

## Brief communication

# The role of category structure in determining the effects of stimulus preexposure on categorization accuracy

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What are the effects of preexposure of stimuli on participants' subsequent ability to categorize them accurately? An experiment employing artificial, abstract, visual stimuli confirms that, for adult humans, the effect of preexposure is dependent upon category structure. Whether preexposure has beneficial or detrimental effects is shown to be dependent on the way category examples are generated from the category base patterns. The results are predicted by salience reduction accounts of perceptual learning but may be problematic for stimulus differentiation accounts.

It is well established, with human participants, that preexposure to stimuli can lead to an increased ability to discriminate between them. McLaren, Kaye, and Mackintosh (1989, see also McLaren & Mackintosh, 2000), however, note that preexposure of a single stimulus typically retards the rate at which an animal subsequently learns to associate that stimulus with an outcome (e.g., food). This phenomenon, known as latent inhibition, has been well attested in a number of species (see Lubow, 1989, for a review). One reasonable explanation for the phenomenon is that presentation of a stimulus without reinforcement progressively reduces the subjective salience of that stimulus. How can these two observations be reconciled?

McLaren et al.'s (1989) suggestion was that when exposure involves more than one stimulus, preexposure can reduce the salience of common features (which receive more preexposure) more than it reduces the salience of unique features, other things being equal. This differential salience reduction can lead to faster learning of the discrimination. In

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This research was partially supported by a Junior Research Fellowship awarded to Andy Wills by Emmanuel College, Cambridge. The authors would like to thank John Kruschke and Fergal Jones for their helpful comments.

McLaren et al.'s theory, faster learning occurs because associations can be formed selectively to those features that are useful to the discrimination, something that would not initially be possible in the absence of preexposure. More generally, if features useful to a discrimination are more salient than those that are not useful then that discrimination is likely to be facilitated. Thus latent inhibition becomes one mechanism by which perceptual learning can occur.

An alternative class of explanation for the beneficial effects of preexposure on stimulus discriminability involves unsupervised differentiation. For example, the participant might initially consider all presented stimuli to very similar, but after repeated presentations, the participant begins to notice that the stimuli differ systematically in some way. This process of differentiation would clearly aid a subsequent task that required different labels to be learned to each stimulus. This is the class of explanation provided by Gibson for exposure effects (Gibson, 1969). Goldstone's (1998) review of perceptual learning refers to such explanations as differentiation processes. Although the stimulus differentiation class of explanation has sometimes been criticized for its lack of a formal mechanism, Saksida (1999) has recently highlighted that self-organizing networks can produce the sort of stimulus differentiation envisaged.

Thus far, there seems to be little that would let one choose between the salience reduction and differentiation explanations of stimulus preexposure effects. Whilst both, one, or neither process may in fact be in operation, it would be helpful to the theoretical development of both accounts if situations could be found where they make differential predictions. One area in which they may differ is with regard to their predictions as to whether or not preexposure to stimuli could, far from enhancing later learning, actually impair it. The salience reduction account must admit this possibility. It may be that no straightforward latent inhibition effects can be found with human participants for reasons that have been well rehearsed elsewhere (cf. Lubow, 1989). Nevertheless, the reliance on salience reduction as a mechanism for perceptual learning promises that circumstances can be found where salience reduction occurs to the elements of a stimulus that are later required for discrimination learning. If this is so, then a test of this prediction would be of considerable interest, as it is not at all clear that a differentiation account should ever predict reduced discriminability as a consequence of preexposure.

Our first attempt to test this prediction of the salience reduction account of perceptual learning followed on from related work on the effects of preexposure on discrimination learning (McLaren, 1997; McLaren, Leavers, & Mackintosh, 1994). Wills and McLaren (1998) demonstrated that stimulus preexposure could facilitate categorization, as well as discrimination, judgements. The artificial categories employed in their experiments were defined by checkerboard base patterns (see Figure 1, second row) that were used to create examples of categories (exemplars) by changing the shade (black to white, or vice versa) of a small number of randomly selected squares on the base pattern. Participants were first exposed sequentially to a series of exemplars and required to make a novelty judgement for each. Each exemplar was presented twice, so the novelty judgement took the form of deciding whether this was the first or the second time that particular exemplar had been presented. No feedback about the accuracy of these decisions was given.

In their first experiment (Experiment 1a), Wills and McLaren found the expected result—compared to non-preexposed controls, stimulus exposure in the novelty judgement task led to better performance on a subsequent categorization task. The categorization task employed the same base patterns as were used to create the exposure stimuli (by adding random noise to the

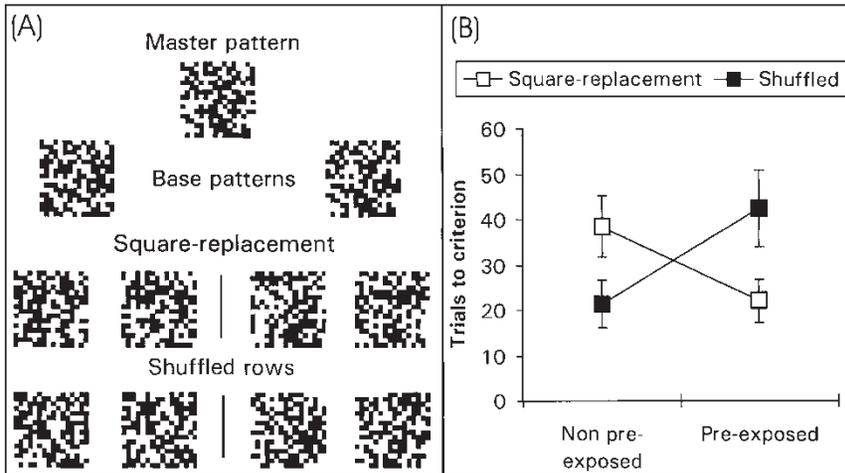


Figure 1. (a) Example stimuli. From an initial master pattern (top row), two base patterns are created (second row). The base patterns differ by the shade of exactly 128 squares. Category examples are created from base patterns by square replacement (third row) or by randomly re-ordering the rows (bottom row). (b) Trials to criterion as a function of preexposure and stimulus type. Error bars indicate one standard error above and below the mean.

base pattern). Given the apparent similarity of the base patterns to each other, neither the salience reduction nor the differentiation class of explanations outlined above would be embarrassed by this result.

Experiment 1b demonstrated that stimulus preexposure could lead to worse performance, rather than better, if the way in which examples were created from base patterns was changed slightly. This experiment employed the same base patterns and procedures as the first, but exemplars in both phases were created by randomly re-ordering all the rows of the base pattern. Hence, the 3rd row might become the 1st row, the 9th become the 12th, the 1st become the 8th, and so on. Performance on the categorization task was still above chance with this example creation method, but now participants who had been previously exposed to stimuli created in this shuffled manner were *worse* at categorizing the shuffled stimuli than participants with no previous exposure.

Purely in empirical terms, this is an important result because it was the first time (as far as we are aware) that a retardation in learning as a result of unmasked preexposure had been demonstrated in adult humans. Retardation in learning had been observed in adult humans previously, but either only under conditions in which the participant's attention was deliberately drawn away from the stimuli during preexposure (e.g., Ginton, Urca, & Lubow, 1975), or in preparations such as electrodermal response (e.g., Lipp, Siddle, & Vaitl, 1992) where other explanations such as habituation of an unconditioned response are possible.

Wills and McLaren's (1998) results are relatively straightforward to explain from a salience reduction account. McLaren et al.'s (1989) theory, which also motivated the current line of enquiry, posits that when a feature in the stimulus reliably predicts the co-occurrence of another, previously unpredicted, feature, an association forms from predicting feature to predicted feature. The learning rule in operation is the widely used delta rule (e.g., McClelland & Rumelhart, 1985). In addition to this standard associative process, a

“modulator” system causes unpredicted features to form new associations faster than well predicted features. The ability to rapidly form associations corresponds to high salience in this system. Features whose occurrence is predicted by co-occurring features have low salience. Features whose occurrence is not predicted in this way have high salience.

This relationship between predictability and salience allows the frequency of occurrence of a feature to indirectly influence its salience. Take the case of the categories generated by adding noise—that is, changing randomly selected squares from white to black or vice versa, which we will term square-replacement stimuli. Any given stimulus will contain a number of both common and unique features. Repeated presentation of the stimuli results in a reduction in salience for both common and unique features. This is because the set of unique features will begin to predict each other’s occurrence, and the set of common features will also begin to predict each other’s occurrence. The common features, however, occur more often than the unique features and hence will predict each other’s occurrence more strongly than the unique features do. The salience of the common features will therefore be lower than that of the unique features, leading to a beneficial effect of preexposure.

Now consider the shuffled stimuli. Just as for the square-replacement stimuli, preexposure will reduce the salience of features as they become increasingly predicted by co-occurring features. The difference is that, unlike the square-replacement stimuli, there is no simple relationship between the frequency of occurrence of a feature and how well it predicts category membership (see Wills & McLaren, 1998, pp. 263–264). In the absence of such a relationship, preexposure cannot be expected to produce an analogous perceptual learning effect to that found in the square-replacement stimuli. Moreover, the predictability-based account of McLaren et al. (1989) provides an explanation for why preexposure can lead to retardation—because a feature’s salience is highest when its occurrence on a particular trial is unpredicted. For example, consider a column in a shuffled stimulus that has 10 black squares in base pattern one. In the context of the other features of base pattern one, features in that column are somewhat predicted to be black. This means that if a black feature does occur its salience will be fairly low. If a white feature occurs its salience will be relatively high. Unfortunately, a white feature in this location will tend to be diagnostic of the opposite category. In our example, this will be true if there are fewer than 10 black squares in the base pattern of the opposing category (and the odds will be in favour of this). The result is that preexposure often makes features diagnostic of the opposite category more salient than those diagnostic of the appropriate category. This will clearly be detrimental to subsequent categorization accuracy. Similar processes are predicted to occur in square-replacement stimuli, but square-replacement stimuli, unlike shuffled stimuli, can benefit from the differential frequency of common and unique features.

In contrast to a salience reduction account, detrimental effects of preexposure on stimulus discriminability seem difficult to explain with a differentiation account. Preexposure should, in principle, lead to further differentiation of the representations of the stimuli encountered and hence have a beneficial effect. However, in practice, there are a number of ways the results of Wills and McLaren (1998) could, in principle, fit with a differentiation account.

First, whilst categorizations of both types of stimulus were above chance, non-preexposed participants found the shuffled stimuli significantly harder to categorize than the square-replacement stimuli. Presumably this results from the input representations being more similar for the shuffled stimuli than for the square-replacement stimuli. Perhaps the

representations are sufficiently similar that stimuli from different categories acquire the same detector (in other words, perhaps the system develops a representation that encompasses stimuli from both categories). If this seems a little post hoc, bear in mind that, other than differentiation, the primary use of competitive networks is the unsupervised categorization of input stimuli. Whether any particular stimulus set is differentiated or compressed depends on the dynamics of the proposed system. If the square-replacement stimuli could be made harder to categorize than the shuffled stimuli whilst retaining the same preexposure effects, this would be evidence against a “difficulty leads to compression” type of argument.

Second, it might be argued that the result has a motivational rather than representational explanation. Suppose that the novelty task in the preexposure phase is particularly difficult for shuffled stimuli. Despite the absence of feedback in this phase, participants might recognize that they have done badly and hence become de-motivated to perform well in the categorization phase. This results in the detrimental effect of preexposure. In contrast, the novelty judgement task is easy with the square-replacement stimuli, and hence participants’ motivation to perform well is enhanced. Accuracy data were not reported in Wills and McLaren (1998), although unpublished analysis failed to find any significant difference in accuracy between preexposure conditions, with a trend towards shuffled stimuli being easier.

Third, Wills and McLaren (1998) employed a free classification procedure in their categorization phase. In free classification, participants classify stimuli into groups of their own making in any way that seems reasonable or sensible to them. There is no feedback. Whilst it might seem odd to talk about the accuracy of classifications of artificial stimuli in the absence of feedback, accuracy (or rather consistency) can be assessed in terms of the extent to which the participant’s classification corresponds to the experimenter’s. Wills and McLaren developed a statistic that indexes consistency on a scale of 0 to 1 in a way unaffected by the number of classification groups employed. The authors contend that their results are not an artefact of the particular procedure and measure employed. However, this is primarily an empirical matter, and the result would be substantially strengthened if it could also be demonstrated with a more standard “guess-and-correct” methodology.

## Method

The experiment involved two phases. In the first phase, participants were preexposed to a number of examples from each of two artificial categories. In the second phase, participants classified new examples from the same two categories, receiving feedback about each response. On the basis of previous results, and the predictions of the McLaren et al. (1989) theory, we derived the following hypothesis—relative to nonexposed controls, preexposure would facilitate classification if examples were created from the base patterns by changing the shade of randomly selected squares, but it would retard classification if examples were created by the random rearrangement of rows. If such a result were found, it would provide evidence in favour of a salience change explanation of exposure learning and perhaps raise some questions for a stimulus differentiation account. Speed of learning in the categorization phase was to be the main dependent variable, indexed through a standard “trials-to-criterion” measure.

Relative to Wills and McLaren’s (1998) experiments, the square-replacement stimuli involved the modification of many more squares. This was done in order to reverse the ordering of difficulty of the two categorizations. In the Wills and McLaren experiments, non-preexposed participants found the shuffled stimuli more difficult. It was hoped that, in the current experiment, the square-replacement stimuli would be the more difficult, though of comparable difficulty to the shuffled stimuli.

### *Participants and apparatus*

The participants were 48 adults from the Cambridge (UK) area. All were paid for their participation, and all were aged between 18 and 30 years. Participants were tested individually in quiet cubicles. The experiment was run on Acorn RISC PCs with 14-inch colour monitors (Acorn AKF60). Participants sat about 1 m from the screen, which was approximately at eye level. Responses were collected via standard PC-style keyboards.

### *Stimuli*

Figure 1a illustrates the process of stimulus construction. Each stimulus was a  $16 \times 16$  array of black and white squares. These “checkerboards” measured 2.5 cm on a side and were presented in the centre of the screen against a mid-grey background.

Stimulus generation was a two-stage process. The first stage involved the creation of *base patterns*. A checkerboard, containing equal numbers of black and white squares but otherwise randomly generated, was created. Two base patterns were created from this *master pattern* by inverting the colour of each square in each of four randomly selected rows. The four rows changed were entirely different for the two base patterns. The two base patterns therefore differed from each other in the colour of 128 squares.

The second stage of stimulus generation involved the creation of the presented stimuli by distortion of the base patterns. Distortions were created by applying either a *square-replacement* or a *shuffling* manipulation to the chosen base pattern.

The *square-replacement* procedure involved randomly selecting a row of the chosen base pattern and replacing it with a new, randomly generated row of black and white squares. This procedure was repeated eight times, with each row eligible for replacement on each of the eight occasions. In other words, a row could potentially be selected for replacement more than once. This procedure gives rise to stimuli that, on average, differ from the base pattern on approximately 20% of squares.

The *shuffling* procedure involved a random re-ordering of the position of the 16 rows of the stimulus. For example, the 1st row of the base pattern might appear as the 9th row of the presented stimulus, the 3rd as the 2nd, the 13th as the 3rd, and so on.

All stimuli presented to any given participant were generated from the same pair of base patterns, and by the application of just one of the two distortion methods.

### *Procedure*

There were four between-participant conditions, created by the factorial combination of two independent variables. Those independent variables were stimulus distortion (square placement vs. shuffled) and preexposure (preexposed vs. non-preexposed). This logical design was repeated over 12 sets of four participants. A different pair of base patterns (see Stimuli) was allocated to each set of four participants.

In all four experimental conditions, the experiment comprised two phases. In the preexposed conditions, Phase 1 involved a *running-recognition* task, and Phase 2 involved a *categorization* task (procedures below). In the non-preexposed conditions, Phase 1 was an unrelated experiment of approximately the same duration as the preexposure phase, and Phase 2 was again categorization. The unrelated experiment involved the concurrent acquisition of a number of sequential discriminations involving a variety of stimuli unrelated to those in the current experiment—for example, green squares that differed slightly in hue.

*Running-recognition phase.* Checkerboard stimuli were presented on the screen one at a time. For each stimulus, the participant had to decide whether this was the first or the second time that particular stimulus had been presented. The “X” and “>” keys on the computer keyboard were used for response,

and the allocation of these keys to the responses “first time” and “second time” was counterbalanced across participants. A response caused the immediate presentation of the next checkerboard stimulus. No feedback was provided.

Stimuli were presented in blocks of 48, and the participant was encouraged to rest for a few seconds between blocks. Participants were (correctly) informed that each stimulus occurred twice in a block and never occurred more than twice across the whole phase. The 24 different stimuli presented in each block were generated from the base patterns using the appropriate stimulus distortion procedure (shuffling or square-replacement, dependent on condition). Equal numbers of stimuli were created from each of the two base patterns.

Trial ordering within each block was determined by a semirandom procedure designed to minimize the effectiveness of position within a block as a cue of whether the stimulus is being presented for the first or the second time. Clearly, the last stimulus in a block must have been presented before. In addition, this procedure sets the first three stimuli in a block as novel stimuli. However, between Trials 4 and 47, trial number is a poor predictor of whether a stimulus has been presented before this procedure is employed. Full details of the procedure may be found in Wills and McLaren (1998, p. 243)

The running-recognition phase involved five blocks of 48 stimuli. Instructions given to participants emphasized accuracy rather than speed, but a time-out procedure moved the participant on to the next stimulus if they took more than 4250 ms to respond. Participants were asked to avoid time-outs where possible.

*Categorization phase.* This phase employed a standard two-choice with feedback category-learning procedure. For any given participant in the preexposed conditions, the base patterns and stimulus distortion method used in this phase were the same as those employed in the running-recognition phase. No explicit reference to the previous phase was made in the instructions given to participants.

Stimuli were presented one at a time in the centre of the screen, and participants were asked to categorize each using one of the two response keys (“X” or “>”). On detection of a response, the stimulus was replaced by a feedback message of 1000-ms duration, which, in turn, was followed by presentation of the next stimulus. The feedback message was either the word “WRONG!” presented in the centre of the screen and accompanied by a beep, or the word “Correct!” with no accompanying sound.

At the beginning of the phase, one base pattern was arbitrarily designated as the “X” pattern and the other as the “>” pattern. The correct response for stimuli generated from the “X” pattern was “X”, and the correct response for stimuli generated from the “>” pattern was “>”.

Stimuli were presented in four blocks of 48 items, and the participant was encouraged to rest for a few seconds between blocks. An equal number of “X” and “>” patterns were presented in each block, and presentation order was randomized.

All 192 stimuli presented in this phase were generated independently using the appropriate procedure. For the majority of participants, this meant that all 192 patterns were different from each other, and different to all of the 240 patterns presented in the running-recognition phase. This was not explicitly controlled for, however.

As in the running-recognition phase, accuracy was emphasized over speed but participants were timed out after 4250 ms.

## Results

Reported effects are significant at the .05 level, two-tailed, unless otherwise stated. Rate of learning in the categorization phase was the main dependent variable of interest. This was indexed here by the number of trials taken to reach a criterion of six consecutive correct responses. The criterion, selected prior to data collection, is the one we have used previously in

categorization experiments of this type (e.g., McLaren, 1997) and was designed to represent a level of performance unlikely to occur through chance responding. A total of 47 of the 48 participants tested reached criterion within the 192 trials available.

The participant who failed to reach criterion was in the preexposed, shuffled condition. This participant was excluded from further analysis. In order to balance the effects of this exclusion, the participant with the highest number of trials to criterion was also removed from each of the other three conditions. A number of other methods of dealing with this one failure to reach criterion were also investigated, including inclusion of the participant as 193 trials to criterion and exclusion of just that participant. The conclusions drawn in the Discussion are not affected by the particular procedure adopted.

Mean number of trials to criterion in each of the four experimental conditions are shown in Figure 1b. These data were first subjected to an overall, two-factor, between-subjects analysis of variance (ANOVA). Preexposure did not significantly affect performance as a main effect,  $F(1, 40) = 0.135$ , and neither did stimulus distortion type,  $F(1, 40) = 0.065$ . However, the interaction between these two factors was significant,  $F(1, 40) = 8.659$ .

As determined prior to running the current experiment, the two effects of central theoretical interest are (1) the effect of preexposure with square-replacement stimuli, (2) the effect of preexposure with shuffled stimuli. Separate  $t$  tests for the two stimulus types revealed a significant reduction in performance due to preexposure for the shuffled stimuli,  $t(20) = 2.16$ , and an increase in performance due to preexposure for the square-replacement stimuli,  $t(20) = 2.00$ , which was significant at .05 as a one-tailed test. Nonparametric tests (Wilcoxon rank-sum) on the full data set including the outlier confirm these results ( $W = 117.5$  and  $120.5$ ,  $Z = 1.88$  and  $1.70$ , both significant at .05 as a one-tailed test).

In the absence of preexposure, there was a trend for the participants presented with shuffled stimuli to take fewer trials to reach criterion, which was very nearly statistically significant,  $t(20) = 2.03$ . Performance in the preexposure phase (calculated over trials 4 to 47 of each block) was relatively poor, mean accuracy being 64.4% in the row-replacement condition and 59.9% in the shuffled condition. Both levels of accuracy were significantly greater than chance (defined as 50% correct),  $t(10) = 5.00$ , for the shuffled condition, and  $t(10) = 6.81$ , for the row-replacement condition.

The trend for higher accuracy in the row-replacement condition did not reach conventional levels of significance,  $t(20) = 1.56$ . Nevertheless, one possibility is that the difference in difficulty gave rise to the results in the categorization phase due to some general motivational factor. If such a motivational factor was of importance then one might expect mean accuracy at preexposure to negatively correlate with trials-to-criterion at categorization. No evidence for this proposition was found,  $r^2 = .03$ ,  $N = 22$ .

In a task with minimal explicit time pressure, reaction time is best considered as a secondary measure of performance. However, for completeness, mean reaction time across the four blocks of the categorization phase was calculated for each participant, and the resulting data were used to perform a two-factor, between-participants ANOVA. Differences between the four means were small in proportion to their absolute values, and no effects approached significance, maximum  $F(1, 40) = 0.221$ . Mean reaction time in the preexposure phase did not significantly differ between the two preexposure conditions,  $t(20) = 0.42$ .

## Discussion

Stimulus preexposure affects the rate at which a subsequent categorization of those stimuli is learned. The direction of that effect—acceleration or retardation—is dependent on the manner in which category examples are created from base patterns. The result is predicted by a salience reduction account of perceptual learning, but may be problematic for a stimulus differentiation account. The results are also important from a purely empirical point of view. This experiment constitutes perhaps the clearest demonstration in adult humans of a retardation of learning as a result of unmasked preexposure. As we have noted, retardation in learning has been observed in adult humans, but either only when the participant's attention was drawn away from the stimuli during preexposure (e.g., Ginton et al., 1975) or in preparations such as electrodermal response (e.g., Lipp et al., 1992) where explanations based on habituation of an unconditioned response are possible.

In the introduction, an experiment by Wills and McLaren (1998) was described that also showed that the direction of the effect of preexposure was critically dependent on the stimulus creation procedure. It was argued that such a result, whilst potentially problematic for a stimulus differentiation account, could actually be explained in a number of ways. The principal explanations were that (1) shuffled stimuli were so difficult that compression rather than differentiation occurred, (2) the result was an artefact of the motivational properties of the preexposure task, or (3) the result was an artefact of the non-standard categorization procedure employed. The results of the current experiment make these explanations less likely. The results of Wills and McLaren have been shown to be robust across a change of procedure (free classification to standard categorization) and a reversal of the order of difficulty of the two stimulus types. Little supportive evidence was found for a motivational account of the effects of preexposure; stimulus type did not have a significant effect on the difficulty of the preexposure task, and performance on the preexposure task did not predict performance on the categorization task.

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*Original manuscript received 31 July 2002*

*Accepted revision received 7 March 2003*