Psicológica (2015), 36, 185-204.

Evidence for feature and location learning in human visual perceptual learning

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In Experiment 1, human participants were pre-exposed to two similar checkerboard grids (AX and X) in alternation, and to a third grid (BX) in a separate block of trials. In a subsequent test, the unique feature A was better detected than the feature B when they were presented in the same location during the pre-exposure and test phases. However, when the locations of the features were swapped during the test (A was tested in the location occupied by B during pre-exposure and *vice versa*), B was detected better than A, suggesting that intermixed pre-exposure enhances the attention paid to the location of the unique features rather than the features themselves. In Experiment 2, participants were given intermixed or blocked pre-exposure to AX and X, and were then required to detect the differences between pairs of stimuli containing either the pre-exposed unique feature A or a new feature, N, presented in a familiar location (used for pre-exposure) or a new location within the checkerboard grid. Participants that were given intermixed pre-exposure showed a facilitated capacity to detect A than N, and detected better the unique features in the familiar than in the new location. In contrast, participants in the blocked condition did not show any effect of feature or location. These results provide evidence that both location and feature learning processes take place during intermixed (but not blocked) pre-exposure.

[*] This work was supported by a grant (Ref: PSI2011-26850) from the Spanish *Ministerio de Ciencia e Innovación* to JP. MMMF's contribution was possible thanks to the FPU Program of the Spanish Ministerio de Educación (AP2007-01332). Maria Manuela Moreno-Fernández, Departamento de Psicología, Universidad de Jaén, Spain (now at University of Deusto, Bilbao, Spain). Nurizzati Mohd Saleh and Jose Prados, School of Psychology, University of Leicester, United Kingdom. Address for correspondence: Jose Prados. School of Psychology. University of Leicester. University Road . LE1 9HN – Leicester, United Kingdom. E-mail: jpg19@le.ac.uk

Pre-exposure to similar stimuli can benefit their subsequent discrimination. One factor known to modulate exposure learning is the schedule according to which the to-be-discriminated stimuli are presented. For example, intermixed exposure to similar stimuli (AX, BX, AX, BX…; where A and B are the unique features of the stimuli, and X the common elements) facilitates subsequent discrimination to a greater extent than equivalent exposure in separate blocks of trials (a block of AX trials followed by a block of BX trials) (e.g., Artigas, Sansa, & Prados, 2006; Dwyer, Hodder, & Honey, 2004; Honey, Bateson, & Horn, 1994; Lavis & Mitchell, 2006; Prados, Artigas, & Sansa, 2007; Symonds & Hall, 1995). Accordingly, alternated pre-exposure to AX and BX is more likely to engage perceptual learning processes that enhance the discriminability of the stimuli than blocked pre-exposure.

Lavis and Mitchell (2006) developed a procedure to assess perceptual discriminations in humans by means of same/different judgments using visual scenarios. In their experiments, participants were pre-exposed to four very similar multi-coloured checkerboard grids in which the common element X represented the majority of the grid. The unique elements, A, B, C and D were small localized constellations of five coloured squares. A red cross located in a particular area was the unique feature A; a red cross located in a different area was B. A purple C-shaped constellation located in a third and a fourth locations were C and D. Participants were given pre-exposure to AX and BX in alternation, and pre-exposure to CX and DX in separate blocks of trials. Following pre-exposure, participants were presented with pairs of stimuli and had to decide whether they were the same or different. Participants detected the differences between AX and BX, pre-exposed in alternation, better than between CX and DX, pre-exposed in blocks. This is an elegant replication of the intermixed-blocked effect using a task in which only the perceptual components of AX and BX seem to account for their improved discrimination.

The Lavis-Mitchell discrimination procedure has been widely used over the last few years, and a significant body of evidence has been reported to suggest that fine discriminations assessed through same/different judgments can be explained in terms of salience modulation processes. For example, in an experiment by Wang and Mitchell (2011), participants were given alternated presentations of AX and BX, and a separate block of pre-exposure trials with a different background stimulus, Y. Subsequent test trials were carried out in which participants had to detect the differences between AX and BX on the one hand, and CY and DY on the other. The results showed a better discrimination with AX-BX than with CY-DY, in spite of the fact that C and D were entirely novel unique features at the time of test and therefore could be expected to have an intact salience. To account for these results, intermixed pre-exposure has been suggested to increase the attention paid to unique features A and B by establishing an accurate representation of these features on memory; once a detailed and stable representation of A and B has formed, a top-down attentional process would use these representations to discriminate AX from BX. (e.g., Mitchell, Kadib, Nash, Lavis and Hall, 2008; see Mitchell & Hall, 2014, for a full review).

More recently, a few studies using the Lavis-Mitchell task have shown that rather than changes in attention to the intrinsic properties of the unique feature (shape and colour), intermixed pre-exposure induces changes in the attention paid to the location of the feature. In a study by Wang, Lavis, Hall and Mitchell (2012, Experiment 3; see also Jones & Dwyer, 2013), following alternated pre-exposure to AX and BX, participants were given test trials in which they were required to discriminate between AX and BX on the one hand, and between two novel stimuli, CX and DX (which involved new features presented in novel locations) on the other hand. Participants readily discriminated between AX and BX, and showed a poorer performance in the presence of CX and DX. In additional test trials, however, the pre-exposed features A and B were presented in the new locations, and the novel features C and D were presented in the familiar locations previously used during pre-exposure to AX and BX. The results showed that participants now readily discriminated between C and D whereas the discrimination between A and B was significantly poorer. These results strongly suggest that locations rather than features attract the attention of the participants during the test.

In addition to this location learning, Wang et al. (2012) reported some evidence of feature learning: comparing the A-B and C-D discrimination in the novel locations, it was found that participants detected better C and D than A and B, suggesting that novel features attract more attention than familiar features pre-exposed in alternation. This result is in conflict with the results previously reported by, for example, Wang and Mitchell (2011). If confirmed, it would support the notion that pre-exposure reduces the effective salience of cues to a level below that controlled by novel stimuli (e.g., McLaren & Mackintosh, 2000). It is important to note that, in similar experiments, Jones and Dwyer (2013) did not observe any advantage of novel over pre-exposed features presented in a novel location.

A limitation of the studies reported by Wang et al. (2012) and Jones and Dwyer (2013) is that they only considered the effects of intermixed pre-exposure; the effect of blocked pre-exposure upon the salience of the location and the intrinsic properties (shape and color) of the unique features remains therefore unexplored. Also, as pointed out above, conflicting results have been reported in relation to the changes of salience of the intrinsic properties of the unique features. The experiments reported below aimed to assess the effect of intermixed and blocked pre-exposure upon the salience of the intrinsic properties and the location of the unique features in human visual perceptual learning.

EXPERIMENT 1

METHOD

Experiment 1 aimed to assess the relative contribution of feature and spatial learning to the intermixed-blocked effect. Participants were given pre-exposure to AX and X in alternation, and to BX in a separate block of trials. After pre-exposure, participants were required to detect the unique features A and B in a series of test trials in which AX and BX were compared with the background stimulus X (AX *vs*. X and BX *vs*. X trials; these trials were compared with an equal number of trials in which the same stimulus was presented twice: AX *vs*. AX and BX *vs*. BX trials). For participants in the Congruent group, A and B (the features given intermixed and blocked pre-exposure respectively) were presented during the test in the same location used during the pre-exposure phase. For participants in the Incongruent group, A was presented in the location used for B during the pre-exposure phase; and B was presented in the location used for A during the pre-exposure. Intermixed pre-exposure has been said to better protect the salience of the unique features than blocked pre-exposure (e.g., Hall, 2003; Mitchell et al., 2008). If participants' ability to detect the unique features A and B depends upon their intrinsic features (shape and colour) rather than their location, A should be better detected than B both in the Congruent and the Incongruent groups. However, if participants use the location to detect the unique features, then A would be better detected than B in the Congruent group, whereas the opposite result could be expected in the Incongruent group.

In the experiments reported below, the general procedure developed by Lavis and Mitchell (2006) has been followed for the pre-exposure phase; for the test phase, however, we implemented a few changes in the same/different task to improve the sensitivity of our measures. In earlier experiments carried out in our laboratory we observed (by analysing the actual responses and the feedback provided by our participants after the completion of the test) that when participants were tested in the same/different task with, for example, AX and BX, it was not infrequent that participants only detected the unique feature A, but were completely unaware of the existence of a second unique feature B. In these cases, by looking at the location of feature A participants could score very high in discrimination (100% of correct responses in the same/different task); but this high score did not match with the actual detection of the two features: what can be interpreted as successful detection of B simply corresponds to the absence of A. To avoid this bias, we designed a task in which rather than responding same or different, the participants had to determine whether there were differences between the two stimuli presented in a test trial, and were required to click on the area in which the change had been detected—or, if no changes were detected, in a "No changes detected" response box (e.g., Moreno-Fernandez, Prados, Marshall, & Artigas, 2010). In that way we could monitor the actual detection of the unique features (e.g., A and B) of interest.

Participants. Sixty-four students from the University of Leicester (59 women and 5 men; mean age 20.12; range = 18-46) participated in this Experiment in exchange for course credit. They all had normal or corrected-to-normal vision and no previous experience with the task.

Apparatus and Stimuli. The experiment was conducted on Windows XP based personal computers and stimuli were presented on 17 inch TFT screens. We used Microsoft Office Power Point to control stimulus presentations and register the responses.

A checkerboard with 400 coloured squares based on one of the stimuli employed by Wang & Mitchell (2011) was used as the background stimulus (X) of the present experiment. The unique feature A was a distinctive constellation of coloured squares (e.g., a red inverted T) located in a particular area of the X background (e.g., upper-left location); the unique feature B was a distinctive constellation of coloured squares (e.g., a blue inverted T) located in a particular area of the X background (e.g., the lower-right location) (see Figure 1). Both the colours of the unique features (red and blue) and the locations (upper-left and lower-right) were fully counterbalanced.

Design and procedure. The experiment took place in two phases: pre-exposure and test. The pre-exposure phase consisted of a total of 180 trials: 60 trials of AX in alternation with 60 trials of X, and a separate block of 60 presentations of BX (the order in which AX/X and BX appeared was counterbalanced across participants). The test phase consisted in a difference detection task that included 12 Same trials (6 AX *vs*. AX; and 6 BX *vs*. BX) and 12 Different trials (3 AX *vs*. X; 3 BX *vs*. X; 3 X *vs*. AX; and 3 X *vs*. BX) in which participants were required to report any differences detected between the two members of each pair. The test trials were organised in a sequence in which all the different trial types were presented at random with the restriction that all the different trials should be presented once every eight trials, and the same trials were presented twice every eight trials; in that way, there were three blocks of eight trials containing each 2 AX *vs*. AX trials; 2 BX *vs*. BX trials; 1 AX *vs*. X trial; 1 BX *vs*. X trial; 1 X *vs*. AX trial; and 1 X *vs*. BX trial. The locations of the unique features A and B were maintained between phases for participants in Group Congruent. For participants in the Group Incongruent, A (pre-exposed in alternation) was presented during the test in the location previously used for B during pre-exposure, and B (pre-exposed in blocks) was presented during the test in the location used for A during pre-exposure.

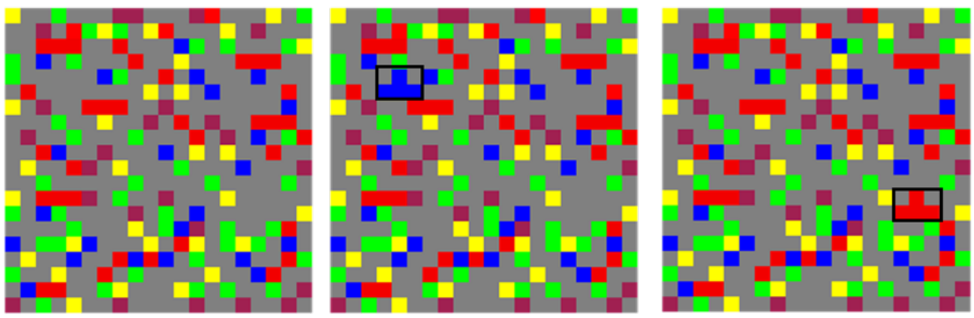

Figure 1. Examples of stimuli X (left), AX (centre) and BX (right) used in Experiment 1. The unique features A and B are presented within black boxes that did not appear in the Experiment. The features A and B and the position they occupied in the grid were counterbalanced across participants.

Participants were randomly assigned to one group (Congruent or Incongruent), and tested in pairs in an experimental room with two computers (the participants could not see each other or the other's screen during the testing session). Once seated in front of the computer monitor, participants were provided with a set of instructions (in white font against a black background) on the screen:

[Pre-exposure instructions] "*In the first phase of this experiment you will see some coloured grids, one at a time. Please examine them carefully. The grids are very similar but some of them have small differences. Please try to find these differences. Pay careful attention because you will be asked what you think about them later*".

A grey button with the sentence "Click here when you are ready to continue" appeared at the bottom of the screen. Participants had to click on this grey button to start the pre-exposure phase. During pre-exposure, each stimulus was presented for 500 ms, followed by a 1500 ms inter-trial interval where the stimulus disappeared and the black background was present. All participants were given alternated pre-exposure to AX and X, preceded or followed by a block of BX presentations. No responses were requested during this phase. Once the pre-exposure phase was completed, the following instructions were presented:

[Test instructions] "*In this phase of the experiment you will see two grids, one after the other, on each trial. Your task is to identify any differences between the two grids and click on the screen, using the left-hand button of the mouse, where you believed the difference occurred. If you did not detect a change please click on the 'No change detected' box. Please feel free to ask any questions you may have*."

Participants had to click a grey button with the sentence "Click here when you are ready to continue" to start the test phase. A test trial started with the presentation of a stimulus for 1000 ms; a 1000 ms black screen was then presented, and this was followed by the presentation of the second stimulus for 1000 ms. After that, the second stimulus remained in the screen but a grey button with the sentence "No changes detected" appeared bellow so that a response could be given at that point. The participants could click in any area of the checkerboard and in the "No changes detected" box. In the Different trials, if they clicked in the area (an invisible rectangle of 2 x 3 squares that could contained the unique features A and B) in which a change occurred between the two test stimuli, that was registered as a correct response. Clicking in any other area of the checkerboard, or the "No changes detected" box was registered as an incorrect response. In the Same trials, in which there were no differences between the two test stimuli, clicking in the checkerboard was registered as an incorrect response, and clicking in the "No changes detected" box was registered as a correct response. The participants were allowed to respond just once per test trial. Once the participant had responded, a new screen was presented with a grey button centred in the middle with the sentence "Click here when you are ready to continue". Participants had to click on this button to initiate a new test trial.

Dependent variable and statistical analysis. The percentage of correct responses was calculated for the Same and Different trials. In the Same trials, (AX *vs*. AX; BX *vs*. BX) the correct response was to click in the "no differences detected" box. In the Different trials, the correct response was to click in the area in which A or B had been presented (in the first or the second stimulus of each test trial). These data were analysed using an ANOVA; a significance level of $p < .05$ was set for all the statistical analyses reported.

RESULTS AND DISCUSSION

Figure 2 displays the average of correct responses on Same and Different trials for the Intermixed and the Blocked condition in the groups tested with a Congruent (unique features presented in the same location during pre-exposure and test) and Incongruent (unique features presented in different locations during pre-exposure and test) location. A quick inspection of the graph reveals a higher percentage of correct responses on Same than on Different trials. More interesting, the opposite pre-exposure effect can be observed in the Congruent and Incongruent groups in the Different trials.

An ANOVA with Trial Type (Same *vs*. Different), Pre-exposure (Intermixed *vs*. Blocked), and Group (Congruent *vs*. Incongruent) as factors showed a significant effect of Trial Type, $F(1, 62) = 104.67$, $\eta_p^2=.62$, as well as a significant Pre-exposure x Group interaction, $F(1, 62) = 8.31$, $\eta_p^2=.11$, and a significant triple interaction Trial Type x Pre-exposure x Group, $F(1, 62) = 11.52$, $\eta_p^2=.15$. The remaining factors and interactions were all non-significant (Fs<1). To analyse the triple interaction, two ANOVAS with Group and Pre-exposure as factors were carried out on the data of the Same and the Different trials respectively. In the Same trials, neither the main factors nor the interaction was significant, Fs<1. In the Different trials, the main factors were both non-significant, Fs<1; there was, however, a significant Group x Pre-exposure interaction, $F(1, 62) = 12.53$,

η_p^2=.16. Further analyses carried out to analyse this interaction (Simple Main Effects) showed that the percentage of correct responses was higher in the Intermixed than in the Blocked condition in the Congruent group, $F(1, 31) = 7.34$, η_p^2=.19. On the contrary, in the Group Incongruent, the percentage of correct responses was higher in the Blocked than in the Intermixed condition, $F(1, 31) = 5.20$, η_p^2=.14.

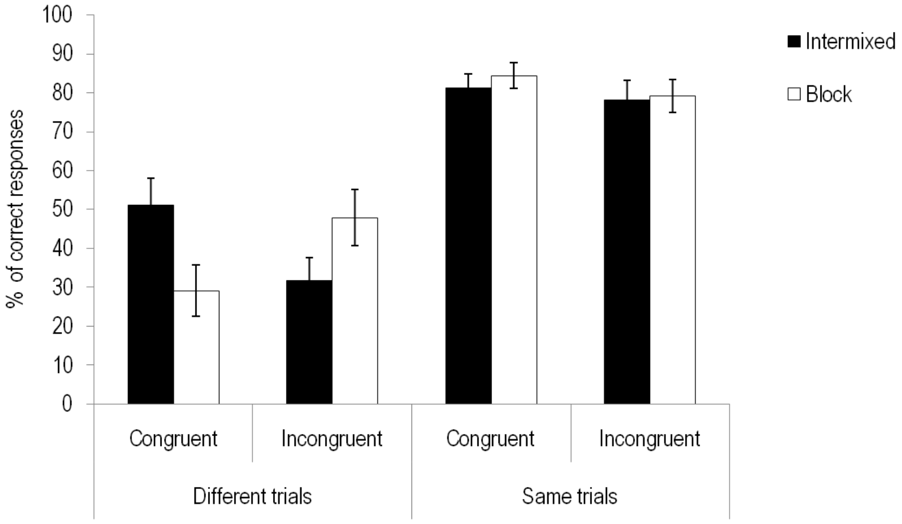

Figure 2. Mean percentage of correct responses (±*SEM*) in the Intermixed and Blocked conditions on same and different trials for the Congruent and Incongruent Groups.

The results of the Group Congruent replicate the pattern of results originally reported by Lavis and Mitchell (2006): better discrimination after intermixed than blocked pre-exposure. This could erroneously suggest that intermixed pre-exposure engages learning processes that increase the salience of the intrinsic properties of the unique feature A. The results of the Group Incongruent, however, strongly suggest that it is not the unique feature A what is attended to and detected during the test, but the location occupied by this unique feature during the intermixed pre-exposure: participants detected better the unique feature B (pre-exposed in blocks) when it was presented in the location occupied by the feature A during the pre-exposure phase; and showed a worsened capacity to detect the unique feature A (pre-exposed in alternation) when it was presented in the location occupied by B during pre-exposure.

These results replicate those reported by Wang et al. (2012) and Jones and Dwyer (2013) in highlighting the role of location learning after intermixed pre-exposure; and show that blocked pre-exposure does not increase the attention paid to the location occupied by the pre-exposed feature B. Neither of the unique features (A, pre-exposed in alternation; or B, pre-exposed in a separate block of trials) seem to experience a change in the attention paid to their intrinsic properties.

EXPERIMENT 2

Experiment 1 clearly showed that intermixed pre-exposure results in an increase of attention to the location occupied by the unique feature A. Although there is no evidence for a change in the salience of the intrinsic properties of this feature, Experiment 1 cannot be taken as proof that intermixed pre-exposure does not affect their salience.

Previous experiments have proven beyond doubt that intermixed pre-exposure results in an increase in the attention paid to the intrinsic properties of the unique feature (shape and colour) independently of the location learning processes. For example, in an ingenious experiment, Lavis, Kadib, Mitchell, and Hall (2011) gave pre-exposure to four distinctive versions of the same visual pattern, AX, BX, CX and DX. Each unique feature (A, B, C and D) had a unique shape, colour (red, blue, green yellow, or purple) and location. AX and BX were presented in alternation, whereas CX and DX were pre-exposed in separate blocks of trials. As usual, participants showed a better detection of differences in a same-different task when tested with AX and BX than when tested with CX and DX (the basic intermixed/blocked effect). In a separate test, a colour-matching task was used in which the shape of the different unique features were presented unfilled (filled white) in the centre of a grey square which was the same size as the pre-exposed grids and the same grey as the non-coloured squares of those grids. Below this gray square there were five buttons coloured in red, blue, green, yellow, and purple. Participants were instructed to click the button whose colour matched the shape presented in each test trial. Participants selected the correct colour more frequently in the intermixed condition (presentations of A and B) than in the blocked condition (presentations of C and D). Superior discrimination produced by the intermixed pre-exposure (in the same/different task) was therefore associated with better memory of the unique features of the intermixed stimuli. This finding seems to be consistent with the account of perceptual learning outlined by Mitchell et al. (2008), suggesting that intermixed pre-exposure allows better processing of the unique features of the stimuli so that they become better encoded in memory.

The results of Experiment 1 suggest that the location used for blocked pre-exposure remains unattended; in that case, the blocked pre-exposed location should be equivalent to a novel location. As an alternative, blocked pre-exposure might allow detection of the location and the unique feature, but the absence of changes throughout the block of pre-exposure trials could result in a reduction in the attention paid both to the location (in which case we could expect participants to somehow avoid this uninteresting area) and the feature. If the shape and colour of the stimuli C and D (pre-exposed in blocks) of the study by Lavis et al. (2011) were equivalent to novel features, we could conclude that intermixed pre-exposure increased the salience of the unique features A and B, as suggested by Mitchell et al. (2008). However, if the features C and D had lost part of their initial salience as a result of blocked pre-exposure, then intermixed pre-exposure could have merely maintained the initial salience of A and B, as suggested by, for example, Hall (2003). To allow for an accurate interpretation of this kind of data we need to further explore the effects of blocked pre-exposure upon the salience of the location of the unique feature and its intrinsic properties, shape and colour.

Experiment 2 was designed to further assess how intermixed and blocked pre-exposure affect the detection of the pre-exposed feature, A, in a familiar and a new (non-pre-exposed) location. Detection of the pre-exposed feature A was compared to the detection of a novel unique feature, N, which was also presented in familiar and new locations. Participants in the group Intermixed were given pre-exposure to AX and X in alternation; participants in the group Blocked were given pre-exposure to AX and X in separate blocks of trials. After pre-exposure, participants were required to detect the unique features A (pre-exposed) and N (non-pre-exposed) in a series of test trials in which AX and NX were compared with the background stimulus X (AX *vs*. X and NX *vs*. X trials). In half of the test trials, A and N were presented in a familiar location (the location where A had been presented during pre-exposure); in the remaining trials, they were presented in a new location within the checkerboard grid. In the present experiment, in contrast with Experiment 1, we omitted the *same* trials in which the same stimulus was presented twice (i.e., AX *vs*. AX).

METHOD

Participants. Sixty-four students from the University of Leicester (51 women and 13 men; mean age 20.39; age range = 18-34) participated in this Experiment in exchange for course credit. They all had normal or corrected-to-normal vision and no previous experience with the task.

Apparatus and Stimuli. Experiment 2 made use of the task described for Experiment 1. The unique features A and N could be an inverted T or an L-shaped figure coloured in red or blue. These unique features could be located in the upper-left or the lower-right areas of the grid (see Figure 1). Both the shape and colour of the unique features (A and N) and the locations (upper-left and lower-right) were fully counterbalanced.

Design and procedure. The experiment took place in two phases: pre-exposure and test. The pre-exposure phase consisted of a total of 100 trials: 50 trials of AX and 50 trials of X were presented in alternation (AX, X, AX, X…) in the group Intermixed and in separate blocks of trials (AX, AX… X, X) in the group Blocked; the order of the presentation of AX and X was counterbalanced in both groups. The test phase consisted in a difference detection task that included 16 trials in which participants were required to report any differences detected between the two members of each pair. In this experiment we omitted the Same trials in which two identical stimuli were presented in succession; a number of experiments carried out in our laboratory have shown that the relevant data always come from the Different trials (participants always show an almost asymptotic level of correct responses to the Same test trials), and the omission of the Same trials does not result in any change in the pattern of response to the Different trials. In half of the test trials, the background X was compared with a stimulus containing the pre-exposed unique feature A, which could be located in the familiar location (used for pre-exposure) or in a new location. In the remaining test trials, the background X was compared with a stimulus containing a new unique feature N, which could be located in the familiar location (used for pre-exposure with the feature A) or in a new location. There were eight trial types during the test: AX *vs*. X; NX *vs*. X; X *vs*. AX; X *vs*. NX; A'X *vs*. X; N'X *vs*. X; X *vs*. A'X; X *vs*. N'X (where A and N refer to these features presented in the familiar location used for pre-exposure; and A' and N' refer to these features presented in a new location). Each trial type was presented twice in a random sequence with the restriction that the same trial type could not be presented in subsequent trials. If participants detected any differences between two stimuli in a given test trial, they were instructed to click in the area in which the difference was detected; if they did not detect any differences, they were told to click in the "No changes detected" response box.

RESULTS AND DISCUSSION

Figure 3 displays the average of correct responses during the test trials for the Intermixed and the Blocked groups in the presence of the unique feature A (pre-exposed) and the new unique feature, N, in a familiar (used for pre-exposure) and a new location. A quick inspection of the graph reveals that participants in the intermixed group show a better performance than participants in the blocked condition. While participants in the intermixed group seem to show a significant effect of feature (better detection of the pre-exposed feature A than the new feature N) and location (better detection of the unique features in the familiar than in the new location), participants in the blocked condition show a flat performance, with no effect of feature or location. The levels of response shown by participants in the group Blocked are similar to the performance showed by participants in the different trials in which the features were presented in the location that had been used for blocked pre-exposure in Experiment 1.

An ANOVA with Pre-exposure (Intermixed *vs*. Blocked), Feature (Pre-exposed *vs*. Non-pre-exposed) and Location (Familiar *vs*. New) as factors showed a significant effect of Pre-exposure, $F(1,62)=4.85$, $\eta_p^2=.07$, as well as a nearly significant Pre-exposure x Feature interaction, $F(1,62) = 3.09$, p=0.08, $\eta_p^2=.08$ and a nearly significant Pre-exposure x Location interaction, $F(1,62) = 3.03$, p=0.08, $\eta_p^2=.04$. The remaining factors and interactions were all non-significant (Fs<1).

Further analyses carried out to analyse the Pre-exposure x Feature interaction (Simple Main Effects) showed that, for participants in the Intermixed group, the percentage of correct responses in the presence of the pre-exposed feature A was higher than in the presence of the novel feature N, $F(1, 31) = 4.22$, $\eta_p^2=.12$; for participants in the Blocked group this difference was non-significant, $F<1$. Analyses carried out to analyse the Pre-exposure x Location interaction (Simple Main Effects) showed that, for the participants in the Intermixed group, the percentage of correct responses was higher in the Familiar than in the New location, $F(1,31)=4.92$, $\eta_p^2=.13$; for participants in the Blocked group this difference was non-significant, $F<1$.

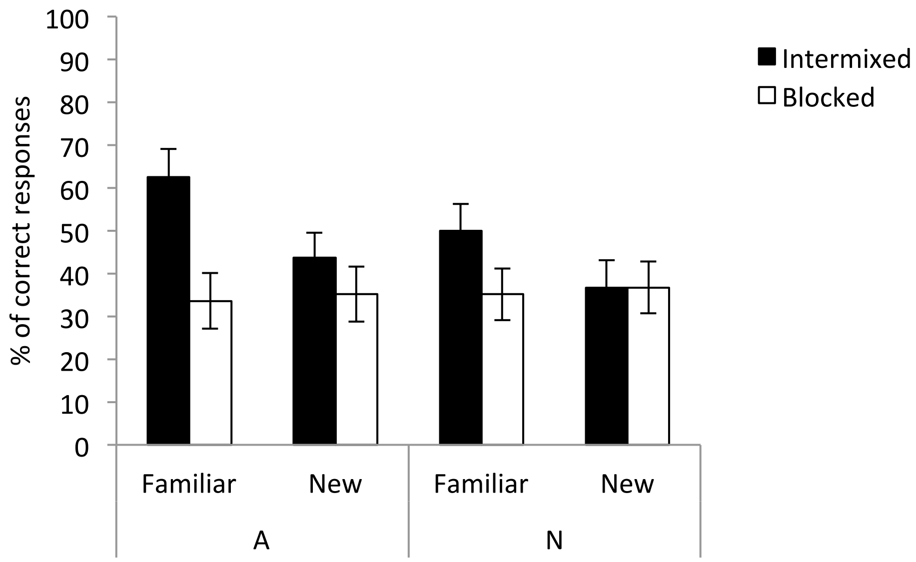

Figure 3. Mean percentage of correct responses (±*SEM*) in the Intermixed and Blocked groups in the presence the unique features A (pre-exposed) and N (non-pre-exposed) presented in a familiar (used for pre-exposure) and a new location.

The present results showed that participants that were given intermixed pre-exposure to AX and X showed a higher percentage of correct responses than participants that were given blocked pre-exposure—the basic intermixed/blocked effect. Furthermore, the data reported in Figure 3 clearly suggest that group Intermixed responded better in the conditions in which a familiar feature or location was present (A-Familiar; A-New; and N-Familiar) than group Blocked, whereas both groups seem to respond in similar ways in the condition in which both the feature and the location were new (N-New). Unfortunately, the relevant interactions (Pre-exposure x Feature and Pre-exposure x Location) were only marginally significant. In spite of this we carried out further analyses to see whether we could substantiate a differential effect of familiarity of the feature and the location in the pre-exposed and blocked groups. The results suggest that blocked pre-exposure affects neither the salience of the intrinsic properties of the unique feature nor its location. In contrast, participants in the group intermixed showed a higher percentage of correct responses in the test trials with A (the pre-exposed feature) than in the test trials with the novel feature N. This result, a case of feature learning, would contrast with the one reported by Wang et al. (2012), and suggests that intermixed pre-exposure enhances rather than reduces the salience of the intrinsic properties of the unique features. Finally, participants in the group intermixed showed a better detection of the unique features when they were presented in the familiar than in the new location, which suggests that as a result of intermixed pre-exposure the location in which the unique feature was presented becomes more attended by the participants, an instance of location learning which replicates the previous findings of Wang et al. (2012), Jones and Dwyer (2013) and the results of Experiment 1.

GENERAL DISCUSSION

The present research aimed to assess the nature of the mechanisms that modulate perceptual learning in humans using a visual task. The results of the group Congruent of Experiment 1 replicated the basic intermixed-blocked effect originally reported by Lavis and Mitchell (2006). The results of the group Incongruent showed that this intermixed-blocked effect was due to an increase in the attention paid to locations were the unique features were presented during intermixed pre-exposure: detection of the unique feature A was very poor when it was presented in a non-attended location (the location occupied by the feature B during blocked pre-exposure); in contrast, participants readily detected feature B when it was presented in the location previously used to pre-expose the unique feature A. This pattern of results strongly suggests that it is the location rather than the intrinsic properties (shape and colour) of the unique feature A what attracts the attention of the participants in the present task. These results replicate those recently reported by Wang et al. (2012, Experiment 3) and Jones and Dwyer (2013) emphasizing the role of location learning during intermixed pre-exposure; and show that blocked pre-exposure does not affect the salience of neither the location nor the feature.

Experiment 1 could not, however, discard the possibility that the salience of the unique feature A (pre-exposed according to an intermixed schedule) could have been subject to changes in salience. There are good reasons to expect intermixed pre-exposure to increase the salience of the unique intrinsic properties of the unique feature: Lavis et al. (2011) showed an advantage in a shape-colour matching task of the intermixed over the blocked pre-exposure procedures, a result which was independent of the location of the features during pre-exposure and test. In the present Experiment 1, even if intermixed pre-exposure increased the salience of the feature A it could be difficult to detect it in the location used for blocked pre-exposure. This location, in which no changes were detected during blocked pre-exposure, might have been explicitly ignored by the participants, making it hard to detect even a highly salient feature. To assess the potential changes in salience of the unique feature A, its detectability should be compared with the detectability of a novel non-pre-exposed feature in familiar and novel locations.

Experiment 2 was designed to assess whether intermixed and blocked pre-exposure modulate the salience of the intrinsic properties (shape and colour) of the unique feature as well as the salience of its location. To do so, we compared the detectability of a pre-exposed feature with the detectability of a novel non-pre-exposed feature, on the one hand, and assessed the ability of our participants to detect a unique feature in familiar and new locations on the other hand. It is generally agreed that blocked pre-exposure reduces the salience of the pre-exposed stimuli (e.g., Hall, 2003; McLaren & Mackintosh, 2000); accordingly, we could expect both the intrinsic properties and the location of the pre-exposed unique feature to attract less attention after blocked pre-exposure than novel (non-pre-exposed) features and locations. In contrast with these predictions, the results of the group given blocked pre-exposure showed no differences between the pre-exposed and the novel feature, on the one hand, and between the familiar and the new location, on the other hand. These results suggest that the location and the intrinsic properties of the unique feature used for blocked pre-exposure remained unnoticed, and therefore unknown to the participants. As a consequence, the blocked condition could be said to be equivalent to a non-pre-exposed control group in this kind of visual perceptual learning task.

The results of the group Intermixed of Experiment 2 should be interpreted with some degree of caution due to the marginal level of signification of the relevant interactions. In spite of the marginally significant Pre-exposure x Location interaction, the analysis of the main effects showed that participants in the Intermixed group detected the unique features (A and N) better in the familiar location used for pre-exposure than in a new location. These results, replicate and extend the data reported by Jones & Dwyer (2013), Wang et al. (2012) and the results of Experiment 1, and can therefore be taken to be a reliable outcome.

The other main result from Experiment 2, indicating a better detection of the pre-exposed than the novel feature is more controversial. Once again the Pre-exposure x Feature interaction showed only a marginal significance; analysis of the main effects, however, showed that participants in the intermixed pre-exposure group detected better the pre-exposed feature A than the novel feature N, strongly suggesting that intermixed pre-exposure increases the salience of the intrinsic properties of the unique feature A. The feature effect observed in Experiment 2 is in conflict with the results observed in Experiment 1, which did not suggest a feature effect (see also Jones & Dwyer, 2013), as well as with those reported by Wang et al. (2012), who observed an advantage of the non-pre-exposed over the pre-exposed feature when they were presented in a novel location.

The main difference between Experiment 1 and 2 is the experimental design (within-subjects in Experiment 1 and between-subjects in Experiment 2). During the pre-exposure phase of Experiment 1, participants were given exposure trials with AX and X in alternation, and with BX in a separate block of trials. In the present Experiment 2 participants were simply exposed to AX and X in alternation. In the experiment reported by Wang et al. (2012, Experiment 3) there were two pre-exposed features (A and B) and two familiar locations (used for the pre-exposure of A and B) as well as two non-pre-exposed features (C and D) and two non-familiar locations. In the present Experiment 2 the design was simplified to one pre-exposed feature (A) and one familiar location; and one non-pre-exposed feature (N) and one non-familiar location. It could be said that the attentional load during the pre-exposure phase in Experiment 1 and in the Wang et al. experiment (it also applies to the Jones & Dwyer, 2013, experiments) was higher than in the present Experiment 2. An increase in the attentional load during pre-exposure might have limited the processing of the relevant unique features during intermixed pre-exposure, resulting in relatively poor representations of these features. In contrast, the Experiment 2 reported here using a simplified pre-exposure procedure might have allowed adequate processing of the feature A which could result in a more accurate representation.

Wang et al. suggested their result could be taken to support the McLaren & Mackintosh (2000) theory of perceptual learning, which by assuming automatic processes of association formation and salience change could predict a decrease in the salience of features pre-exposed according to an intermixed schedule. According to Wang et al. (2012), evidence for these automatic processes could only be obtained by directing the attention of the participants to the locations in which the critical features were presented during pre-exposure. The results of the present Experiment 2, in which attention of the participants was directed to the location in which changes appear in every trial, did not support this hypothesis. As an alternative, participants seem to detect and adequately process the intrinsic properties and the locations of the unique features during intermixed pre-exposure. This could have resulted in the establishment of accurate representations of these stimuli, which could subsequently be used in a top-down attentional process to help discrimination.

A process by which the unique feature properties could be detected and processed has been described by Honey and Bateson (1996) and Mitchell et al. (2008) following the principles of Wagner's SOP model (Wagner, 1981). The detection of the unique feature is likely to occur in the intermixed pre-exposure condition, where there are numerous changes in a particular area of the pre-exposed stimulus. In the blocked pre-exposure condition, where only one change takes place in a particular area, the detection of the unique feature would be very hard. As a consequence, it would be unlikely that the features and locations used in blocked pre-exposure could be accurately represented, and their detectability would not differ from the detectability of other novel locations and features. In the intermixed presentation of AX and X, given that the background stimulus X is presented in every trial, it is likely to be maintained in the periphery of attention (in A2 in Wagner's terminology). Therefore, the background X would suffer short-term habituation, which would prevent its access to the information processor; as a consequence, the background information can be expected to be poorly represented. On the contrary, the unique feature A, which is only presented in every other trial, will receive the majority of the attention (activated in Wagner's A1 state) allowing the establishment of an accurate representation of its intrinsic properties (shape and colour) and location. This representation could be used by a top-down attentional process to detect any differences between the comparison stimuli at the time of test. The results reported here seem to be coherent with this kind of explanation.

To conclude, the present experiments confirm that location learning plays an important role in visual perceptual learning in humans. However, contrary to previous reports which could not find convincing evidence for feature learning, the present Experiment 2 suggests that the salience of the intrinsic properties of the unique feature is improved during intermixed pre-exposure. The nature of the learning mechanisms that improve the salience of the intrinsic properties and the location of the pre-exposed unique feature might very well correspond to the salience modulation mechanism outlined by Honey and Bateson (1996) and Mitchell et al. (2008).

RESUMEN

Aprendizaje perceptivo visual en humanos: Evidencia de aprendizaje de lugar y de contenido. En el Experimento 1, los participantes fueron expuestos a dos estímulos visuales muy similares (AX y X, donde X hace referencia al fondo visual y A se refiere a un elemento único que permite la discriminación entre AX y X) de forma alternada, y a un tercer estimulo (BX) en un bloque de ensayos separado. Durante una fase de prueba se puso de manifiesto que el elemento único A era más fácilmente detectable que el B cuando se presentaban en la misma posición que ocuparon durante la exposición. Sin embargo, cuando se cambiaron las posiciones (A se presentó en la posición ocupada por B durante la exposición y *viceversa*), B se detectó mejor que A. Este resultado sugiere que lo exposición alternada a AX y X incrementa la atención que prestan los participantes a la localización y no al contenido (forma y color) del elemento único. En el Experimento 2, los participantes fueron expuestos a AX y X en alternancia o en bloques; en la prueba se les pidió que detectaran las diferencias entre pares de estímulos que contenían el elemento único A o un elemento nuevo, N, que podían presentarse en la localización familiar (usada durante la exposición) o en un localización novedosa. Los resultados mostraron que la exposición alternada permite una mejor detección del elemento pre-expuesto A (aprendizaje de contenido); y que los dos elementos únicos (A y N) se detectan más fácilmente en la localización familiar que en la localización novedosa (aprendizaje de lugar). Por el contrario, los participantes del grupo de exposición en bloques no mostraron evidencia de aprendizaje de lugar ni de contenido. Los resultados sugieren que los participantes aprenden a atender tanto la localización como el contenido del estímulo único durante la exposición alternada, pero no durante la exposición en bloques.

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(Manuscript received: 15 October 2014; accepted: 7 January 2015)