results and discussion

A critical significance $\alpha = .05$ was set for all statistical analyses, unless otherwise stated. Analyses for all experiments reported here included inspection of data regarding the preexposure phase. Misses to press the central key were analysed to guarantee that participants' attention to the task was not compromised. These analyses revealed that most participants did not fail to press the key, and those who did, failed only a few times (no more than five times across the 240 preexposure trials). Given the high number of preexposure trials, preexposure was not considered to be compromised for any participant and all were kept for analysis.

Accuracy of response in this and the subsequent experiment, was calculated using the nonparametric A′ index (Donaldson, 1992, 1993), using the hit rates (correctly identifying as old a studied item) and false alarm rates (incorrectly classifying as old a novel item). $A' = 0.5$ represents chance performance and $A' = 1$ perfect performance. Finally, $0 < A' < 0.5$ represent performance confusion.

In order to analyse the proportion of hits (correctly classifying as old a stimulus that was presented during the preexposure phase) and false alarms (incorrectly classifying as old a stimulus that was not presented during the preexposure phase), 1 ("sure old") and 2 ("probably old") answers were collapsed. Distractors were not preexposed—they do not belong to either the intermixed or the blocked condition—therefore classification of false alarms was done relatively to the targets. Each distractor that possessed characteristics in common with a given preexposed target was classified as the target's presentation type. For example, because AX was preexposed intermixed, a distractor that changes only in the colour of feature A is considered a distractor of the intermixed condition. In this way, every distractor was classified as intermixed or blocked for each participant, based on the stimuli that were presented during preexposure (the same approach was used for Experiment 2).

The right panel of Figure 2 depicts the mean proportion of hits and false alarms for each preexposure condition in Experiment 1. Using the false alarm and hit rates, we calculated accuracy values for each condition of preexposure, which are depicted in the left panel of Figure 2. Following our predictions, accuracy is higher for the intermixed preexposure than for the blocked preexposure, $t(17) = 2.16$, $p = .045$, $dz = 0.51$. Moreover, when comparing the obtained A' values with the critical chance level of .50, only intermixed preexposure resulted in a significantly higher level of discrimination, $t(17) = 2.91$, $p = .01$, $d = 0.68$, and $t(17) = .88$, $p = .39$, $d = 0.21$, respectively. It should also be noticed that this difference in accuracy is achieved by a higher hit rate for the intermixed condition as well as a slight decrease in false alarm rates relative to the blocked condition (see right panel of Figure 2).

We also analysed whether the preexposure condition had an effect on the distribution of false alarms between the two types of distractors: colour distractors and shape distractors. This analysis of the distribution of false alarms responses across distractor type was implemented by calculating the percentage of false alarms for each condition and distractor type.

Neither shape nor colour seem to elicit more false alarms than the other, for either the intermixed ($M_{colour} = 44\%$ and $M_{shape} = 56\%$) or blocked condition ($M_{colour} = 53\%$ and $M_{shape} = 47\%$). A two-way repeated measures ANOVA revealed no main effect of type of distractor, $F(1, 17) = 0.21$, $p = .65$, $MSE = 0.26$, main effect of preexposure condition, $F(1, 17) = 0.13$, $p = 0.73$, $MSE = 0.44$, or any interaction between type of distractor and preexposure condition, $F(1, 17) = 0.88$, $p = .36$, $MSE = 0.25$.

In sum, these results show that the participants' ability to discriminate targets from distractors is higher for the intermixed condition. After blocked preexposure performance is not only worse but also at chance level. These results are consistent with Mitchell, Nash, and Hall's (2008) proposal that the intermixed advantage stems from the better encoding of the unique features of the stimuli and consequent richer memory trace for those features. As seen in this experiment, participants remember both colour and shape of the unique features of the stimuli only in the intermixed condition.

EXPERIMENT 2

The results of Experiment 1 show better encoding and memory for the unique features of each

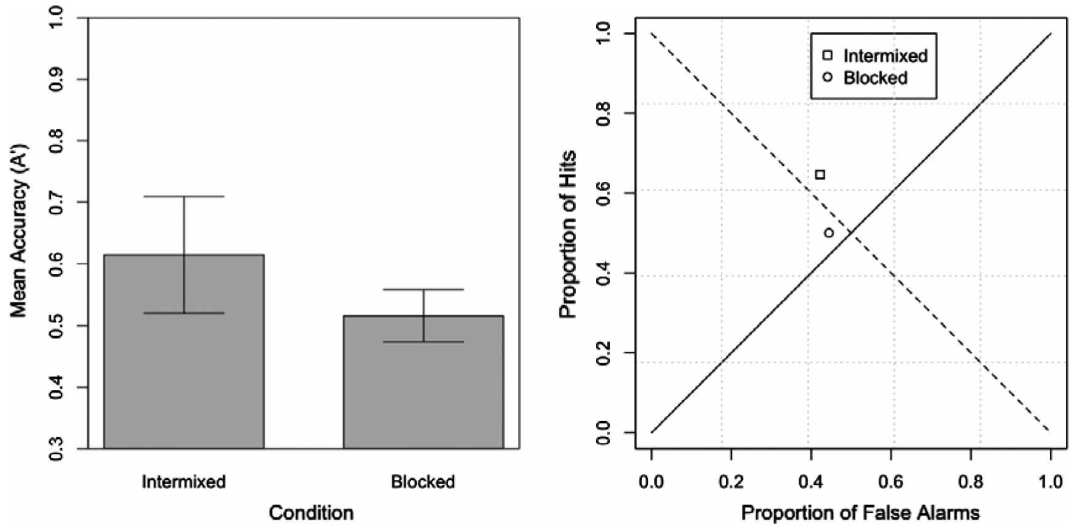

Figure 2. Accuracy for both conditions of Experiment 1. The right panel depicts the mean accuracy for the 2 conditions as a function of the hit and false alarms rates; the thick positive diagonal represents chance performance and the dashed negative diagonal represents responses bias: Responses on the line indicate no bias, responses above that line represent a conservative criterion (i.e., a tendency to answer ‘‘new’’), and under that a liberal criterion (i.e., a tendency to answer ‘‘old’’). The left panel depicts the accuracy for each preexposure condition. Blocked preexposure resulted in discrimination performance at chance level while intermixed preexposure was significantly better. Error bars indicate 95% confidence intervals.

stimulus during intermixed preexposure. However, another principle of the account proposed by Mitchell, Nash, and Hall (2008) envisages this better encoding as the result of differential processing of the unique and common features of the stimuli during intermixed presentation. In this sense, it should also be the case that memory for the common features is equivalent in both preexposure conditions.

In Experiment 2 we approach this question using a procedure similar to the one used in Experiment 1 but changing the distractors used. In this experiment there are two kinds of distractors: Some constitute changes only in the common features of the stimuli (X to Y) and others involve changes to both the common features (X to Z) and the unique features (M, N, O, and P). Stimuli that changed in both the unique and common features kept the relative position of the unique features (i.e., where the bigger agglomerate of colour was positioned in the checkerboard) but the unique feature changed in both colour and shape.

Mitchell, Nash, and Hall's (2008) theory predicts different accuracy in correctly rejecting the different kinds of distractors based on how the stimuli were preexposed. Following intermixed preexposure of AX and BX, correct rejection of AY and BY should be low. Moreover, for MZ and NZ it should be high. Following blocked preexposure to CX and DX, on the other hand, there should be no difference in accuracy for CY, DY, OZ, and PZ. The reason for this dichotomy is the differential encoding of unique versus common features during intermixed preexposure, whereas for the blocked preexposure both unique (C and D) and common (X) features are equally encoded.

Method

Participants. Eighteen Psychology undergraduate students from the University of Minho (3 men, $M_{age} = 21$ years, $SD = 5.2$ years, age range: 17–38) took part in this experiment in return for course credit. All participants had normal or corrected-to-normal vision and were not aware of any colour-vision deficiency. Participants were tested individually in the same room, and had not participated in the previous experiment.

Apparatus and stimuli. The four stimuli used in the preexposure phase of Experiment 1 (AX, BX, CX, and DX) were also used in this experiment. Additionally, eight more stimuli were created for this experiment: four stimuli that differed from the four original stimuli in every detail but the unique feature (AY, BY, CY, and DY; feature distractors) and another four stimuli that differed from the original ones in every detail but the relative location of the unique feature (MZ, NZ, OZ, and PZ; position distractors). To create the background Y, each of the brighter colours of background X was changed to one of the other brighter colours (e.g., blue into yellow and yellow into red), so that the ratio of grey to brighter colours in the grid was the same, but the colours were not in the same relative place. Z stimuli were created by changing 150 grey squares of the X background to the five brighter colours, and the brighter squares of the X background were coloured grey. Then the particular attributes were added, in the same positions as the ones from preexposed stimuli, following the rules stated in Experiment 1. Every other detail not stated here was the same as in Experiment 1.

Design and procedure. As in Experiment 1, this experiment had two phases: a preexposure phase and a test phase. Preexposure and test phases were identical to that of Experiment 1 in every detail but for the stimuli used as distractors in the recognition test (AY, BY, CY, DY and MZ, NZ, OZ, PZ).

Results and discussion

The right panel of Figure 3 depicts the mean proportion of hits and false alarms for Experiment 2. False alarms and hit rates were used to calculate the accuracy (A′) in the task, as described in Experiment 1 (see left panel of Figure 3). Accuracy during the recognition test was identical for intermixed and blocked stimuli, $t(17) = 0.27$, $p = .79$, $dz = 0.11$, and above chance for both conditions (both comparisons to $A' = 0.5$ $ps < .05$).

Analysis of the number of false alarms for each type of distractor revealed a main effect of type of distractor, $F(1, 17) = 19.51$, $p < .001$, $MSE = 0.38$, no main effect of preexposure condition, $F(1, 17) = 1.15$, $p = .30$, $MSE = 0.59$, but an interaction between the two variables, $F(1, 17) = 6.23$, $p = .02$, $MSE = 0.38$. Post hoc analyses correcting the critical α value using the Bonferroni correction for multiple comparisons (corrected $\alpha = .025$)

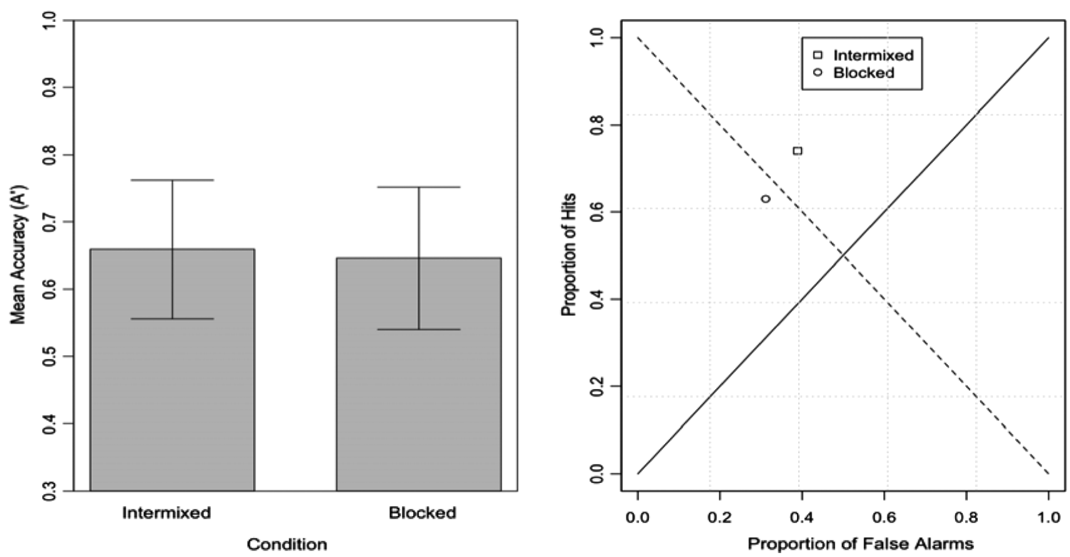

Figure 3. Accuracy for both conditions of Experiment 2. The right panel depicts the mean accuracy for the 2 conditions as a function of the hit and false alarms rates; the thick positive diagonal represents chance performance and the dashed negative diagonal represents responses bias: Responses on the line indicate no bias, responses above that line represent a conservative criterion (i.e., a tendency to answer ''old''), and under that a liberal criterion (i.e., a tendency to answer ''novel''). The left panel depicts the accuracy for each preexposure condition. Performance was equally good after both intermixed and blocked preexposures. Discrimination was significantly above chance for both conditions and there was no difference between the two. Error bars indicate 95% confidence intervals.

revealed that, in the intermixed condition, the proportion of false alarms is higher for feature distractors ($M = 0.85$) than position distractors ($M = 0.15$), $t(17) = 4.68$, $p < .0001$, $dz = 1.10$. For the blocked condition no difference was found ($M_{\text{feature}} = 0.63$ vs. $M_{\text{position}} = 0.37$), $t(17) = 1.43$, $p = .17$, $dz = 0.34$.

These results show an absence of the intermixed-blocked effect in a task involving discriminations based on the common feature (X) of the stimuli (as opposed to the unique features A, B, C, and D of the stimuli as in Experiment 1). In fact, following the proposal by Mitchell, Nash, and Hall (2008) that the intermixed advantage is due to better encoding of the unique features, one might expect that when the task does not allow for the use of that information both conditions will be at the same level.

The result of greater interest, however, is the observed interaction for false alarms rates. Intermixed preexposure resulted mainly in false recognition of distractors that shared the unique feature with target stimuli, whereas for the blocked condition the type of distractor did not affect false recognition. This pattern of results is what one would expect if in the blocked condition all the features of the stimuli (both unique and common) underwent the same superficial encoding process. For the intermixed condition, on the other hand, Mitchell, Nash, and Hall (2008) propose a differential encoding of the features. The false alarms pattern is consistent with this proposal: There is a very low proportion of false alarms for MZ and NZ distractors and most of the false alarms were for AY and BY stimuli, that changed only in the common features.

In the General Discussion we compare these predictions with predictions of other theories for the advantage of intermixed preexposure and analyse how a memory mechanism is most probably involved in this advantage.

GENERAL DISCUSSION

Discriminating very similar stimuli has to be done by identifying each stimulus' unique features, while ignoring their common features. Gibson (1969) proposed that during preexposure attention will be directed towards the unique features of the stimuli while common features would be progressively ignored. A possible mechanism behind this effect might be a more efficient processing of the unique features and the processing decay of common features associated with their constant repetition in every successive presentation (Mitchell, Nash, & Hall, 2008). This differential processing of the features that constitute each stimulus will lead to differential encoding and memory traces.

Experiment 1 presented evidence that the unique features of the stimuli are better recalled in the intermixed condition. Participants were given intermixed preexposure to AX/BX and blocked preexposure to CX_DX. Immediately after the preexposure phase, participants completed a recognition memory task in which the four preexposed stimuli were presented along with eight new stimuli (distractors). All distractors had the X feature and changed only in colour or shape of the unique feature relative to one of the preexposed stimuli. Discrimination between targets and distractors was higher for the intermixed condition and at chance level for the blocked condition. Because all stimuli presented in the recognition memory task share the common feature X, one can conclude that any discrimination that might have taken place during target identification was done based on the unique features of each stimulus. In this sense, as expected after an efficient encoding of its properties, participants' recollection of the unique feature is high in detail, involving information about the colour and shape and not only overall location information. Chance level performance for the blocked condition, however, indicates the inability of participants to discriminate targets and distractors based on the colour and shape of the unique features.

We also present evidence for a differential processing of unique versus common features of the stimuli during intermixed preexposure. Experiment 2 replicated the conditions of Experiment 1 with only one change: The distractors varied in either only the common feature (X to Y) or both in the common feature and the all the properties of the unique feature except its location in the checkerboard (X to Z). Under these circumstances, intermixed preexposure resulted in more false alarms for stimuli that changed only in the common features when compared to stimuli that changed also in the unique features. There was no difference in false alarms between the two types of distractors in the blocked condition, which would suggest no differential encoding during preexposure for each of the features that constitute CX and DX.

Throughout this paper we have followed one account of perceptual learning that involves processing decay and memory encoding differences as well as attentional bias. As we have shown, our results are consistent with the provisions of the theory proposed by Mitchell, Nash, and Hall (2008) by showing differential memory for unique and common features of the stimuli.

However, Mundy et al. (2007) proposed a related account that, although not specifically making predictions about memory encoding might, with added assumptions, also account for the results presented here. Mundy et al. argue for an attentional weighting mechanism as the basis for the intermixed-blocked effect. Similar to Mitchell, Nash, and Hall (2008), under this account the relevant difference between intermixed and blocked presentation is in the pattern of repetition of the stimulus features. In the intermixed condition of AX/BX, X is presented in every trial. Thus, X will be presented twice as frequently as A or B. This differential frequency of presentation will result in differential adaptation to the features and allow for attention to be directed to the unique features. In the blocked condition, on the other hand, all features of the stimuli are presented in every trial and all will undergo the same adaptation process to the same extent. Although not a specific prediction of the theory, one might expect that A and B, as a result of receiving greater attention, will undergo more processing and thus be better encoded in memory. This prediction is consistent with the results presented here. The remaining features (X, C, and D), did not receive as much attention, and are expected to be not as well encoded in memory, what is also consistent with the results presented here.

There are, however, two other accounts of the intermixed-blocked effect that cannot as easily accommodate the results presented here. Hall (2003) proposed a mechanism involving salience modulation. Hall proposes that whereas direct activation of a feature representation will lead to a loss in salience and habituation, associative activation will reverse the habituation process and increase salience. More precisely, during intermixed preexposure of AX and BX, both A and B are associated with X. In this way, X will associatively activate B during AX trials and A during BX trials. Critically, thus, A and B salience will never be lost, and might possibly be enhanced. The common feature X, on the other hand, will undergo a habituation process and lose novelty. During blocked presentation of CX and DX all the features of the stimuli will undergo habituation and the absence of the alternation pattern will not allow the reversed habituation mechanism to take place.

One of the outcomes of the reversed habituation process proposed by Hall (2003) is that A and B will maintain their salience, typical of novel stimuli. It can also be assumed that novelty is kept by a weaker memory encoding of A and B. Conversely, X, C, and D will lose salience and become familiar features. The present results show that the unique features are better recalled after intermixed preexposure, which is not consistent with the proposal that the unique features will maintain their novelty through a reversed habituation process and common features will habituate. Moreover, more familiar features should be better recalled, what is the contrary of the poor memory for the common features found. Nonetheless, one way to reconcile the present results with Hall's proposal might be considering that associative activation increases attention (and thus salience, but not novelty) to the unique features of the stimuli and results in better encoding and memory for those features.

Finally, McLaren and Mackintosh (2000) propose that during intermixed preexposure to two compounds (AX/BX) the presence of the common feature X will promote the formation of links between A and X in AX trials and between B and X in BX trials (unitisation). As a result, X will evoke both A and B but, as A predicts the absence of B in AX trials and B the absence of A in BX trials, A and B will be more salient than X. This greater saliency will prevent unitisation of A-X and B-X and inhibitory links will be formed between A and B which will lead to reduced generalisation between the two compounds (that in turn leads to better discrimination between AX and BX). Moreover, this theory envisages that greater saliency is related with weaker stimulus representation. One can argue that the higher discriminability of A and B could account for the results seen here, but it is not clear how mutual inhibition between the two unique features would result in better memory performance in the recognition memory task (see also, Lavis et al., 2011; Mitchell, 2009).

It is also interesting to note that, in Experiment 2, no difference in accuracy between blocked and intermixed preexposures was found. This cannot be attributed to the use of a memory recognition task, as in Experiment 1 we used the exact same task and an advantage for the intermixed condition was found. Two reasons might have led to equally good performance after intermixed and blocked preexposure in Experiment 2: similar encoding of the X features for both schedules or overall reduced difficulty for discriminations.

On the one hand, as shown in Experiment 1 and discussed throughout this paper, the intermixed schedule maximises attention and memory for the unique features of the stimuli, while decreasing encoding of their common features. In this sense, it is perhaps not surprising that in a task in which discrimination cannot be totally established based on the unique features of the stimuli, performance does not benefit particularly from an intermixed presentation. Additionally, blocked and intermixed schedules are not expected to differ in the way the common features of the stimuli are encoded. Thus, given that most of the discriminations in Experiment 2 involved comparing the common features, equal performance is expected.

On the other hand, distractors and targets were overall more different in the second experiment, possibly contributing to an easier task. If difficulty of discrimination plays any role in the advantage of intermixed preexposure, that advantage would be lost, or at least weakened, with easier tasks. Nonetheless, the pattern of false alarms seen in Experiment 2 points to the first explanation as the most plausible. In the intermixed condition most of the false alarms occurred for distractors that shared only their unique feature with the targets. On the contrary, in the blocked condition, there was no effect of distractor type. False alarm rates were not substantially greater for distractors that shared only the unique feature with the targets.

CONCLUSION

The evidence presented here demonstrates, for the first time using recognition memory tasks, that the advantage of intermixing two very similar stimuli is related with differential attention and encoding of their features. More precisely, encoding of the unique features of the stimuli is more efficient during intermixed presentation, resulting in a good representation and memory for those features (Experiments 1 and 2). However, the common features are not as well encoded, resulting in worse representation and memory. Blocked preexposure results in a less effective encoding of both the unique and common features of the stimuli and a less detailed memory for the features of the stimuli (Experiments 1 and 2).

This pattern is consistent with the account of the intermixed/blocked effect that envisages encoding and memory differences between the blocked and intermixed conditions proposed by Mitchell, Nash, and Hall (2008). Mundy et al. (2007) proposed a similar account that can also explain the results presented here if one adds the plausible assumption that greater attention to the features will lead to better encoding.

Additionally, the inexistence of an advantage for the intermixed condition in Experiment 2, although consistent with the theoretical framework presented, provides initial evidence that whether intermixing is or not advantageous is also dependent upon the characteristics of the testing task (for a similar demonstration in category learning, see Goldstone, 1996). It may come as no advantage at all to have a detailed memory representation of the unique features of the stimuli if that information is not relevant for the correct resolution of the problem.

To return to our biology teacher in the introduction who tried to find the most effective way to present information: Our research indicates that intermixing exemplars from each cell type during presentation is a good option. Intermixed presentation will result in better memory for the important unique features a student needs to notice for good discrimination between cell types. Better discrimination will promote better learning and possibly transfer to new situations (Kornell, 2009; Taylor & Rohrer, 2010). However, more research is needed to fully understand the exact extent of this memory advantage, and the nature of the interaction between encoding and test conditions.

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