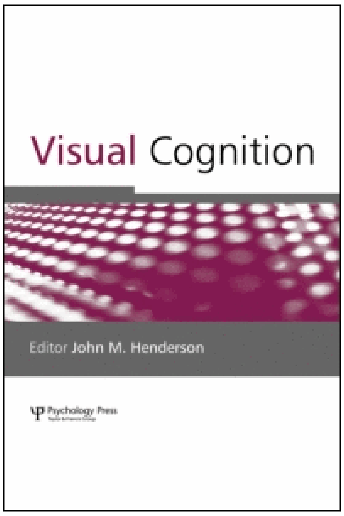

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Perceptual learning and acquired face familiarity: Evidence from inversion, use of internal features, and generalization between viewpoints

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Perceptual learning and acquired face familiarity: Evidence from inversion, use of internal features, and generalization between viewpoints

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Pairs of similar faces were created from photographs of different people using morphing software. The ability of participants to discriminate between novel pairs of faces and between those to which they had received brief, unsupervised, exposure (5×2 s each) was assessed. In all experiments exposure improved discrimination performance. Overall, discrimination was better when the faces were upright, but exposure produced improved discrimination for both upright and inverted faces (Experiment 1). The improvement produced by exposure was selective to internal face features (Experiment 2) and was evident when there was a change in orientation (three-quarter to full face or vice versa) between exposure and test (Experiment 3). These findings indicate that perceptual learning observed following brief exposure to faces exhibit well-established hallmarks of familiar face processing (i.e., internal feature advantage and insensitivity to a change of viewpoint). Considered in combination with previous studies using the same type of stimuli (Mundy, Honey, & Dwyer, 2007), the current results imply that general perceptual learning mechanisms contribute to the acquisition of face familiarity.

There are important differences between the processing of familiar and unfamiliar faces (for a review see Hancock, Bruce, & Burton, 2000). For example, the relative importance of the internal features of faces (e.g., eyes or mouth) over the external features (e.g., hair or face outline) is greater in the recognition of familiar than unfamiliar faces (e.g., Ellis, Shepherd, & Davies, 1979) and changes in viewpoint or expression have less impact on the processing of familiar faces than novel faces (e.g., Bruce, 1982). These kinds of effects are also evident if instead of utilizing the fact that some people are more frequently encountered (e.g., in the media) than others, the familiarity of the faces is manipulated experimentally. For example, moderate levels of

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exposure to either still or video images of previously unfamiliar individuals produces an improvement in performance on both matching (Bonner, Bruce, & Burton, 2003) and discrimination (O'Donnell & Bruce, 2001) tasks that is selective to internal features of the face. This improvement in matching based on internal features produced by exposure has been replicated for shorter familiarization periods (10×2 s; Clutterbuck & Johnston, 2005) and the same period of exposure also facilitates performance on a gender decision task (Clutterbuck & Johnston, 2004).

Gibson (1963) gave the classic definition of perceptual learning as "any relatively permanent and consistent change in the perception of an array, following practice or experience with this array" (p. 29). The fact that the processing of familiar and unfamiliar faces differs has often been ascribed to a process of perceptual learning that is assumed to take place during exposure to particular faces (e.g., Bruce & Burton, 2002; O'Toole, Abdi, Deffenbacher, & Valentin, 1995; Valentine, Chiroro, & Dixon, 1995). However, relatively little detailed analysis has been provided about the nature of the perceptual learning process itself or the circumstances under which it might operate. One clear exception to this is seen in work of Gold and colleagues (e.g., Gold, Bennett, & Sekuler, 1999a, 1999b; Gold, Sekuler, & Bennett, 2004). These studies demonstrated that familiarization with face stimuli improved the accuracy with which they were identified in noise. Moreover, they demonstrated that this perceptual learning was due to an increase in the internal signal strength of the familiar faces. Interestingly, theses studies also demonstrated that the same was true of nonface stimuli, implying a continuity between the mechanisms underpinning perceptual learning with face and nonface stimuli.

In a series of experiments that examined the conditions under which perceptual learning takes place, Mundy, Honey, and Dwyer (2007) created a set of difficult to discriminate stimuli by using a morphing procedure on pictures of faces. Although not specifically designed to address face processing, the fact that the stimuli used were pictures of faces raises the possibility that the results observed could shed some light on how perceptual learning occurs with faces. Mundy et al. demonstrated that discrimination between two very similar faces (A and A*) was improved by a brief (5×2 s) period of (unsupervised) exposure to each of them and that this improvement was influenced by the way in which the faces were presented during exposure: It was more marked (1) for faces that had been presented in an intermixed way (i.e., A, A*, A, A* ...) than those presented in a blocked fashion (i.e., A, A, ... A*, A*, ...), and (2) following simultaneous exposure to the faces (i.e., A and A*) than after intermixed exposure. These findings are of theoretical interest for a number of reasons. First, the findings suggest that the improvement in the discriminability of familiar faces does not simply reflect the amount of exposure per se (cf. Gaffan, 1996; Hall, 1991;

Honey, 1990; see also Clutterbuck & Johnston, 2005); for example, the total amount of exposure is equated after intermixed and blocked exposure and following simultaneous and intermixed exposure and yet these schedules produced different levels of perceptual learning. Second, the observation that intermixed exposure is a more effective condition for improving subsequent discrimination than blocked exposure is evident both in other sensory domains in humans (e.g., flavours and odours; see Dwyer, Hodder, & Honey, 2004; Mundy, Dwyer, & Honey, 2006) and in other species (chicks, e.g., Honey, Bateson, & Horn, 1994; rats, e.g., Symonds & Hall, 1995). This consistency encourages the view that there might be an important continuity in the mechanisms that underlie perceptual learning in human face processing and perceptual learning with other stimuli and in other species.

Of course, the commonalities observed between perceptual learning with faces and other stimuli reported by both Gold et al. (1999a, 1999b, 2004) and Mundy et al. (2007) might well reflect the operation of general processes that are content independent, but have nothing to do with face processing per se. In particular, both sets of experiments used the same images during both exposure and testing, which allows the possibility that participants could have relied entirely on picture processing (cf. Bruce, 1982). Thus, it might be argued that the perceptual learning effects observed by both Gold et al. and Mundy et al. relied on quite different mechanisms than those ordinarily engaged by real faces. It was with these concerns in mind that the three experiments reported here were conducted, using the intermixed exposure schedule that was shown to be particularly effective in producing perceptual learning by Mundy et al. In particular, we investigated whether: (1) The stimuli used by Mundy et al. exhibit the inversion effects normally seen with faces (Experiment 1; cf. Yin, 1969); (2) the results reported by Mundy et al. reflected a change in the processing of the internal features of the faces or their external features (Experiment 2; cf. Ellis et al., 1979); and (3) the improvements produced by exposure are only evident when the viewpoint of the faces remains the same between exposure and test or are also apparent when the viewpoint, and thus the specific image used, changes (Experiment 3; cf. Bruce, 1982). If inversion effects are seen and the effects of exposure are both primarily on the processing of the internal features and are unaffected by a change in viewpoint, then it would suggest that the pictures of faces used in these experiments engage mechanisms ordinarily used for face processing. Moreover, it would confirm that the perceptual learning process observed in face processing are similar to those observed with other stimuli and in other species and suggests that such general perceptual learning mechanisms contribute to the acquisition of face familiarity.

EXPERIMENT 1

The design of Experiment 1 is summarized in Table 1 and examples of the stimuli that were used are shown in the upper panel of Figure 1. Like Mundy et al. (2007), the stimuli were created using a morphing procedure in which pictures of two relatively similar faces were chosen as the endpoints and a set of intermediate faces was produced. To a first approximation, the similarity of the members of these pairs was akin to that of identical twins (for the effects supervised training on twin discrimination, see Stevenage, 1998; see also Robbins & McKone, 2003). In the exposure stage of the experiment participants were given a limited number of intermixed exposures to four pairs of faces (A and A*, B and B*, C and C*, D and D*), while a further two pairs of faces were not exposed (E and E*, F and F*). Of the four exposed pairs, two were exposed upright (A and A*, B and B*), and two were exposed inverted (C and C*, D and D*). Participants were given no explicit feedback about the pictures during the exposure stage. During the test stage participants were required to learn a discrimination between each pair of stimuli with immediate feedback given during this phase: Three pairs of faces were presented upright on test (A and A*, C and C*, E and E*) and the remainder were presented inverted (B and B*, D and D*, F and F*). There were, therefore, two factors: Type of exposure (upright, inverted, or no-exposure) and test orientation (upright or inverted). If the pictures of morphed faces were indeed being processed as faces then performance should be better in the upright test conditions. In addition, if brief pre-exposure does improve discrimination the performance should be better in the exposed conditions (cf. Mundy et al., 2007).

TABLE 1
Design of Experiment 1

Condition	*Exposure*	*Discrimination test*
Upright–upright	5 × A and 5 × A* upright faces	A = M and A* = U: Upright
Upright–inverted	5 × B and 5 × B* upright faces	B = M and B* = U: Inverted
Inverted–upright	5 × C and 5 × C* inverted faces	C = M and C* = U: Upright
Inverted–inverted	5 × D and 5 × D* Inverted faces	D = M and D* = U: Inverted
No exposure–upright	No exposure	E = M and E* = U: Upright
No exposure–inverted	No exposure	F = M and F* = U: Inverted

A–F* represent different faces; upright/inverted face represents the orientation at which the face was shown during exposure or test. The discrimination test involved learning an arbitrary feature assigned to each face within a pair: M and U denote married and unmarried, respectively.

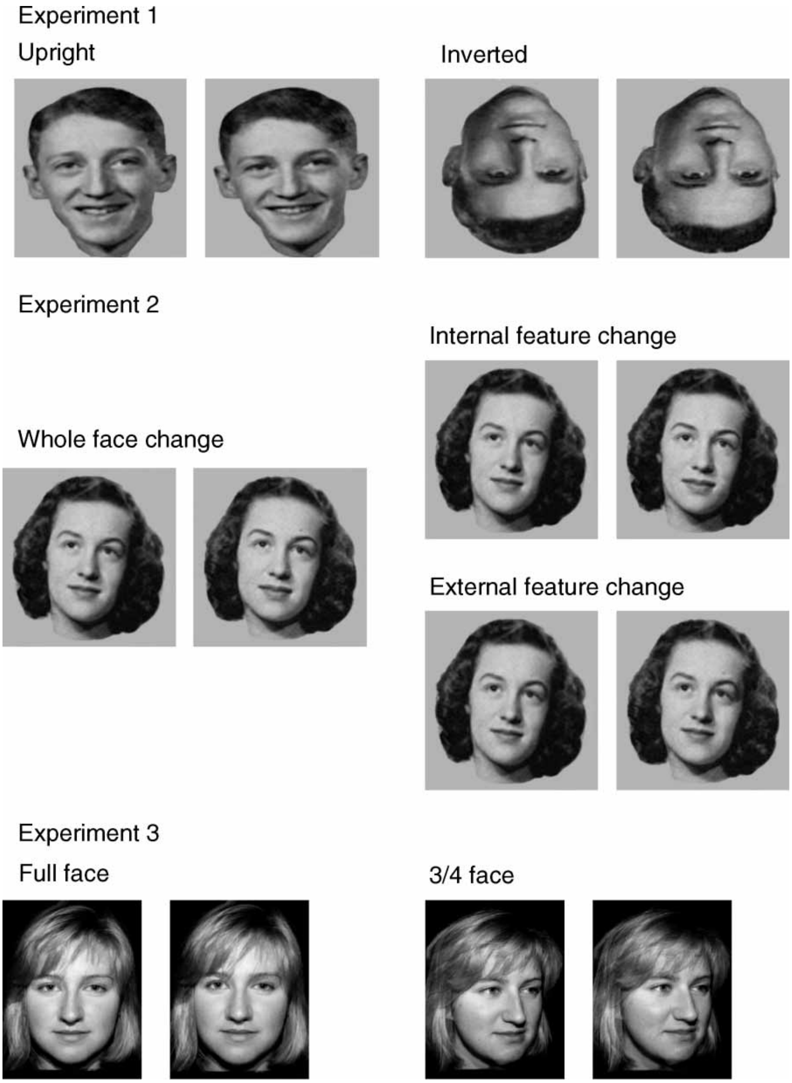

Figure 1. Examples of stimuli used. Upper panel shows stimuli from Experiment 1: Upright (left) and inverted (right). Middle panel shows stimuli from Experiment 2: Whole face change (left), internal feature change (right upper), and external feature change (right lower). Lower panel shows stimuli from Experiment 3: Full face (left) and three-quarter face (right).

Method

Participants and apparatus. Thirty-two students, 20 female and 12 male (aged 18–23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision. An IBM-compatible PC was used to display the stimuli, using custom-written software, on a LCD screen in an evenly lit, quiet room. For the purposes of the experiment, the "A" key was covered in a red coloured sticker marked with the letter "M" and was used by participants to indicate that the pictured person was married, and the "L" key was covered with a green coloured sticker marked with the letter "U", and was used by participants to indicate that the pictured person was unmarried.

Stimuli. The stimuli were created using a software package dedicated to morphing called Morpheus 1.85™. Six morphs were created using black and white portrait photographs of three men and three women. The pictures of each pair were homogenized so that size, resolution, and lighting were identical and they were morphed together along a 30-point scale. Position 1 was 100% Face X, 0% Face Y, position 15 was 50% Face X, 50% Face Y, and position 30 was 0% Face X, 100% Face Y. Images were selected from each morphed continuum at points 13 (56.6% Face X, 43.3% Face Y) and 17 (43.3% Face X, 56.6% Face Y). These six pairs of pictures formed the test set for all participants (i.e., A and A*, B and B*, C and C*, D and D*, E and E*, F and F*) and the size of each image presented on screen was 10.2 cm (high) × 9.9 cm (wide).

Exposure and test procedure. Participants were seated approximately 70 cm directly in front of the computer screen. Prior to the initial stage of the study the following instructions were displayed:

> In the following presentation, you will see several sets of "Look-alikes". You will see each separate look-alike more than once, and some may be upside-down. When prompted, please indicate using the numeric keypad how many times you think you have seen each particular person.

Each face was displayed in the centre of the screen for 2 s, replaced with an even grey background and the participants were asked how many times they had seen that face. Entering a response triggered the next trial. The intertrial interval was thus self-paced and was normally in the region of 1–2 s. This process continued until all faces had been seen five times. The following instructions were then shown prior to the change detection stage of the study:

> You will now see a second series of "Look-alikes". You will have seen most of them before. One of each pair is married, the other is unmarried. Your task is to select which is which. Use the RED key marked M to

choose married people, and chose the GREEN key marked U to choose the unmarried people. The computer will inform you if you are correct.

Each face was displayed in the centre of the screen for a maximum of 10 s, during which time participants were required to press a key indicating their response (married or unmarried), the response triggered removal of the face which was replaced by written feedback relating the accuracy of their selection (Correct or Incorrect). The feedback remained on the screen for 2 s before the presentation of the next trial. If no response was given within the 10 s the stimulus was removed and the participant prompted to respond. Both the response and latency were recorded. After every 24 trials the participant was given the opportunity to rest before pressing a key to continue to the next set of trials.

Design and counterbalancing. During the exposure stage, participants were exposed to four pairs of faces, two upright (A and A*, B and B*) and two inverted (C and C*, D and F*). The computer randomly chose the exposed faces from a selection of six pairs (three male, three female), with the constraint that two were to be female, and two male, with one of each gender in each of the two orientations. Both pictures from one pair were presented before the presentation of pictures from the next pair. For half of the participants the first and third pair consisted of inverted faces, and the second and fourth pairs were upright faces; the remainder of the participants received inverted faces as the second and fourth pairs, and the first and third pairs were presented upright. Stimuli were presented one at a time and both of the faces from each pair were presented five times with the order of presentation intermixed (e.g., A, A*, A, A*, . . .).

The four pairs of exposed faces were presented during the discrimination stage of the experiment, along with two further pairs of faces that were not previously exposed. Half of the faces were presented upright on test and the remainder were inverted. There were, therefore, six conditions: Upright–upright, upright–inverted, inverted–upright, inverted–inverted, no exposure–upright, and no exposure–inverted. For each participant, the assignment of faces to these six conditions was arranged as follows: The computer randomly selected one of the exposed upright faces to be tested in the same orientation (the upright–upright condition); the remaining exposed upright face was tested inverted (the upright–inverted condition). One of the exposed inverted faces was randomly selected to be tested in the same orientation (the inverted–inverted condition); the remaining exposed inverted face was tested upright (the inverted–upright condition). One of the novel faces was randomly selected to be tested in the upright orientation (the no exposure–upright condition), and the remaining novel face was tested inverted (the no exposure–inverted condition). Although the assignment of faces to condition was randomized, rather than explicitly counterbalanced, across participants each face was used between five and seven times in each condition.

During the test phase one face from each pair was randomly assigned to be married and the other face from each pair unmarried and participants were required to learn these assignments. Participants received four blocks of trials with each of the six pairs of faces. Each block consisted of exposure to faces from a single experimental condition, and there was one block from each of the conditions in each set of six blocks. Four faces were presented in each block such that each face in a given pair was presented twice, with the order of presentation randomized. The order in which the blocks were presented was randomized within each set.

Data analysis. During the exposure stage, participants' estimates of the number of occasions that they had seen each of the four faces were recorded. In none of the experiments reported here were there any participants who exhibited aberrant patterns of responding (e.g., higher estimates than the total number of stimuli presented during exposure or repeated entry of the same number) that might indicate that a participant had not been attending either to the instructions or during the exposure stage. During the test phase the first response in the first block of discrimination learning for each condition was random, because participants had yet to receive feedback on any of their choices. Therefore, the accuracy of responding on this block was not directly comparable to that in the following three blocks. Thus, the primary measure of performance (examined as the percentage correct) is the accuracy of responding averaged over Blocks 2–4. Inspection times were also examined to assess any effects of the speed of responding on accuracy. All statistical tests reported used a Type I error rate of .05.

Results and discussion

Figure 2 shows the discrimination scores from Experiment 1 with the test conditions involving upright faces on the left and those involving inverted faces on the right. Inspection of this figure indicates that discrimination performance was better overall with upright faces than it was with inverted faces. Furthermore, with both upright and inverted faces performance was most proficient when the faces had been exposed in the same orientation as they were tested, indicating a perceptual learning effect that was specific to the exposed orientation. Analysis of variance (ANOVA) revealed no significant effect of exposure condition (upright, inverted, no exposure), $F(2, 62) = 2.25$, $p = .11$, an effect of test orientation, $F(1, 31) = 39.24$, $p <$ .001, and a significant interaction between the two factors, $F(2, 62) = 5.12$,

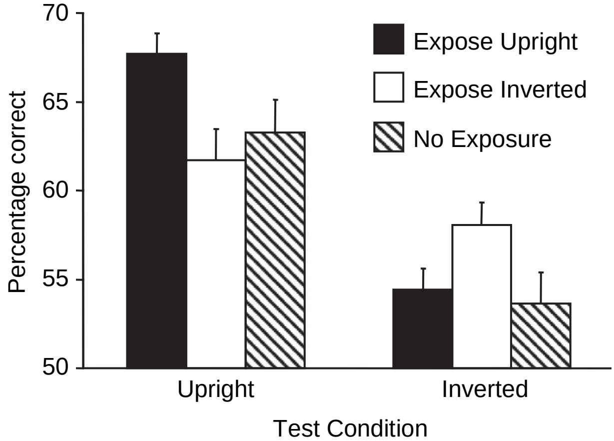

Figure 2. Experiment 1. Mean discrimination accuracy as percentages correct (with SEM). The bars on the left of the figure represent performance when tested with upright faces while bars on the right represent performance with inverted faces.

$p < .01$. An analysis of simple main effects revealed that in the upright test conditions, performance was better after upright exposure than it was after inverted or no exposure, $F(1, 31) = 4.52$, $p < .05$, and $F(1, 31) = 9.08$, $p < .01$, respectively; while the inverted and no exposure conditions did not differ, $F < 1$. In the inverted test conditions, performance was better after inverted exposure than it was after upright or no exposure, $F(1, 31) = 6.36$, $p < .05$, and $F(1, 31) = 4.25$, $p < .05$, respectively; while the upright and no exposure conditions did not differ, $F < 1$. The failure to find an exposure advantage in the orientation change conditions is unlikely to reflect a simple floor effect as performance was above chance in all conditions, minimum $t(31) = 2.08$, $p < .05$. Table 2 shows the inspection time data from Experiment 1 and ANOVA revealed no effects of exposure condition or test orientation and no interaction between these factors (Fs < 1).

The stimuli used here produced a large inversion effect of the sort traditionally reported for face stimuli (e.g., Yin, 1969). Whilst inversion effects are seen with other stimuli, without such an inversion effect it would have been difficult to maintain that the current stimuli were being processed as faces. There was also an advantage for the exposed stimuli—albeit only when the stimuli were tested in the same orientation as they were presented during exposure. This finding is consistent with the suggestion that exposure to the stimuli had rendered them more discriminable (cf. Gold et al., 1999a, 1999b, 2004; Mundy et al., 2007). Shepard (1986) noted, however, that learning to categorize stimuli requires both discriminating between the stimuli and linking those stimuli to categories (e.g., married and unmarried

TABLE 2
Mean reaction times in seconds (with SEM) during discrimination training for each condition in Experiments 1, 2, and 3

	Inspection time (s)	*SEM*
Experiment 1		
Upright–upright	1.866	0.112
Upright–inverted	1.833	0.108
Inverted–upright	1.908	0.078
Inverted–inverted	1.918	0.093
No exposure–upright	1.883	0.087
No exposure–inverted	1.855	0.108
Experiment 2		
Whole exposed	1.020	0.040
Whole control	1.078	0.050
Internal exposed	1.070	0.053
Internal control	0.969	0.051
External exposed	1.065	0.062
External control	0.929	0.056
Experiment 3		
Exposed–same	3.740	0.253
Exposed–change	3.747	0.298
Control	3.780	0.281

in the current circumstances). Importantly, Shepard also argued that it is discrimination that will be the limiting factor when the stimuli are similar, as they are in the current experiment. However, it is still at least possible that exposure, rather than increasing the discriminability of the stimuli, increased the readiness with which links between the stimuli and categories were acquired. In Experiments 2 and 3 a different assay of the effects of exposure was used (same/different judgements) in which there is no requirement for the categories into which the stimuli are placed to be learnt. Under these circumstances, if an effect of exposure was observed it would be directly attributable to a change in the discriminability of the stimuli.

EXPERIMENT 2

The design of Experiment 2 is summarized in Table 3 and examples of the stimuli used are shown in the middle panel of Figure 1. During the exposure stage, participants received intermixed exposure to two pairs of faces (A and A*, B and B*) without explicit feedback. During the test stage, participants made same/different judgements about sequentially presented faces and were given feedback regarding the accuracy of their responses. Two pairs of faces, one familiar (A and A*) and one novel (C and C*) were used to confirm that

TABLE 3
Design of Experiment 2

Condition	*Exposure*	*Discrimination test*
Whole		
Exposed	5 × A and 5 × A* intermixed	A versus A*
Control	No exposure	C versus C*
Internal–external		
Exposed	5 × B and 5 × B* intermixed	B versus B^{*INT}
		B versus B^{*EXT}
Control	No exposure	D versus D^{*INT}
		D versus D^{*EXT}

A–D* represent different faces. The superscript INT refers to a change in the internal features of the face only; the superscript EXT refers to a change in the external features of the face only. The discrimination test involved same–different judgements for sequentially presented faces.

our exposure treatment would improve the detection of whole faces changes (changes in both internal and external features). The remaining familiar faces (B and B*), and a further pair of novel faces (D and D*), were used to determine the locus within the face of the perceptual learning effect. To this end, participants received test trials in which the external features of the faces were identical and the internal features were different (i.e., B and B^{*INT} and D and D^{*INT}) and other trials on which the internal features were identical and the external features differed (i.e., B and B^{*EXT} and D and D^{*EXT}). These test trials should allow us to determine whether exposed faces are more readily discriminated than novel faces and whether this effect reflects a change in the processing of the internal or external features of the faces.

Method

Participants and apparatus. Thirty-two students, 23 female and 9 male (aged 18–23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision and none had taken part in Experiment 1. An IBM-compatible PC was used to display the stimuli, using custom-written software, on a LCD screen in an evenly lit, quiet room. On a standard keyboard, the "A" key was covered with a green coloured sticker labelled "YES", the "L" key was covered with a red coloured sticker labelled "NO", and these were used by participants to indicate whether or not there was a change of stimuli during the test phase of the experiment.

Stimuli. Four morphs were created using the methods outlined in Experiment 1. These four pairs of pictures (i.e., A and A*, B and B*, C and C*, D and D*) formed the set from which "whole" face-change pairs were drawn. Copies of each of the faces in the four face-pairs were further processed, using Adobe Photoshop 6™, so that the internal features (eyes, nose, and mouth) of one face replaced those of the second face, and vice versa. This created a further pair of faces corresponding to each of the original four pairs: For example one containing the internal features of A and the external features of A* ($A^{INT}A^{*EXT}$) and one containing the internal features of A* and the external features of A ($A^{*INT}A^{EXT}$). This formed the set from which "internal" and "external" face-change pairs were drawn. All images measured 10.2 cm (high) × 9.9 cm (wide) when displayed on the screen.

Exposure and test procedure. The general procedures were as described in Experiment 1 although the instructions were altered to reflect the change in task used during test. Before the exposure stage of the study the following instructions were displayed:

> In the following presentation, you will see several sets of "Look-alikes". You will see each separate look-alike more than once. When prompted, please indicate using the numeric keypad how many times you think you have seen each particular person.

After all faces had been seen five times the following instructions were shown:

> You will now see a second series of look-alikes. You will have seen some of them before. The face will flash and you will be asked "Does the face change?". Use the "GREEN" key for YES and the "RED" key for NO. The computer will inform you if you are correct.

The first face (henceforth Face 1) was presented on screen for 0.5 s then replaced with an even grey background for 0.3 s. A second face (henceforth Face 2) was then presented for 0.5 s and replaced with an even grey background. Participants were then required to indicate whether the face had changed. The response (Yes or No) triggered written feedback (Correct or Incorrect) which remained on screen for 2s before the presentation of the next trial. If no response was given within 10 s then the participant was prompted to respond.

Design and counterbalancing. During the exposure stage, the participants were exposed to two pairs of faces (e.g., A and A*, B and B*) randomly selected from the four face-pairs. Faces were presented one at a time and both of the faces from each pair were presented five times with the order of presentation intermixed. Both pictures from one pair were presented before the presentation of the other pair.

One of the exposed pairs and one of the nonexposed pairs were randomly assigned to the "whole-change" condition (A and A*, C and C*). The remainder were assigned to the "internal/external-change" condition (B and B*, D and D*). Assignment was constrained so that across participants each face was used equally often in each condition. Participants received four blocks of trials with each of the four pairs of faces from each experimental condition. The order in which blocks of face pairs were presented was randomized with the restriction that participants received one block with each face pair before being given the opportunity to rest prior to continuing.

Each test block consisted of eight trials. During a "whole-change" block, the identities of Face 1 and Face 2 were randomized with the constraint that in every block, four trials involved no change between Face 1 and 2 (e.g., $A \rightarrow A$ or $A^* \rightarrow A^*$), four trials involved a change from one face to its partner (e.g., $A \rightarrow A^*$ or $A^* \rightarrow A$). During an "internal/external-change" block, the identity of Face 1 was randomized with the constraint that each face (B or B*) was used equally often. The identity of Face 2 was randomly chosen from a set of four faces (B, B*, $B^{INT}B^{*EXT}$, $B^{*INT}B^{EXT}$), with the constraint that in every block there were to be: Two "internal" changes, where the external features of Face 1 were retained in Face 2, but the internal features were swapped for those of its partner (e.g., $B \rightarrow B^{*INT}B^{EXT}$ or $B^* \rightarrow B^{INT}B^{*EXT}$); two "external" changes, where the internal features of Face 1 were retained in Face 2, but the external features were swapped for those of its partner (e.g., $B \rightarrow B^{INT}B^{*EXT}$, $B^* \rightarrow B^{*INT}B^{EXT}$); and four trials where there was no change between Faces 1 and 2 (e.g., $2 \times B \rightarrow B$ and $2 \times B^* \rightarrow B^*$).

Data analysis. The primary measure of performance in Experiment 2 was the accuracy of responding (examined as the percentage correct) during the test. Inspection times were also examined to assess any effects of the speed of responding on accuracy.

Results and discussion

Figure 3 shows the accuracy scores for Experiment 2. Inspection of the left-hand portion of the figure indicates that participants were more accurate in making same/different judgements regarding whole face changes when the faces were familiar than when they were novel. Inspection of the right-hand portion of the figure indicates that this effect of exposure was also evident when the to-be-detected change involved the internal features of the faces (central pair of bars), but was not evident when the to-be-detected change involved the external features of the faces (right-hand pair of bars). ANOVA

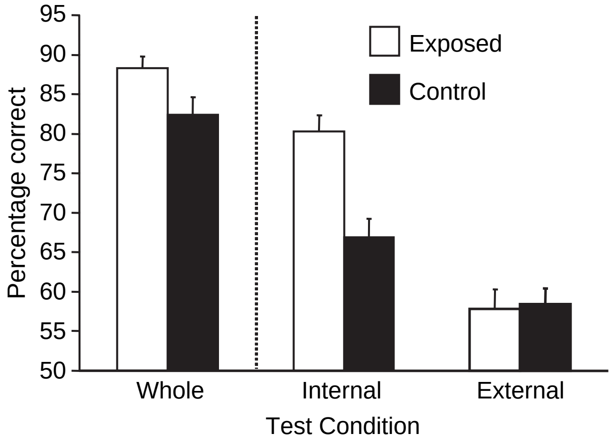

Figure 3. Experiment 2. Mean discrimination accuracy as percentages correct (with SEM). Whole, internal, and external refer to the nature of the features that differed on test, while exposed and control refer to whether or not the faces had been presented prior to test.

confirmed that there was an exposure effect when the changes involved the whole face, $F(1, 31) = 19.87$, $p < .001$. A separate ANOVA conducted on the test trials involving internal and external changes revealed significant effects of exposure, $F(1, 31) = 23.78$, $p < .001$, and change type, $F(1, 31) = 48.76$, $p < .001$, and a significant interaction between these factors, $F(1, 31) = 5.42$, $p < .05$. Analysis of simple main effects revealed an effect of exposure in the internal-change conditions, $F(1, 31) = 18.81$, $p < .001$, but no difference in the external-change conditions, $F < 1$. The failure to find an exposure advantage in the external-change conditions does not reflect the fact that external changes were not detected because performance was above chance for all conditions, minimum $t(31) = 3.13$, $p < .005$.

Table 2 shows the mean reaction times for Experiment 2. ANOVA revealed no significant effect of exposure in the whole change conditions, $F < 1$, and a second ANOVA revealed that although reaction times were significantly longer in the exposed conditions, $F(1, 31) = 5.06$, $p < .05$, there was no significant effect of change type or interaction between the two factors, Fs < 1. The main effect of exposure suggests that the processing of both internal and external features were influenced by exposure, while the absence of a significant interaction between exposure and change type indicates that it is unlikely that the speed with which participants responded contributed to the differences in discrimination accuracy.

Experiment 2 demonstrates that brief intermixed exposure to pictures of faces produces a perceptual learning effect that is selective to the internal features of the faces—an effect that is revealed by a change detection task.

This effect was evident using the kind of stimuli and after the brief form of exposure used by Mundy et al. (2007). An advantage for the processing of internal features is commonly observed with highly familiar stimuli and similar results have also been observed with familiarization produced by relatively extended experimental exposure (e.g., Ellis et al., 1979; see also Bonner et al., 2003; Clutterbuck & Johnston, 2004, 2005; O'Donnell & Bruce, 2001). The fact that, without explicit instructions to concentrate on internal features, our brief alternating exposure protocol produced an advantage for subsequent discrimination that was selective to the internal features of the face suggests that this exposure method is particularly effective in supporting the development of at least one key feature of familiar face processing. One aspect of previous results not observed here is a general advantage for external features. However, this advantage may be dependent on particular aspects of the stimuli used. For example, O'Donnell and Bruce (2001) report near errorless change detection with respect to hairstyle. In the present case the morphing process produces differences in the external stimuli that are more subtle than is the case with unmorphed faces.

EXPERIMENT 3

In this experiment we assess whether or not the influence of brief exposure to pictures of faces is dependent on maintaining the same image from exposure to test by examining the effect of a change in viewpoint. The design of Experiment 3 is summarized in Table 4 and the lower panel of Figure 1 shows an example of the six pairs of faces that were used. Each face could be presented in full or three-quarter face view. In the exposure stage, participants received limited exposure to four pairs of faces (A and A*, B and B*, C and C*, D and D*) with members of each pair presented one at a time and in alternation. Two pairs of exposed faces were presented in full face view and two in three-quarter face view. In the second stage, participants were required to make same/different judgement about the exposed stimuli that were either presented in the same orientation as they had been during exposure (exposed–same condition) or in the alternative orientation (exposed–changed condition). Two pairs of novel faces (E and E*, F and F*) were only presented during the second stage (control condition). During the test stage, faces were shown two at a time and participants were asked whether they were the same or different and were given immediate feedback regarding the accuracy of their responses. The issue of principal importance was whether or not discrimination between exposed faces was better than between faces that were not exposed and whether any such perceptual learning effect was evident when the angle at which the face was presented changed between exposure and test.

TABLE 4
Design of Experiment 3

Condition	*Exposure*	*Discrimination test*
Exposed–same	Full face: A, A*, A, A*...	Full face: A versus A*
	¾ face: B, B*, B, B*...	¾ face: B versus B*
Exposed–change	¾ face: C, C*, C, C*...	Full face: C versus C*
	Full face: D, D*, D, D*...	¾ face: D versus D*
Control	No exposure	Full face: E versus E*
		¾ face: F versus F*

A–F* represent different faces; full face and three-quarter face represent the angle at which the face was shown. The discrimination test involved same–different judgements for simultaneously presented faces.

Method

Participants, apparatus, and stimuli. Twenty-six undergraduate students, 24 female and 2 male (aged 18–23), recruited from the School of Psychology at Cardiff University, were given course credit for taking part. All participants had normal or corrected-to-normal vision. The apparatus used was the same as in Experiments 1 and 2 with the exception that the "Q" key was covered with a red "SAME" sticker and the "P" key was covered with a blue "DIFF" sticker and these keys were used by the participants during the second stage to indicate their responses.

Using the methods described in Experiment 1, 12 morphs were created using black and white portrait photographs of three men and three women in two orientations: Full face and three-quarter face (31 degrees left profiles). The on-screen dimensions each picture was 16.76 cm (wide) × 13.02 cm (high).

Exposure and test procedure. The exposure phase was exactly as described for Experiment 2. The following instructions were shown prior to the test phase of the study:

> You will now see a second series of look-alikes, side by side on the screen. You may have seen some of them before. Your task is to decide whether they are different or the same. Place your fingers on the red and blue keys. Press the red key "SAME" if you think the faces are identical, or the blue key "DIFF" if you think they are different. The computer will give you feedback.
>
> Remember! Some faces ARE identical, others may look identical, but in fact they are NOT, there are subtle differences!

In the discrimination phase, the faces were presented side by side on the screen, one pair at a time until the participants responded same or different. The response triggered removal of the face, which was replaced by written feedback (Correct or Incorrect) that remained on the screen for 2 s before the presentation of the next trial. After every 24 trials, participants were given the opportunity to rest before continuing.

Design and counterbalancing. Pairs of faces were assigned to the following three conditions: Exposed–same, where the faces were presented either full or three-quarter face in both exposure and discrimination phases; exposed–change, where faces presented three-quarter face in the exposure phase were presented in full face during discrimination testing and vice versa; control, where the faces were first encountered during the discrimination either in full or three-quarter face. The assignment of faces to conditions was counterbalanced so that each pair was presented equally often in each condition and at each viewing angle. The order in which the faces were exposed in the exposure phase was also counterbalanced.

During the discrimination phase, four trials with a face pair were given as a block before moving onto the next face pair. In two trials the same stimulus was presented on both sides of the screen (e.g., A A and A* A*). The other two trials consisted of one copy of each face in the pair (e.g., A A* and A* A). The order in which these trials were presented within a block was randomized. The order in which blocks of face pairs were presented was randomized with the restriction that participants received one block with each face pair before being given the opportunity to rest prior to continuing. There were four blocks of trials with each pair of faces.

Data analysis. The primary measure of performance in Experiment 3 was the accuracy of responding (examined as the percentage correct) during the test. Inspection times were also examined to assess any effects of the speed of responding on accuracy.

Results and discussion

A preliminary analysis of the exposed groups found no effect of the angle at which faces were presented and no interaction between exposure condition and orientation; therefore the accuracy scores were collapsed over test orientation. Figure 4 shows these accuracy scores for Experiment 3. Inspection of this figure indicates that performance was more accurate in both the exposed–same and exposed–changed conditions than in the nonexposed control condition. ANOVA revealed a significant effect of exposure condition, $F(2, 50) = 5.07$, $p < .01$. Subsequent tests revealed that

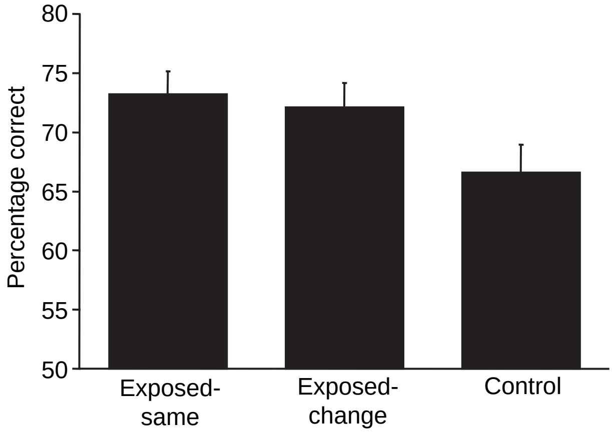

Figure 4. Experiment 3. Mean discrimination accuracy as percentages correct (with SEM). Faces in the exposed–same condition were presented at the same angle (either full or three-quarter face) during exposure and test; in the exposed–change condition the angle was changed between exposure and test (between full and three-quarter face); and there was no exposure before test in the control condition (involving either full or three-quarter face).

accuracy in both the exposed–same and exposed–change conditions was superior than in the control condition, $F(1, 25) = 9.94$, $p < .005$, and $F(1, 25) = 4.53$, $p < .05$, respectively, and that the two exposed conditions did not differ, $F < 1$. Table 2 shows the reaction time data from Experiment 3. There was no significant effect of exposure condition ($F < 1$). In the absence of significant differences in reaction times it is unlikely that the speed with which participants responded contributed to differences in accuracy.

The results of Experiment 3 show that brief exposure to our morph-created faces produced a perceptual learning effect that is not specific to the particular views of the faces presented during exposure. The key implication of this fact is that the advantage of exposure is not dependent on image-based processing because it was not affected by a change in the stimuli that was produced here by a change in viewpoint (see also, Bruce, 1982).

GENERAL DISCUSSION

Three experiments examined the effect of brief unsupervised exposure to pictures of faces on participants' subsequent ability to discriminate between them. Experiment 1 demonstrated that discrimination was better when the faces were presented upright than when they were inverted and that the discrimination was better for exposed faces when they were tested in the same orientation as exposure. Experiment 2 demonstrated that the advantage in discrimination performance conferred by exposure was selective to internal features of the faces. Experiment 3 demonstrated that exposure produced an advantage irrespective of whether or not there was a change in the angle at which the faces were viewed, and thus a change in the images presented, between exposure and test. The fact that the current tasks involved discrimination, either learning to categorize people as married or unmarried in Experiment 1 or making same/different judgements in Experiments 2 and 3, requires comment as these indices of performance differ from many other studies of face processing that are based on performance in tests of recognition memory or face matching. This emphasis on recognition and matching directly reflects one of the key goals of face processing, namely the ability to identify individuals. However, identifying an individual is not simply a process of matching from a stored sample to a target, but also requires the ability to discriminate between that sample and nontargets. This is not to say that recognition and discrimination tasks address entirely separate aspects of behaviour: For example, while Ellis et al. (1979) used recognition tasks in their demonstration that internal features are more heavily weighted than external features in representation of familiar faces that they are in unfamiliar faces, O'Donnell and Bruce (2001) used a discrimination task to demonstrate that this internal weighting was selective to the eye region. The fact that the current tasks focus on discrimination of similar faces complements and extends previous studies of acquired face familiarity which used different performance assays.

Inversion effects, an advantage for internal features in the processing of familiar faces, and the fact that the processing of familiar faces is not disrupted by a change in image, have all be demonstrated previously in the context of face processing (e.g., Bruce, 1982; Bonner et al., 2003; Ellis et al., 1979; O'Donnell & Bruce, 2001, Yin, 1969). The results of Experiments 1–3 show that these well-established findings are also seen in the current situation where the images used were created with a morphing procedure and familiarity was induced experimentally by intermixed, brief exposure. The fact that well-established results from the face processing literature have been replicated with the current stimuli and testing procedures confirms that the current stimuli are indeed being processed as faces and that the experimental exposure did produce characteristics of familiar face processing.

The fact that the current procedures exhibit several hallmark features of face processing is especially important in the light of previous findings using procedures similar to those of Experiments 1–3. Mundy et al. (2007) demonstrated that the schedule of exposure affects perceptual learning with pictures of faces in that intermixed exposure (i.e., A, A, . . . A*, A*, . . .) is superior to blocked exposure (i.e., A, A, . . . A*, A*, . . .), and simultaneous exposure (i.e., A and A*) is superior to intermixed exposure. As noted in the introduction to this paper, similar results have been reported with other stimuli and in other species. The pattern of results reported by Mundy et al. is consistent with the idea that perceptual learning mechanisms of a general nature (e.g., Gibson, 1969; Hall, 2003; McLaren & Mackintosh, 2000; Saksida, 1999) contribute to the processing of face stimuli. This conclusion was necessarily speculative on the basis of the results presented by Mundy et al. alone, because they presented no direct evidence that their stimuli did in fact engage face processing mechanisms. The results of Experiments 1–3 provide direct support for this conclusion.

Gold and colleagues (e.g., Gold et al., 1999a, 1999b, 2004) demonstrate that perceptual learning with both faces and nonface stimuli is due to an increase in the internal signal strength of the familiar stimuli. Considered together with the current results, those of Mundy et al. (2007) suggest that the schedule of exposure has the same effects on face processing (i.e. a superiority for intermixed over blocked exposure) as it does with nonface stimuli. This parallel suggests a common mechanism is responsible for perceptual learning effects seen with faces and nonface stimuli. This is not to deny that face processing is in many ways "special" as a cognitive activity (cf., Ellis & Young, 1989; Farah, Wilson, Drain, & Tanaka, 1998), but simply to assert, with respect to perceptual learning, that mechanisms appear to be conserved across stimuli. Although the parallels between perceptual learning with face and nonface stimuli imply a common mechanism, it remains an open question whether face processing relies on rather general mechanisms for perceptual learning or whether face-specific processing happens to conserve the operating characteristics of other, ubiquitous learning mechanisms.

The current results also demonstrate that unsupervised, brief, intermixed exposure to two similar faces generates key features of familiar face processing during subsequent tests. This form of exposure was the same as that used by Mundy et al. (2007). Accepting that the results reported by Mundy et al. and Gold and colleagues (e.g., Gold et al., 1999a, 1999b, 2004) support the conclusion that stimulus-general mechanisms of perceptual learning contribute to face processing implies a further idea: Namely that general perceptual learning mechanisms contribute, at least in part, to the acquisition of face familiarity. It has previously been assumed that the superior processing of familiar faces was due to some perceptual learning process that occurs during exposure to the relevant faces. The current results, taken alongside those of Mundy et al. (2007), support the idea that perceptual learning is indeed involved with the superior processing of familiar faces and, as already mentioned they suggest that the perceptual learning mechanisms involved are stimulus-general rather than being specific to the face domain.

Finally, three features of our experiments require comment. First, whereas many previous laboratory demonstrations of acquired familiarity effects involved supervised learning (in which labels were learnt for the faces; e.g., O'Donnell & Bruce, 2001; Stevenage, 1998), the current results confirm that some characteristic properties of face familiarity can be produced by unsupervised exposure. Second, the current experiments used a very restricted amount of exposure (as little as 10 s to a single view of a face) compared to previous demonstrations of acquired familiarity (e.g., Bonner et al., 2003, which used 90 s exposure to multiple views of a face). However, our results are not unprecedented, as Clutterbuck and Johnston (2004, 2005) report that a total of 20 s of unsupervised exposure was sufficient to improve performance on matching and gender decision tasks. Third, in conjunction with the results of Mundy et al. (2007) our results imply that it is not simply the amount of exposure but also how that exposure is arranged that contributes to the familiarity–based changes in face perception. In summary, these results confirm, using discrimination tasks, that some qualitative changes in face perception due to familiarity do not require supervised training and can occur relatively rapidly.

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