Perceptual learning with complex visual stimuli is based on location, rather than content, of discriminating features.

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Short Title: LOCATION AND CONTENT IN PERCEPTUAL LEARNING

NOTE: This is a copy of the authors', final peer-reviewed manuscript as accepted for publication in the Journal of Experimental Psychology: Animal Behavior Processes. This article may not exactly replicate the final version published in the APA journal. It is not the copy of record. The final publication is available in the Journal of Experimental Psychology: Animal Behavior Processes, 2013, Vol. 39, No. 2, pages 152–165.

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Abstract

Exposure to complex checkerboards (comprising a common background, e.g. X, with unique features, e.g. A-D, that are placed in particular locations on the background) improves discrimination between them (perceptual learning). Such stimuli have been used previously to probe human perceptual learning but these studies leave open the question of whether the improvement in discrimination is based on the content or location of the unique stimuli. Experiment 1 suggests that perceptual learning produced by exposure to AX and BX transferred to stimuli that had new unique features (e.g. C, D) in the position that had been occupied by A and B during exposure. However, there was no transfer to stimuli that retained A and B as the unique features but moved them to a different location on the background. Experiment 2 replicated the key features of Experiment 1, no transfer of exposure learning based on content, but perfect transfer of exposure learning based on location, using a design which allowed for independent tests of location- and content-based performance. In both the experiments reported here, superior discrimination between similar stimuli on the basis of exposure can be explained entirely by learning where to look, with no independent effect of learning about particular stimulus features. These results directly challenge the interpretation of practically all prior experiments using the same type of design and stimuli.

Keywords: perceptual learning, humans, intermixed, location

Perceptual learning can be defined as a relatively long lasting change to an organism's perceptual system which improves the ability to respond to their environment (Goldstone, 1998). There have been numerous demonstrations, across a variety of stimuli and species, that exposure without explicit training will enhance discrimination between otherwise confusable stimuli (for reviews see, Goldstone, 1998; Hall, 1991). Moreover, the schedule by which stimuli are exposed also influences the development of perceptual learning over and above the amount of exposure. Consider two similar stimuli AX and BX (where A and B refer to their unique elements and X to the elements they have in common): Intermixed exposure (i.e. AX, BX, AX, BX….) will result in superior subsequent discrimination between AX and BX than will the same amount of blocked exposure (i.e. AX, AX, …. BX, BX, ….), and in turn both forms of exposure will support superior discrimination than no pre-test exposure at all (e.g. Honey, Bateson, & Horn, 1994, in chicks; Mundy, Honey, & Dwyer, 2007, in humans; Symonds & Hall, 1995, in rats).

One of the earliest theoretical accounts of this effect was provided by Gibson (e.g. 1963, 1969) who suggested that perceptual learning was due to a process of comparison-driven stimulus differentiation whereby exposure to the stimuli enhanced the effectiveness of the unique features (which distinguish similar stimuli) relative to the common features (which do not). Gibson's suggestion implies that perceptual learning will result in the salience of, and/or the attention towards, the unique features A and B being greater than for the common features X. While Gibson's own presentation of this idea left the mechanisms underpinning stimulus differentiation relatively undefined, there have been numerous subsequent attempts to unpack this process (e.g. Hall, 2003; Mitchell, Nash, & Hall, 2008; Mundy, et al., 2007). Despite the differences in detail between these accounts (and there are many) they all rely on the idea that exposure can by some means produce changes to the relative salience of the unique and common features of the critical stimuli. However, while superior discrimination

following exposure is certainly consistent with the enhancement of the salience the unique features as a result of exposure (in particular intermixed exposure), it is not uniquely so. For example, standard associative principles suggest that intermixed exposure to AX and BX will result in mutual inhibition between the unique features A and B thus reducing generalisation between AX and BX (e.g. McLaren, Kaye, & Mackintosh, 1989; McLaren & Mackintosh, 2000).

One strategy used in the investigation of perceptual learning, and of the mechanisms which underlie it, has been to use stimuli that afford the direct manipulation of their constituent elements. For example, studies of perceptual learning in rats have often used compound flavours where a common element (e.g. sucrose – X) is combined with one of two unique elements (e.g. salt or lemon – A/B) (e.g., Mackintosh, Kaye, & Bennett, 1991). This allows testing of the elements alone as a means of assessing the effects of perceptual learning on those elements themselves, and has provided evidence for both changes in stimulus salience (e.g., Blair & Hall, 2003; Blair, Wilkinson, & Hall, 2004), and for the development of mutual inhibition (e.g., Dwyer, Bennett, Mackintosh, 2001; Dwyer & Mackintosh, 2002). The same strategy has also been used in the study of perceptual learning with complex visual stimuli in humans. In particular, a series of studies (e.g. Lavis & Mitchell, 2006; Mitchell, Kadib, Nash, Lavis, & Hall, 2008; Wang & Mitchell, 2011) used checkerboard stimuli (See Figure 1 for examples) that were created by taking a 20 × 20 grid of multicoloured squares (these were the common features: X) and then adding, to a particular place on the background, features made of blocks of 4-6 squares, consisting one or two colours (the unique features: A/B. The exact details of both the unique and common features differed slightly between experiments). As with the compound flavour stimuli, these compound visual stimuli allow for the separate analysis of the unique stimuli, and such analyses have suggested, amongst other things, that intermixed exposure to such checkerboards results in

better memory for the unique features than does blocked exposure (Lavis, Kadib, Mitchell, & Hall, 2011) and that people fixate on the unique stimuli more after intermixed exposure than otherwise (Wang & Mitchell, 2011: c.f. Wang, Lavis, Hall, & Mitchell, 2012).

Taken at face value, this series of studies has provided a rich vein of information regarding the nature of perceptual learning and the constraints under which it develops. However, there is at least one good reason to think experiments using these stimuli may be far less informative than has been supposed. That is, the unique features A/B always appear in the same place on the background X, and so any exposure-dependent influence on the discriminability of AX and BX might reflect learning about the content of those unique features (e.g. a learnt change in their salience) or about their location (e.g. learning where to look for discriminating features). To labour the point, the perfect correlation between the content of a unique feature (e.g. its colour or shape) and its location (i.e. where it appears on the background X), means that it is impossible to ascertain the relative contributions of these aspects of the unique stimuli to the learning effects observed. For example, the fact that people fixate on the unique features A and B after intermixed exposure (Wang & Mitchell, 2011) may be due to these features being particularly salient and thus able to attract attention or it may be due to people attending to the location where the critical differences occurred. The correlation between content and location is particularly problematic because the theoretical analyses of perceptual learning noted above are all silent with respect to the location of unique features and instead are expressed in terms of the effects of exposure on the content and relationship between these features.

It should be noted that are a two studies that give some suggestion as to what might happen if this correlation were broken. Lavis and Mitchell (2006) used checkerboards in which all 400 of the squares in the 20 × 20 grid were coloured and unique features A and B were identical in content, but differed only in location. Despite there being no difference in

the content of the A/B features exposure to AX and BX improved subsequent discrimination (relative to control conditions using novel stimuli) and intermixed exposure produced better discrimination than did blocked exposure. The similarity of results to experiments where A/B did differ in content suggests that differences in the location of a unique stimulus, in the absence of differences in content, are sufficient to support perceptual learning. Such a result raises the possibility that the improvements in discrimination prompted by exposure to these checkerboard stimuli depends on learnt changes in where to look for discriminating features, rather than learning about the content of those features themselves. However, a closer consideration of the stimuli used by Lavis and Mitchell (2006) suggests an alternative possibility. As all squares on the background were coloured, different patterns would be obscured/revealed as the unique feature was moved from place to place on the background. That is, although the explicitly manipulated feature had the same content at two different locations, the underlying parts of the background differed at these points so there were some content differences between AX and BX. More recently, in Experiment 3 of Wang et al. (2012) it was found that after exposure to AX and BX, eye gaze during test is directed to the location at which A and B appeared during training, regardless of whether the exposed features A and B, or novel features C and D, were present at these locations. Moreover, discrimination performance with both novel and exposed features was better when they appeared at the location at which A and B were presented during initial exposure than when they appeared elsewhere. Taken together, these demonstrations raise the possibility that people can learn about location rather than just about content, but leave open the question about whether anything that is learnt about content influences discrimination performance at all.

Therefore, the main aim of the current studies was to break this perfect correlation between content and location and to begin to assess their relative contributions to perceptual

learning. We approached this by examining whether exposure-produced improvements in the discrimination of stimuli that differed in both the content and location of the unique features would transfer to test stimuli that used either the same unique content (but at a different location) or different unique content (but at the same location).

Experiment 1

Experiment 1 examined whether learning based on exposure to stimuli that differed in the content and location of unique features would transfer to stimuli for which only one of the content or location was maintained from the exposure phase. Figure 1 shows examples of the stimuli used and Table 1 summarizes the design. All participants were exposed to stimuli which differed in terms of the content and location of the unique features (see Figure 1A): For example, one unique feature (A) was added to the top left of the background (X) and a second unique feature (B) was added to the top right. At test, all participants were tested with these exposed stimuli (the Exposed condition). All participants were also tested with stimuli containing two novel unique features, C and D, that were presented at the same location as A and B had appeared in during the exposure phase (the Location Same condition: See Panel B of Figure 1). If the content of unique features is critical to what is learnt during exposure, then performance in the Exposed condition will be superior to that in the Location Same condition. However, if learning where to look for differences between stimuli is sufficient to support exposure effects, then performance in these two conditions will be equivalent. Finally, all participants were tested with stimuli where the unique features appeared in different places from that in which A and B were presented during the exposure phase (the Location Different condition). For half of the participants, these test stimuli used the previously exposed unique features (A and B) but in a different location (See Panel C of Figure 1 – Location Different-Content Same), while for the remainder of the participants, the

test stimuli used novel unique features (E and F: See Panel D of Figure 1 – Location Different-Content Different). For the purposes of description, the participants receiving the Location Different-Content Same condition will be referred to as the Location Different-Content Same group, while the participants receiving the Location Different-Content Different condition will be referred to as the Location Different-Content Different group (although both groups also received trials in the Exposed and Location Same conditions).

If the exposure to the unique features supports perceptual learning, regardless of location, then performance in the Location Different-Content Same condition will be superior to performance in the Location Different-Content Different. However, if exposure effects are entirely determined by learning where to look for differences, with no independent contribution of the content of those differences, then discrimination performance in these conditions will be equivalent. It is important to note that some of these hypotheses suggest that there will be no difference between treatment conditions. Standard null hypothesis tests are unable to assess whether the absence of a significant difference between conditions supports the hypothesis that there is truly no difference between them. To address this issue, Bayesian analysis will be implemented as a means as assessing the relative strength of the evidence for the accepting or rejecting the null (for a discussion, see Rouder, Speckman, Sun, Morey & Iverson, 2009).

Method

Participants

Participants consisted of 24 undergraduate students, between the ages of 18 – 24. They were recruited from the School of Psychology at Cardiff and participated in return for course credit.

Apparatus and stimuli

Two sets of stimuli were used in this experiment, each with a distinct common background (X and Y), to which two sets of distinct unique features were added (A-F for background X and G-L for background Y: comparison of Panels A and E in Figure 1 illustrates these differences). These two entirely separate sets of stimuli allowed each subject to run through the basic exposure/test procedure twice (see below).

Stimuli consisted of 20 x 20 colour checkerboards. All had one common element, X or Y, created by colouring 156 of the 400 squares (blue, green, purple, red, or yellow on X; blue, green, pink, purple, and orange on Y). The remaining squares were grey (for X this grey was lighter than the background which filled the remainder of the screen, and for Y it was darker than the surround). Thus the common elements X and Y differed in the colour, pattern, and placement of the grey and coloured squares. Unique features (A-F and G-L) were added by changing six adjacent blocks of grey squares to two of the brighter colours. Each unique feature differed from all others in colour and shape. These unique features could be added to the backgrounds in one of six locations (roughly top middle and bottom or left or right).

The stimuli were presented centrally on a 17 inch monitor with standard pixel height and width 576 x 576, subtending an approximate visual angle of 22.5° x 22.5°. DirectRT software was used to control the presentation of the stimuli on a PC. The area of the screen surrounding the checkerboard stimuli was a mid-grey, equidistant in lightness between the background greys of stimulus X and Y. A black border separated the checkerboard from the remainder of the screen. The individual squares within the checkerboard were not separated with any border.

Design and procedure

The key test phase involved participants making same/different judgements under multiple conditions which might undermine any transfer of perceptual learning from the

exposure to the test phase. Thus, to familiarise them with the general procedures, all participants were given a practice run through the exposure/test procedure. Each of the two background patterns (X/Y) and each of the unique feature sets (A-F/G-L) were used equally often across participants. The feature sets were assigned to conditions in pairs (e.g. A/B, C/D, E/F) such that each pair was used equally often as the exposed or novel pair (with one pair from the set not being used). In this phase the application of the unique stimuli to the backgrounds was constrained such that A/B (or G/H) were applied to the top left or right of the background, C/D (or I/J) were applied to the middle left or right, and E/F (or K/L) applied to the bottom left/right. Participants showed the typical advantage for discriminating exposed over novel stimuli in this practice phase so its results will not be mentioned further here.

Following the practice example all participants received a second phase of intermixed exposure in which two checkerboards were presented in alternation 60 times each. This used the set of stimuli that had not been seen in the practice run (that is, new unique features, common background, and exposure locations). As noted in Table 1, after the exposure phase participants were given a same-different discrimination task. Half the participants received test trials in three conditions: with the same stimuli as in the exposure phase (the Exposed condition, see Figure 1A), with new unique features placed in the same positions as the unique features from the exposure phase (the Location Same condition, see Figure 1B), and with the same unique features from the exposure phase but in a new location (the Location Different-Content Same condition, see Figure 1C). The other half of the participants also received test trials in which the location of the critical stimuli was different, but in this case the content was also different (the Location Different-Content Different condition, see Figure 1D) – these participant also received the Exposed and Location Same conditions as described above. The unique feature set and common background not used in the practice phase were used here. For participants in the Location Different-Content Same group, the feature sets

were assigned to conditions in pairs (e.g. A/B, C/D, E/F) such that each pair was used equally often in the Exposed and Location-Same/Location-Different conditions (with a third pair not presented for each participant). For participants in the Location Different-Content Different group, the feature sets were assigned such that each pair was used equally often in the Exposed, Location-Same, and Location Different conditions. The location of the stimuli was constrained such that the general region of the background where novel stimuli appeared in the practice phase was used as the location for the Exposed condition and the stimuli in the Location Different conditions were presented at the unused set of locations from the practice phase. Therefore, across participants, the assignment of stimuli was counterbalanced such that each of the unique features (A-L), each of the possible locations (top, middle, and bottom on right or left), and each of the two background patterns (X and Y) was used equally often for all conditions.

The test phase comprised three blocks of 30 trials each. Within each block there were 10 trials from each of the test conditions (5 same and 5 different). The order of trials was randomised within a block and participants were allowed to rest between blocks.

At the start of the experiment, participants were sat approximately 60cm from the computer screen and presented with a set of standardised instructions:

> *"You will be exposed to a set of checkerboards. Pay attention to the stimuli, any stimulus differences will be useful later in the experiment. During exposure, please press the space bar to proceed from one trial to the next. If there are any questions please ask the experimenter now. If there are no questions press the space bar to begin."*

During the exposure phase, each stimulus was presented 60 times, for 470ms each trial. The two exposed stimuli were presented in strict alternation (e.g. AX, BX, AX, BX,….). Each stimulus presentation was followed by a blank grey screen, during which

participants made their space bar presses. Regardless of a space bar press, the following trial was initiated 2000ms after the offset of previous stimulus.

Following the completion of the exposure phase, a second set of instructions were displayed in the same manner as the first. Participants were informed that they would be presented with a succession of pairs of checkerboards, one stimulus at a time. They were told to press the "Z" key if the two stimuli appeared the same and the "/" key if the stimuli appeared different. This instruction remained on screen throughout the test period. On every discrimination trial the first stimulus was presented for 800ms, followed by a blank screen for 550ms before the presentation of the second stimulus for 800ms. A white square was displayed at the interval between trials; this remained on screen for 1400ms after a response had been made, the next trial then commenced. Both the practice and experimental runs used the same instructions and general procedures with participants given the opportunity to rest between runs.

Statistical analysis

The data were examined in terms of proportion of correct same/different judgments (as has been typical with previous experiments of this type) as well as with a signal detection analysis. Sensitivity scores, *d'*, for each participant were calculated by treating hits as the proportion of correct responses given on different trials and false alarms as the proportion of incorrect responses to same trials (i.e. respond "different" when the two images were actually the same). Factorial ANOVA procedures were used to assess the output of both the proportion correct and *d'* data. A significance level of $p < .05$ was set for all analyses.

As noted above, Bayesian analyses were also conducted as a means of assessing the strength of empirical support for the hypothesis that two conditions do not differ. Standard significance testing only assesses how unlikely the observed data is given the assumption of the null hypothesis. As such, it does not provide a direct assessment of whether the absence

of a significant difference can be taken as positive evidence for there being no true difference between conditions. In contrast, Bayesian tests are based on calculating the relative probability of the null and alternative hypotheses, and thus afford the assessment of whether the evidence is in favour of either the null or alternative hypothesis. That is, the Bayes factor (denoted as B_{01}) relates to the probability that the null is true to the probability that the alternative is true given the data observed. Our analysis was performed using the web-based calculator (http://pcl.missouri.edu/) utilising the Jeffreys-Zellner-Siow (JZS) prior because it makes the smallest amount of assumptions regarding the prior distribution (Rouder et al., 2009). The calculation of the Bayes factor requires the specification of an effect size for the alternate hypothesis (although the exact value has relatively little influence on the output of the calculations). The suggested default for this is that the manipulation will produce a difference of one standard deviation between the treatment and control means. While the beneficial effect of exposure on perceptual learning effect is well established, it is difficult to justify which particular demonstration or demonstrations of perceptual learning should be used to set the expected effect size for the current studies. Therefore, in the analyses reported here, we based the specified effect size on the observed difference between Exposed and Novel conditions in each experiment (this gave values of 0.83 in Experiment 1 and 0.52 in Experiment 2). Using these values, which were less than the suggested default, gave a more conservative estimate of whether the absence of a difference between two conditions genuinely supported the conclusion that there was indeed no effect (Rouder et al., 2009). While there are no published algorithms for factorial ANOVA procedures, the key theoretical questions in the current paper can generally be reduced to t-tests equivalent to the comparisons between two groups or conditions, in which case paired or unpaired Bayes t-tests were performed as appropriate. Results are treated as either supporting the null or alternative (or neither) by adopting the convention suggested by Jeffreys (1961) and

recommended by Rouder et al. (2009): A Bayes factor of above 3 suggests there is some evidence to support the null hypothesis, while a factor of 10 indicates strong evidence for the null. Equally, a factor less than 1/3 suggests some evidence for the alternative and less than 1/10 indicates strong evidence favouring the alternative. Any value between 1/3 and 3 constitutes a lack of evidence in support of either the null or alternative.

Results and discussion

Figure 2 shows the test data as mean sensitivity scores (*d'*) for the three test conditions (Exposed, Location Same, and Location Different), as a factor of Group (Location Different-Content Same on the left, Location Different-Content Different on the right). Inspection of the figure suggests that performance was equivalent in the Exposed and Location Same conditions, and both of these were superior to the Location Different conditions. The pattern of results that is similar between the Location Different-Content Same and Location Different-Content Different groups for the test conditions. The test data was analysed with a mixed ANOVA with a between subject factor of Group (Location Different-Content Same or Location Different-Content Different), and within-subject factors of test condition (Exposed, Location-Same, or Location-Different). Analysis of the *d'* scores showed a main effect of test condition, $F(2,44) = 37.84$, $p < .001$, MSE = .941. Simple effects analyses revealed that the Exposed and Location-Same conditions did not differ from each other (Exposed vs. Location Same, $F < 1$, $B_{01} = 4.452$) and that both of these conditions resulted in higher *d'* scored than the Location-Different conditions (Exposed vs. Location-Different, $F(1,22) = 50.90$, $p < .001$, MSE = 2.265, $B_{01} < .001$, Location-Same vs. Location-Different, $F(1,22) = 56.78$, $p < .001$, MSE = 1.721, $B_{01} < .001$). That is, discrimination performance was equivalent for the exposed stimuli and for stimuli that had novel unique features appearing in the same place as the unique features of the exposed stimuli.

Discrimination performance in both these conditions was superior to the test stimuli that had unique features in a different place to that of the exposed stimuli. There was no main effect of Group, nor any interaction involving this factor, largest $F(1,22) = 2.36$, $p = .106$, MSE = .459, for the test condition by group interaction. This is not particularly surprising because the test trials for the Exposed and Location Same conditions were the same in the Location Different-Content Same and Location Different-Content Different groups (albeit that the accompanying test trials were different, and so the Location Different-Content Same and Location Different-Content Different groups differed in the number times that the exposed unique features appeared in the test phase). Critically, there was no hint of a significant difference between the Location Different-Content Same and Location Different-Content Different groups for the Location Different condition ($F < 1$, $B_{01} = 5.189$), despite the fact that in the Location Different-Content Same group the stimuli tested had the same unique features as the Exposed condition, while for the Location Different-Content Different group the unique features were novel.

Panel B of figure 2 displays the mean proportion of correct responses as a factor of Group (Location Different-Content Same and Location Different-Content Different) and test condition (Exposed, Location-Same, or Location-Different) and test trial type (Same or Different). Inspection of the figure suggests that performance was generally higher on same trials than for different trials, and differences between conditions were larger and more apparent on the different trials. Analysis of the proportion data found a main effects of test trial type, $F(1,22) = 16.17$, $p = .001$, MSE = 0.054, test condition, $F(2,44) = 42.33$, $p < .001$, MSE = 0.028, and an interaction between them, $F(2,44) = 21.56$, $p < .001$, MSE = 0.036. Simple effects analyses of the interaction revealed effects of test condition on the different trials (Exposed vs. Location-Same, $F < 1$ $B_{01} = 4.384$, Exposed vs. Location-Different, $F(1,22) = 39.79$, $p < .001$, MSE = 0.156, $B_{01} < .001$, Location-Same vs. Location-Different,

$F(1,22) = 40.91$, $p < .001$, MSE = 0.135, $B_{01} < .001$). There were also some differences between conditions on the same trials (Exposed vs. Location Same, $F < 1$, $B_{01} = 2.624$, Exposed vs. Location-Different, $F(1,22) = 4.56$, $p = .044$, MSE = 0.018, $B_{01} = .529$, Location-Same vs. Location-Different, $F(1,22) = 3.49$, $p = .075$, MSE = 0.015, $B_{01} = .864$). There was no main effect of Group, nor any interaction involving this factor, largest $F(1,22) = 1.32$, $p = .236$, MSE = 0.054, for the trial type by group interaction. Like the *d'* analysis there was no hint of a difference between the Content-Change and Content-Consistent groups for the Location Different condition ($F < 1$ for both same $B_{01} = 3.843$ and different trials $B_{01} = 4.859$).

Before moving to the implications of these results, it is worth noting that the observation here that performance was generally better on same than different trials is entirely consistent with previous investigations using these types of stimuli (e.g., Lavis & Mitchell, 2006; Mitchell, Kadib, et al., 2008; Mitchell, Nash, et al., 2008). Presumably, this effect of trial type represents a bias to report that the two stimuli presented on each test trial were the same which might be attributable to how difficult the stimuli are to discriminate as the bulk of them comprises the same common background (Lavis, et al., 2011). Moreover, our observation that the effects of exposure were largely restricted to the different test trial types is also consistent with previous observations.

In summary, discrimination between stimuli that had novel unique features was equivalent to discrimination between exposed stimuli as long as the novel features appeared at the same location as the unique features that had been present in the exposed stimuli. Moreover, discrimination between stimuli that had the exposed unique features at a different location than that at which they appeared during initial exposure was no better than was discrimination of entirely novel stimuli. That is, the improvement in discrimination produced by exposure transferred entirely to novel content at the exposed location, but not at all to the exposed content at a novel location. These conclusions are unaffected by whether the data

was examined as *d'* or proportion correct, and the interpretation supported by standard null hypothesis testing was bolstered by Bayes factor analyses indicating that the absence of significant differences between particular conditions does genuinely reflect evidence in favour of true absences of effects.

Experiment 2

While the results of Experiment 1 are certainly consistent with the idea that perceptual learning with the current stimuli is entirely determined by learning where to look for the critical differences, rather than learning about what those differences are, there are two aspects of that experiment that might have led to it providing an underestimate of learning about the content of the unique features. Firstly, the comparison of transfer to exposed features at a new location to a totally novel control was between-subject, while the examination of transfer based on location was within-subject. To the extent that between-subject comparisons are less powerful than within-subject comparisons then Experiment 1 might have underestimated the former effect. Secondly, the fact that test trials examining content- and location-based transfer were intermixed puts these two effects into direct competition as any tendency to attend to a particular location would reduce the ability to detect the exposed features when they appeared at a different location[1]. Moreover, for two thirds of the test trials, the critical unique features (either exposed or novel) appeared at the same locations used for the exposed stimuli during exposure, and only one third of the test trials used new locations. The preponderance of trials using this exposed location might have further enhanced any tendency for participants to focus on location to the exclusion of content. While the fact that there was no hint of content-based transfer and there was

[1] A similar issue is present in the test trials of Experiment 3 of Wang et al. (2012).

excellent location-based transfer leaves the relative importance of the two effects in no doubt, the complete absence of content-based learning with these stimuli remains to be established.

The design of Experiment 2 (see Table 2) addressed these issues by examining location and content based transfer in separate groups of participants. All participants received two exposure/test runs, in both of these participants were exposed in an alternating fashion to a pair of checkerboards with unique features which differed in both location and content (as in Panel A of Figure 1). In one run (Exposed conditions) all participants then received a same/different test phase with these exposed stimuli (Exposed), as well as with stimuli that had different unique features in different locations on the same common background (Exposed-Control). For participants in Group Same-Content-Different-Location, the other run (Transfer conditions) involved a same/different test phase with stimuli that retained the same unique feature content as seen in the exposure phase, but moved to a different location (Transfer). There were also test trials with stimuli that had novel unique features in different locations on the same common background (Transfer-Control). For participants in the Group Same-Location-Different-Content, the Transfer conditions involved a same/different test phase with stimuli that changed the unique feature content from the exposure phase, but retained the location (Transfer). There were also test trials with stimuli that had novel unique features in different locations on the same common background (Transfer-Control). In short, the experiment comprised a within-subject manipulation of whether the test stimuli had been exposed in any fashion (Exposed & Transfer vs. Exposed-Control & Transfer-Control) and a within-subject manipulation of whether the test stimuli were exactly the same as in the exposure phase or not (Exposed vs. Transfer). Whether the Transfer conditions maintained the content or location of the exposed unique features was assessed in separate groups (Same-Content-Different-Location vs. Same-Location-Different-Content). By assessing the transfer of learning based on content and location in separate

participants and sessions, this design avoided the direct competition between attending to location and content that may have been present in previous studies.

If the results from Experiment 1 are reliable then in Group Same-Location-Different-Content the difference in performance on the discrimination task between the Exposed and Exposed-Control conditions should be the same as that between the Transfer and Transfer-Control conditions. In contrast, Group Same-Content-Different-Location should only show a difference in discrimination between the Exposed and Exposed-Control conditions, but not show any difference between the Transfer and Transfer-Control conditions. That is, there should be transfer based on location, but not the content, of unique features.

Method

Participants Apparatus and stimuli

Participants consisted of 48 undergraduate students, between the age of 18 and 25, recruited from the School of Psychology at Cardiff University. They received course credit in return for their participation.

Stimuli consisted of 20 x 20 colour checkerboards created as in Experiment 1 that were presented using the same equipment as described previously.

Design and procedure

All participants were given a two runs through an exposure/test sequence. Participants followed the same instructions as those in Experiment 1 during both runs. The basic exposure and test procedures/timings were as outlined in Experiment 1 so only the differences are noted here.

In each run, participants were exposed to a pair of checkerboards that shared a common background (X in one run and Y in the other), and were distinguished by unique features that differed in both content and location. As outlined in Table 2, during one of the

Exposure/Test runs, the same/different discrimination task consistent of trials with exactly the same stimuli as in exposure, plus novel controls (these used the same common background, but had new unique features presented at a new location). This comprised the "Exposed" conditions. During the other run, the same/different discrimination task consistent of trials with stimuli that shared some aspect of the exposed stimuli, plus novel controls (these used the same common background, but had new unique features presented at a new location). This comprised the "Transfer" conditions. For half of the participants (Group Same-Content-Different-Location), the transfer test stimuli retained the content of the unique features from exposure, but moved them to a new location. For the remaining participants (Group Same-Location-Different-Content), the transfer test stimuli retained the location of the unique features, but changed the content. The test phase for each of the two runs comprised two blocks of 40 trials each. Within each block there were 10 trials from each of the test conditions (5 same and 5 different). Within each block trial order was randomised. Between blocks participants were able to pause before continuing by pressing the spacebar (there was also an opportunity to pause mid-way through each block).

The presentation order of the Exposure and Transfer runs was counterbalanced so that half participants were given the transfer run first, and the other half of participants were given the exposure run first. Within these groups, each of the two background patterns (X/Y) and each of the unique feature sets (A-F/G-L) were used equally often in the Exposure and Transfer runs. For the Exposure run, the feature sets were assigned to conditions in pairs (e.g. A/B, C/D, E/F) such that each pair was used equally often as the exposed or novel pair (with one pair from the set not being used for each participant). In the Same-Location-Different-Content group, the remaining feature sets were assigned to conditions in pairs (e.g. G/H, I/J, K/L) such that each pair was used equally often as the transfer-exposed, transfer-test, or transfer control stimuli. In the Same-Content-Different-Location group, these

remaining features were assigned such that each pair was used equally often as transfer-exposed or transfer-control stimuli (with one pair from the set not being used for each participant). The locations at which the unique features appeared were assigned such that each set of locations (top, middle, bottom, on left and right) was used equally often across participants for the Exposed condition, with the Exposed-Control stimuli appearing equally frequently at one of the other two locations. The exposure phase of the Transfer run stimuli always appeared at the locations not used in the Exposure run. During the test phase, in the Same-Content-Different-Location group, the Transfer, and Transfer-control stimuli appeared in the other two locations with equal frequency (thus for half the participants the Transfer-control stimuli appeared where the Exposed stimuli were placed and for the other half the Transfer-Control stimuli appeared where the Exposed-Control stimuli were placed). In the test phase, in the Same-Location-Different-Content group, the Transfer-Control stimuli appeared equally often in either the location where the Exposed, or Exposed-Control stimuli were placed. Therefore, across participants, the assignment of stimuli to condition ensured that each of the common backgrounds (X or Y), each of the unique features (A-L), and each of the possible locations (top, middle, and bottom on right or left) was used equally often for all conditions. Moreover, the assignment of locations was constrained such that for half of the participants attending to the same location in each of the Exposure and Transfer runs would assist performance in the second run, and for half of the participants it would hinder performance in the second run[2].

Results

[2] An initial analysis of the data indicated that there were in fact no carry-over effects of this type, and thus test order was not included in the reported analyses.

Figure 3 displays mean sensitivity score (*d'*) as a factor of Group (Same-Content-Different-Location on the left, Same-Location-Different-Content on the right), stimuli type (Exposed/Transfer vs. Control), and test trial type (same/different). Turning first to the Same-Content-Different-Location Group, performance was greater in the Exposed than Exposed-Control condition, but there was little or no difference between the Transfer and Transfer-Control conditions. In contrast, for the Same-Location-Different-Content Group, the difference between Exposed and Exposed-Control was equivalent to the difference between Transfer and Transfer-Control conditions.

This data was initially subjected to a mixed ANOVA with a between subjects factor of group (Same-Content-Different-Location or Same-Location-Different-Content), and within subject factors of transfer condition (Exposed or Transfer), and exposure treatment (Exposed/Transfer vs. Control). Consistent with the description of the results above, there was a 3-way interaction between group, transfer condition, and exposure condition, $F(1,46) = 10.94$, $p = .007$, MSE = 1.395, indicating that the relative size of the Exposed vs. Exposed-Control and Transfer vs. Transfer-Control differences was influenced by whether the transfer conditions were content- or location-based. In order to explore the different effects of content or location-based transfer indicated by these interactions, separate 2-way ANOVAs were performed for each of Group Same-Content-Different-Location and Group Same-Location-Different-Content.

Taking first the Same-Content-Different-Location group, the most theoretically important result was the significant interaction between transfer condition and exposure condition, $F(1,23) = 13.04$, $p = .004$, MSE = 1.239, (which demonstrates that discrimination was better in the exposed than transfer conditions). Simple effects analyses of the interaction revealed that there was a difference between Exposed and Exposed-Control, $F(1,23) = 19.41$, $p < .001$, MSE = 0.147, $B_{01} = .008$, but there were no differences between Transfer and

Transfer-Control, Fs < 1, B_{01}= 3.077. That is, discrimination between stimuli that shared their unique features with exposed stimuli but with these unique features appearing at a new location was no better with stimuli that had entirely novel unique features. The remainder of the ANOVA revealed that a significant effects of exposure $F(1,23) = 11.082$, $p = .003$, MSE = 1.959 and that the effect of transfer condition approached standard levels of significance, $F(1,23) = 3.85$, $p = .062$, MSE = 1.331.

Turning to the Same-Location-Different-Content group, the key results here were there was a significant effect of exposure, $F(1,23) = 11.70$, $p = .002$, MSE = .944, but that there was no effect of transfer condition, $F<1$, and critically there was no significant interaction between exposure condition and transfer condition, $F<1$. That is, discrimination of novel control stimuli was worse overall than for the Exposed/Transfer conditions combined, and there was no difference in discrimination performance between Exposed and Transfer conditions. In order to match the analysis performed on the Same-Content-Different-Location group we also examined the simple effects for the interaction (even though this was not significant here): The difference between Exposed and Exposed-Control approached standard levels of significance, $F(1,23) = 3.02$, $p = .095$, MSE = 0.138, B_{01}= 1.073, while the difference between Transfer and Transfer-Control reached standard levels of significance, $F(1,23) = 5.82$ $p = .024$, MSE = 0.070, B_{01}= .390. That is, discrimination between exposed stimuli was entirely equivalent to that with stimuli that had novel unique features which appeared in the same location to those of the exposed stimuli (albeit that discrimination in both of these conditions was numerically smaller than that in the Same-Content-Different-Location group).

Panel B of Figure 4 displays the proportion of correct responses. As has been seen previously, performance was generally better on same than different trials, with differences between conditions carried largely by the different trials. This data was again subjected to a

mixed ANOVA with a between subjects factor of group (Same-Content-Different-Location or Same-Location-Different-Content), and within subjects factors of transfer condition (Exposed or Transfer), exposure treatment (Exposed/Transfer vs. Control), and, in this analysis, test trial type (Same or Different). Analysis of the proportion data suggested a similar pattern of results to the sensitivity analysis. Like the sensitivity analysis there was a 3-way interaction between group, transfer condition, and exposure condition, $F(1,46) = 6.79$, $p = .012$, MSE = 0.052, indicating that proportion scores followed a similar trend to the previous analysis. There was also a significant 4-way interaction, $F(1,46) = 4.72$, $p = .035$, MSE = 0.050, which is consistent with the 3-way interaction being driven by performance on the different trials. The remainder of the 4-way ANOVA will not be reported further.

Returning first to the Same-Content-Different-Location group there was a significant interaction between transfer condition and exposure condition, $F(1,23) = 10.27$, $p = .004$, MSE = 0.046 (which demonstrates that discrimination was better in the exposed than transfer conditions), and the interaction between test trial type, transfer condition and exposure condition, $F(1,23) = 11.55$, $p = .002$, MSE = 0.048 (which suggests that the previous interaction was largely carried by the different trials). Simple effects analyses of the three-way interaction revealed that there was a difference between Exposed and Exposed-Control for different trials, $F(1,23) = 23.35$, $p < .001$, MSE = 0.007, $B_{01} < .001$, but not for same trials, $F < 1$, $B_{01} = 1.647$. There were no differences between Transfer and Transfer-Control on either same, $F < 1$, $B_{01} = 1.611$, or different trials, $F < 1$, $B_{01} = 3.784$. That is, discrimination between stimuli that shared their unique features with exposed stimuli but with these unique features appearing at a new location was no better with stimuli that had entirely novel unique features.

For the Same-Location-Different-Content group, the key results here were that there was a significant effect of exposure, $F(1,23) = 8.21$ $p = .009$, MSE = 0.034, but that there was

no significant effect of transfer condition, $F < 1$, and critically no interaction between transfer condition and exposure, $F < 1$, nor any other significant interaction involving transfer condition (largest $F(1,23) = 1.12$, $p = .291$, MSE = 0.034, for the interaction between transfer condition and test trial type). In order to match the analysis performed on the Same-Content-Different-Location group, in both the sensitivity and proportion analysis, we also examined the simple effects interaction (even though this was not significant here): The difference between Exposed and Exposed-Control for different trials approached standard levels of significance, $F(1,23) = 4.03$, $p = .057$, MSE = 0.004, $B_{01} = .757$ but not for same trials, $F(1,23) = 1.57$, $p = .223$, MSE = 0.001, $B_{01} = 1.170$. The difference between Transfer and Transfer-Control for different trials approached standard levels of significance, $F(1,23) = 3.06$, $p = .094$, MSE = 0.008, $B_{01} = 1.094$, but not for same trials, $F(1,23) = 1.29$, $p = .268$, MSE = 0.001, $B_{01} = 1.248$. Again, discrimination between exposed stimuli was equivalent to that with stimuli that had novel unique features which appeared in the same location to those of the exposed stimuli.

Discussion

In summary, after training with stimuli that differed in both the content and location of the unique features, performance on the transfer test was determined by whether this involved the exposed content at a new location (Same-Content-Different-Location Group) or new content that was presented at the same location (Same-Location-Different-Content Group). Performance with exposed stimuli was superior to performance due to content-based transfer, with no evidence of any difference between the Transfer and Transfer-Control conditions for the Same-Content-Different-Location Group. As in Experiment 1, Bayes factor analyses supported the view that this lack of significant difference genuinely supports the idea that there was no content-based transfer. In contrast, performance due to location-

based transfer was no different from performance with the exposed stimuli. While the simple effects analyses of the Transfer and Transfer-Control conditions for the Same-Location-Different-Content Group offer only equivocal support for the presence of a location-based transfer (as these were significant for the *d'* analysis but only approached standard significance levels for the proportion correct analysis), it should be remembered that there was no difference in the size of the exposure and location-based transfer effects in this experiment (if anything, the transfer effects were bigger), and that in Experiment 1 very reliable location based transfer effects were observed.

Therefore, the discrimination phase of Experiment 2 replicated the key findings from Experiment 1. That is, exposure dependant improvements in discrimination ability transferred to new test stimuli when novel unique features of the to-be-discriminated stimuli appeared in the same location as the unique features of the exposed stimuli. However, when the to-be-discriminated maintained the same unique features, but presented them at a new location, there was no transfer of the exposure dependant improvements in discrimination.

General Discussion

The two experiments reported here examined the ability to discriminate between checkerboard stimuli made similar by placing unique features on a common background. In Experiments 1 and 2, the improvement in discrimination performance produced by exposure to stimuli that differed in the content and location of the unique features transferred entirely to stimuli that had new unique features in the same location as the unique features of the exposed stimuli. In contrast, there was no suggestion of any transfer of exposure-produced improvement in discrimination performance when the unique features of the exposed stimuli were moved to a different location. The fact that the content of unique features was unable to support any transfer of exposure learning, but that the location of those unique features

supported complete transfer of learning is entirely consistent with the improvements in discrimination on the basis of exposure being due entirely to participants learning where to look (at least with the type of stimuli examined here).

In one sense, the idea that attention to particular regions of these checkerboard stimuli is critical to performance is somewhat unsurprising. Indeed, Wang and Mitchell (2011) have clearly demonstrated that participants look to the location where exposed unique features appear – even when those features are absent on a given trial. Moreover, in Experiment 3 of Wang et al. (2012) this tendency to look at the location where the exposed features appeared was maintained even when novel features appeared in those places. However, while providing evidence that participants have learnt the location of the unique features of the exposed stimuli, examining gaze direction in this manner does not assess whether they have genuinely learnt nothing about the content of those features at all. Wang et al. (2012) also observed that discrimination accuracy was higher during test when unique features appeared in the location of the trained unique features, regardless of whether those test features had been exposed or were novel. This is certainly consistent with the idea that subjects learn more about location than content, but, again, it does not directly assess whether there was no content-based learning at all. One reason for this is that there was no analysis in Wang et al. (2012) of whether the absence of a significant effect of content exposure genuinely supports the absence of such an effect (such as using the Bayes factor analysis as described here). More importantly, in Wang et al. (2012) participants received a single test-phase involving trials where the exposed features A/B appear in the trained locations or in a new location, while novel features C/D appear either in the trained location for A/B or in a new location. Thus, successful performance on A/B same location trials would effectively reinforce any tendency to attend to this location (and thus support good performance when C/D appears in the same place). But, by reinforcing the tendency to look in a particular location, this

combined test does not offer an uncontaminated assessment of whether learning about content (i.e. the A/B features themselves) could support enhanced discrimination at all. In essence, this design puts the tendency to respond based on location in opposition to any tendency to respond based on content. What is critical for theoretical accounts of perceptual learning is the demonstration from the current experiments that it is ***only*** learning about the location of unique features that matters for discriminating checkerboards constructed in the fashion used here. The results of Experiment 1 here, and Experiment 3 of Wang et al. (2012), are consistent with just this possibility, and the results of the current Experiment 2 confirms it even when content- and location-based performance are not directly opposed.

As noted in the introduction, the idea that exposure-produced improvements in discrimination depend on learning about where the critical differences in stimuli might appear is problematic for all theoretical accounts of perceptual learning that are based on mechanisms involving the content of the exposed stimuli. Obviously, the idea that exposure effects with one type of stimulus is potentially subject to artefacts due to spatial attention (as was seen here) does not mean that content-based mechanisms do not contribute to perceptual learning at all. Indeed few, if any, studies of perceptual learning in non-human animals would admit explanation in terms of deliberate allocation of spatial attention, especially as most such studies have used stimuli such as flavours that cannot be discriminated on location alone (e.g., Blair & Hall, 2003; Dwyer & Honey, 2007; Symonds & Hall, 1995). Moreover, as considered in detail below, not all human-based studies are subject to these attentional confounds. Therefore, before turning to the general implications for the current results for theoretical accounts of perceptual learning in humans, we will first examine the implications for prior studies that used directly comparable checkerboard stimuli.

The initial experiments using checkerboards of this type were reported by Lavis and Mitchell (2006). Experiments 1A and 1B simply showed that intermixed exposure was better

than blocked exposure for promoting subsequent discrimination and thus do not help to distinguish between the different accounts of perceptual learning, so the possibility of an attentional artefact is of little importance (a similar analysis can be applied to the experiments reported by Mitchell, Nash, et al. (2008) who demonstrated that trial spacing cannot explain the superiority for intermixed over blocked exposure). In Experiment 2A of Lavis and Mitchell (2006) participants were exposed to three pairs of stimuli (AX/BX and CX/DX each exposed in alternation, while EX/FX were exposed in blocks) and Experiment 2B used a similar design, save that two pairs were exposed in blocks and one was exposed in alternation. Following this exposure participants were tested for their discrimination within pairs (e.g. AX vs. BX or EX vs. BX) or between pairs (e.g. AX vs. CX or AX vs. EX). Discrimination involving only blocked stimuli was less accurate than discrimination involving a stimulus exposed in alternation regardless of whether the discrimination involved between or within pair comparisons. On the face of it, the facility with which between pair discriminations were made is inconsistent with accounts based on mutual inhibition (e.g., McLaren & Mackintosh, 2000) and thus seems to favour an explanation in terms of intermixed exposure enhancing the salience of the unique features (which was exactly the analysis made by Lavis & Mitchell, 2006). However, because the unique features remained in the same place for within- and between-pair tests, if participants had simply learnt to look to the locations where the unique features of intermixed stimuli appeared, then the success of between-pair discriminations can be explained without recourse to changes in feature salience. Similarly, Mitchell, Kadib, et al. (2008), report that after exposure to AX/BX discrimination was equivalently good for AX/X as it was for BY/Y (i.e. exposure effects generalised to a new common background – Experiment 2). Again, the fact that the unique features remained in the same place regardless of what background was used on test means that a response strategy based on simply looking at the locations where differences occurred

during exposure could entirely explain the observed data without recourse to a change in the salience of the unique features. Finally, Lavis, et al. (2011) report that exposure to the unique features alone facilitates discrimination (Experiment 2). But again, the additional unique feature alone exposures maintained their location and so the influence of these exposures can also be explained purely by an attention to location mechanism. The pattern across all these studies is largely the same – a transfer of exposure learning to test performance that appears to be informative by being inconsistent with theoretical accounts of perceptual learning. However we would argue that no theoretically decisive conclusions can be drawn because the transfer of exposure effects can be explained simply in terms of where participants chose to look. Thus none of the previously reported studies using the types of checkerboard used in the current experiments require explanation in terms of a modification of unique feature salience (however that modification might be supposed to occur), because in every case performance could be entirely determined by subjects learning where to look on the checkerboard.

Now, one obvious rejoinder to the contention that looking in a particular place obviates the necessity for theoretical accounts of changes in feature salience (or indeed any other account of improved discrimination performance) is to speculate that where something appears in a complex visual stimulus should be considered as a feature of that stimulus. Considered in this way, the data reported here become a demonstration that where something appears is the critically important feature. While this suggestion certainly merits consideration, it does not fully address the critique described above. Firstly, the idea that location is a feature directly challenges the interpretation of studies examining the transfer of learning from one situation to another - if the key feature is location then this remains constant despite changes in things like the background or the comparison stimuli and so no real transfer is being examined at all. Secondly, it is not the location that distinguishes the

stimuli (e.g. all of them have a "top left") but the fact that there is a difference in the content that appears at that location between two stimuli. Thus, attending to a location is not to attend to the distinctive aspects of a complex stimulus at all. But perhaps most critically, even if location is considered as a feature then this characterisation of the stimuli still does not address the possibility that looking at a particular location after exposure is the result of a strategic choice on behalf of the participants, rather than being due to their attention being drawn to a particularly salient location.

The potential for strategic choices to influence the performance has long been identified as a challenge for those interested in examining the effects of "mere" exposure on perceptual learning in humans (e.g. McLaren & Mackintosh, 2000). In our current study, and many others, participants are instructed to look for differences between stimuli during the exposure phase. Assuming that they follow these instructions, then when they discover a way of distinguishing the critical stimuli (such as looking in a particular place) then this behaviour will be implicitly reinforced by the success of achieving the task that has been set for them (Mackintosh, 2009). While recognising the possibility of that people may deploy attention in this sort of strategic manner, Lavis et al. (2011) downplay the importance of this possibility by suggesting that this account does not explain how different exposure schedules influence the ability to detect the location of distinctive features. However, during alternating exposure the critical difference between stimuli is present on every trial, and any possible difference that was identified by deliberate search can thus be checked at will. For blocked exposure, only the single transition trial affords the opportunity to directly check whether a feature really does discriminate two stimuli. Thus there is an obvious mechanism for whereby stimulus scheduling could influence the effectiveness of strategic processes. As an aside, the fact that attention to particular locations can explain exposure-dependant discrimination performance does not mean that subjects are unaware of the content of the exposed features.

Indeed, Lavis et al. (2011) found that participants had more accurate memories of the unique features of stimuli exposed in alternation. The critical point made by the current experiments is that despite encoding these exposed features, discrimination performance is not supported by their presence, but only by focusing attention on the place in which they appeared during initial exposure.

So, if many studies based on the type of checkerboard stimuli used here are fatally compromised by the possibility of a strategic direction of attention to location, then where does this leave the investigation of perceptual learning in humans? Perhaps most critically, the basic schedule effects underpinning many analyses of perceptual learning are present in stimuli that are not open to strategic spatial attention (e.g. flavours: Dwyer, Hodder, & Honey, 2004; Mundy, Dwyer, & Honey, 2006). Moreover, other visual stimuli, such as morphed faces (e.g. Dwyer, Mundy, & Honey, 2011; Mundy, et al., 2007), and checkerboards (e.g. McLaren, 1997; Wills, Suret, & McLaren, 2004; Welham & Wills, 2011) or icon arrays (de Zilva and Mitchell, 2012) with probabilistically defined features, have no single defining feature at a constant location and thus strategic attention to particular locations is unlikely to support accurate performance[3]. Indeed, the fact that perceptual learning with morphed faces transfers between full face and three-quarter views (Dwyer, Mundy, Valdeanu, & Honey, 2009) would suggest that people cannot simply be looking in a particular place as the location of any differences would have been changed by the viewpoint transformation. In addition, the fact that exposure to the common element alone improves subsequent discrimination (Mundy, et al., 2007; Wang & Mitchell, 2011) cannot be explained by subjects learning to attend to the critical location during the exposure phase as there is no indication at this point

[3] That is not to say that participants could not approach these tasks in a strategic manner, but that mere attention to a particular area will not suffice to reliably distinguish the stimuli.

of what the critical location might be. So the corpus of unconfounded experimental studies might be reduced by placing the current style of checkerboard to one side, but many studies using other stimulus types remain. There are also studies (including with checkerboards as used here) where the results cannot be explained at all by strategic attention to location. Thus, while the current results do suggest that the theoretical interpretation of some experiments with checkerboards is unsound, a wholesale questioning of theoretical accounts of perceptual learning in humans is not required. For example, the basic existence of schedule effects in human perceptual learning remains well supported, and most particularly, accounts that do not rely on strategic attentional mechanisms (e.g. Dwyer et al., 2011; Hall, 2003; McLaren & Mackintosh, 2000) remain viable.

That said, the impact of the current studies should not be underestimated. The contribution of strategic allocation of attention to particular regions of stimulus space, independent of any change in the representation properties or salience of the features that occur at that space, has formerly been cited as the logically possible confound (Mackintosh, 2009). The current experiments explicitly demonstrate that such content-independent mechanisms can entirely explain exposure-dependant improvements in discrimination performance in one commonly used type of visual stimulus. The current results (as with those of Wang et al., 2012) directly question the theoretical interpretation of all other studies using the same type of checkerboard stimulus. Moreover, the current results provides concrete evidence that implicitly reinforced attentional mechanisms can contribute to the effects of exposure on discrimination performance, and thus that such mechanisms must be considered in all studies of human perceptual learning.

Author Note

The authors would like to thank Rob Honey for his helpful advice on earlier drafts and also the three anonymous reviews for their useful comments and suggestions; particularly the recommendation of including a Bayesian analysis.

This research was funded by a PhD studentship awarded to Scott Jones from the School of Psychology Cardiff University and the Engineering and Physical Sciences Research Council

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Table 1

Design of Experiment 1

Group	Condition	Exposure	Test	Notes
Location Different-Content Same	Exposed	AX/BX		Stimuli C*X/D*X comprise new unique features but in the same location that A and B were presented (Figure 1B). Stimuli A*X/B*X comprise the same unique features but in a new location (Figure 1C).
	Location Same	AX/BX	C*X/D*X	
	Location Different (Content Same)		A*X/B*X	
Location Different-Content Different	Exposed	AX/BX		Stimuli C*X/D*X comprise new unique features but in the same location that A and B were presented (Figure 1B). Stimuli EX/FX comprise the new unique features in a new location (Figure 1D).
	Location Same	AX/BX	C*X/D*X	
	Location Different (Content Different)		EX/FX	

Note: A-E represent "unique" features while X and Y represent "common" background checkerboards (see Experiment 1 methods for details and Figure 1 for examples).

Table 2

Design of Experiment 2

Group	Condition	Exposure	Test	Notes
Same-Content-Different-Location	Exposed	AX/BX	AX/BX	Transfer stimuli (G*Y/H*Y) comprise the same unique features but in a new location (Figure 1C)
	Exposed-Control		CX/DX	
	Transfer	GY/HY	G*Y/H*Y	
	Trasfer-Control		KY/LY	
Same-Location-Different-Content	Exposed	AX/BX	AX/BX	Transfer stimuli (I*Y/J*Y) comprise new unique features but in the same location that G and H were presented (Figure 1B)
	Exposed-Control		CX/DX	
	Transfer	GY/HY	I*Y/J*Y	
	Trasfer-Control		KY/LY	

Note: A-L represent "unique" features while X and Y represent "common" background checkerboards (see Experiment 2 methods for details and Figure 1 for examples).

Figure Captions.

Figure 1: Examples of stimuli used in Experiments 1 and 2. All display the common background (X) unique with unique features outlined in black (this outline was not present during the experiment). Panel A represents the Exposed condition (e.g. AX and BX). The remaining checkerboards are examples of the transfer tests after exposure to AX and BX. Panel B shows stimuli with new unique features (e.g. C/D) at the same location as the unique features using in exposure (Location Same). Panel C shows stimuli with the same unique features, but in different locations (Location Different-Content Same). Panel D shows stimuli with new unique features (e.g. E/F) at a new location (Location Different-Content Different). Panel E shows the alternative background (Y) with an example of additional unique features (e.g. G/H).

Figure 2: Panel A shows the test data from Experiment 1 as mean (with SEM) sensitivity scores (*d'*). Data are displayed as a function of test condition (Exposed, Location Same, or Location Different), training group (Location Different-Content Same or Location Different-Content Different). Panel B shows mean proportion correct (with SEM) for each test condition and training group including test trial type (Same or Different).

Figure 3: Panel A shows the test data from Experiment 2 as sensitivity scores (*d'*) with SEM. The data are organised by transfer group (Group Same-Content-Different-Location on the left, Group Same-Location-Different-Content on the right), and are presented as a function of test condition (Exposed or Transfer), and exposure condition (Exposed/Transfer or Exposed-Control/Transfer-Control). Panel B displays as mean proportion correct (with SEM) for both

transfer groups presented as a function n of test condition, exposure condition, and test trial type (Same or Different).

Figure 1.

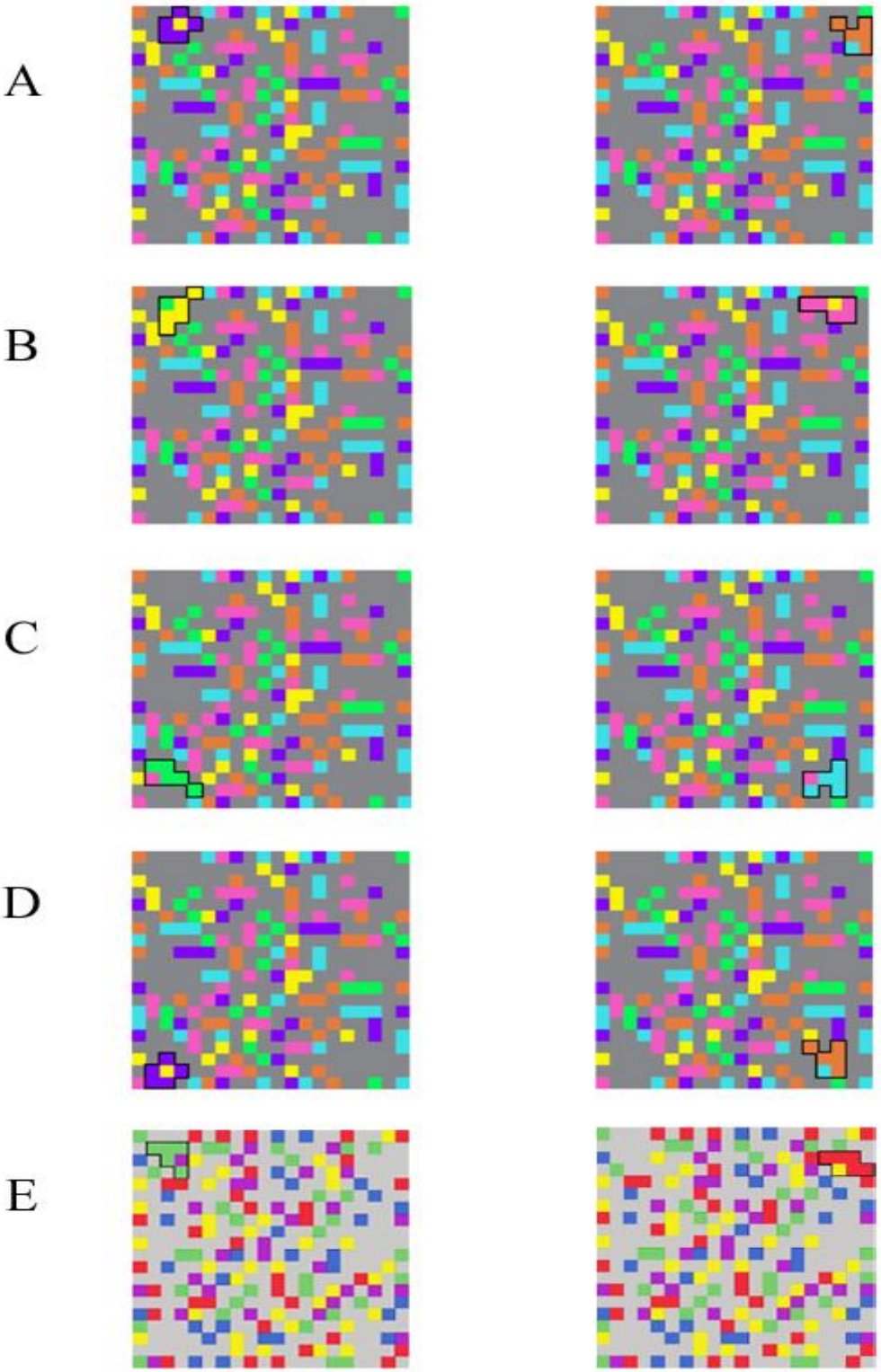


Figure 2.

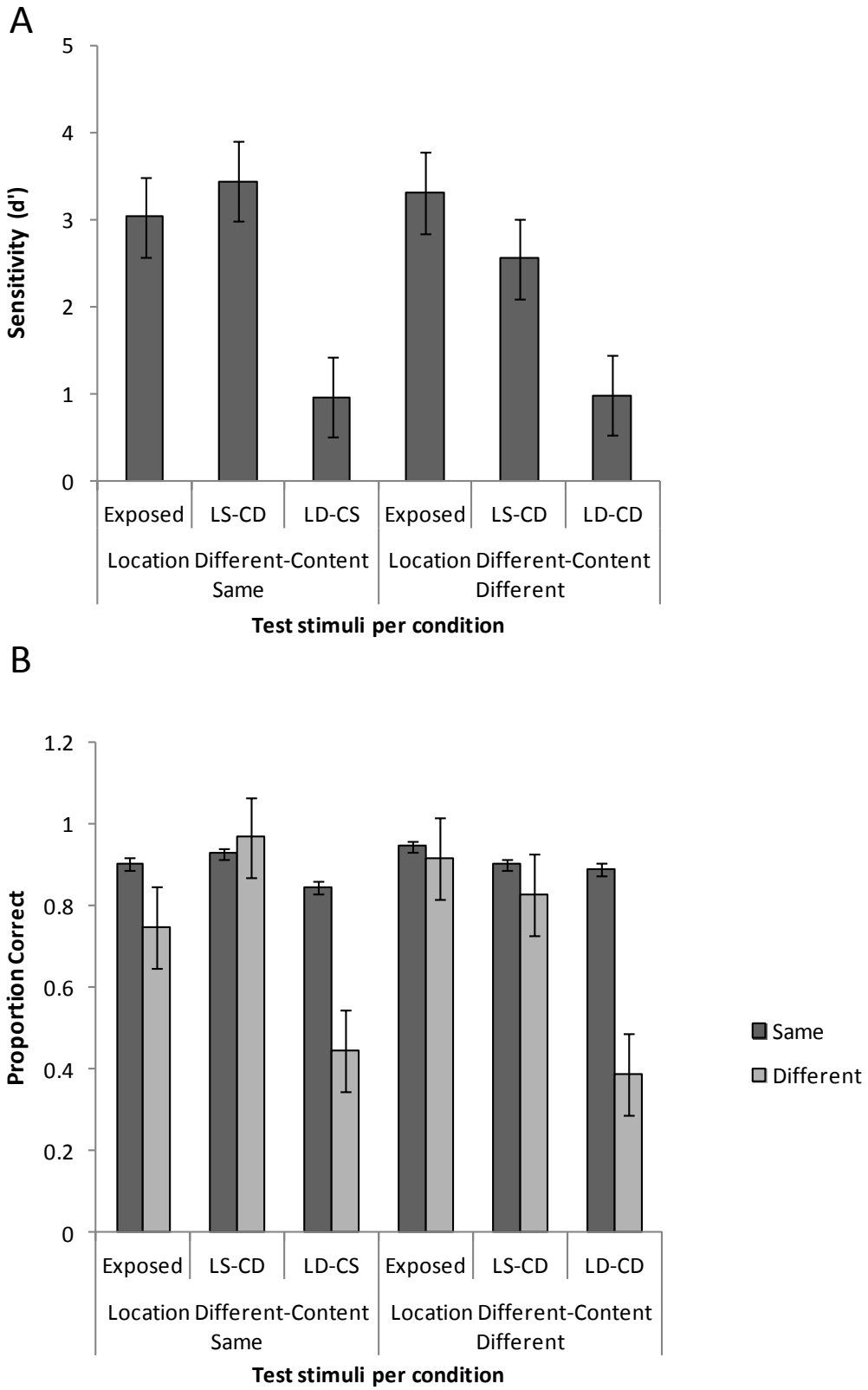
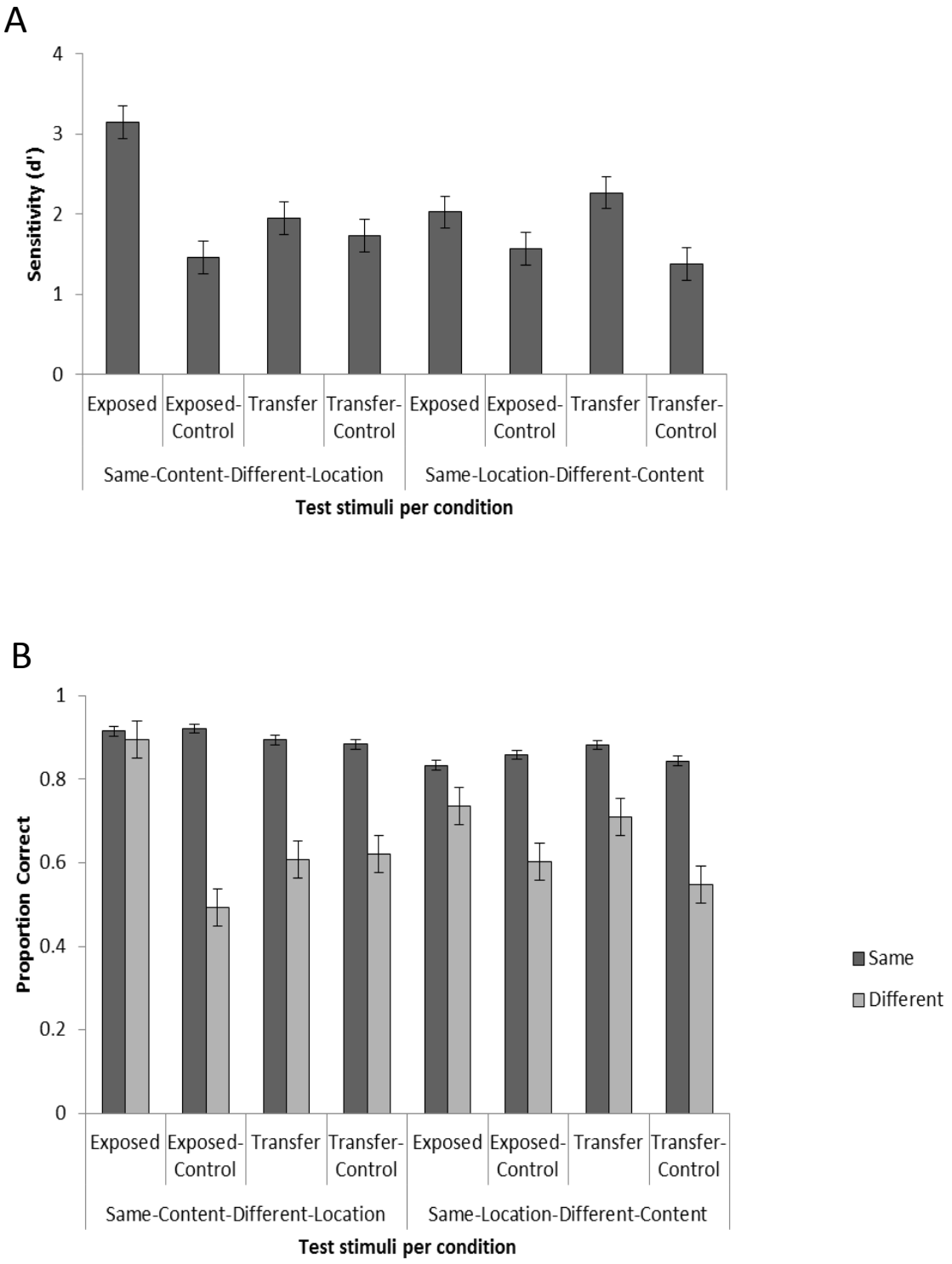

A
Sensitivity (d')
5
4
3
2
1
0
Exposed
LS-CD
LD-CS
Exposed
LS-CD
LD-CD
Location Different-Content Same
Location Different-Content Different
Test stimuli per condition
B
Proportion Correct
1.2
1
0.8
0.6
0.4
0.2
0
Exposed
LS-CD
LD-CS
Exposed
LS-CD
LD-CD
Location Different-Content Same
Location Different-Content Different
Test stimuli per condition
Same
Different

Figure 3.


A
Sensitivity (d')
4
3
2
1
0
Exposed
Exposed-Control
Transfer
Transfer-Control
Exposed
Exposed-Control
Transfer
Transfer-Control
Same-Content-Different-Location
Same-Location-Different-Content
Test stimuli per condition
B
Proportion Correct
1
0.8
0.6
0.4
0.2
0
Exposed
Exposed-Control
Transfer
Transfer-Control
Exposed
Exposed-Control
Transfer
Transfer-Control
Same-Content-Different-Location
Same-Location-Different-Content
Test stimuli per condition
Same
Different