

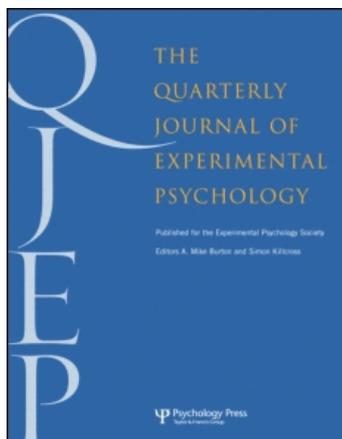
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Perceptual learning in face processing: Comparison facilitates face recognition

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Theoretical analyses of perceptual learning suggest that comparison between similar stimuli aids subsequent discrimination between them. The current studies examined whether the opportunity to compare a target face to other similar faces during a preexposure phase facilitated performance on a matching task. Performance was better when the target face had been presented in alternation with similar comparator faces than if that target had not been exposed before test. Exposure to the target face without comparators, or exposure alternating with dissimilar faces, improved performance relative to the nonexposed control but performance was not as good as when target exposure was given in alternation to similar comparison faces. The effects were not influenced by image changes between exposure and test. It is suggested that exposure to a face in comparison to similar stimuli focuses the central representation of a face on its unique features. In practical terms these results suggest that reliable identification of an individual from their photograph would be improved by viewing that photograph in comparison with photographs of similar people.

Keywords: Perceptual learning; Faces; Adaptation; Identification; Applied.

On 22 July 2005 Jean Charles de Menezes was fatally shot by police on a London train. He had been incorrectly identified as matching the photograph of a terrorist suspect. This tragic misidentification highlighted the fact that it is not a trivial matter to recognize a stranger from their photograph even though law enforcement agents have been acquainting themselves with photographs of suspected criminals in the hope of recognizing them later since the 19th century (Cole, 2001). The fallibility highlighted by the de Menezes

case is entirely in line with field research demonstrating a very substantial error rate when people are given a photo of an unfamiliar target face and are asked to identify them on the street (Logie, Baddeley, & Woodhead, 1987) or decide whether a person matches a credit card photograph (Kemp, Towell, & Pike, 1997).

Laboratory research also supports the idea that, even under ideal conditions, there are substantial error rates when people are given a photo of an unfamiliar target face and are asked to identify it

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in an array of other faces (Logie et al., 1987). More recently Bruce et al. (1999) asked participants to match a still image taken from high-quality video to an array of studio-quality photographs taken on the same day as the videos without any time pressure or memory load. Performance was poor even when the viewpoint and expression of the target and choice arrays was matched, and when these aspects differed performance was even worse (see also Henderson, Bruce, & Burton, 2001). In addition, successful identifications were largely mediated by the external features of the picture (e.g., hair), which could easily change in real-life situations. This poor performance contrasts greatly to the ease with which people can match a familiar face (e.g., Bruce, Henderson, Newman, & Burton, 2001; Burton, Wilson, Cowan, & Bruce, 1999b).

There is an abundance of evidence showing that the processing of familiar and unfamiliar faces differs. For example, it is easier to detect whether or not there is a difference between two pictures when both are familiar than when they are novel (e.g., Buttle & Raymond, 2003), recognition memory for familiar faces is superior to unfamiliar faces when poor-quality images are used (e.g., Burton et al., 1999b), and changes in viewpoint or expression have less impact on the processing of familiar faces than on the processing of novel faces (e.g., Bruce, 1982). Moreover, Ellis, Shepherd, and Davies (1979) have shown that the internal features of the face (e.g., eyes or mouth) have relatively more influence than the external features (e.g., hair or face outline) in recognition memory for familiar than for unfamiliar faces (see also, Young, Hay, McWeeny, Flude, & Ellis, 1985).

Importantly it has also been shown that the bias to the processing of internal features in familiar faces can be produced by laboratory exposure (e.g., Bonner, Burton, & Bruce, 2003; O'Donnell & Bruce, 2001) and that the discriminability of identical twins can also be improved by experimental exposure (Robbins & McKone, 2003; Stevenage, 1998). Although these studies all involved relatively extended exposure to multiple views of each face they do demonstrate that at

least some aspects of the superior processing associated with familiar faces can be produced by experimental exposure. Bruce et al. (2001) also showed that recognition was poor with unfamiliar individuals and that, with one exception, watching a one-minute video clip of some targets was not sufficient to raise the recognition rates above otherwise unfamiliar targets. The one exception to this failure was that when the videos were watched in pairs, and the participants were asked to discuss the people they were watching, then there was a significant increase in performance. The idea that encouraging in-depth processing of a face improves later recognition is supported by classic studies showing that making personality judgements about presented faces improved later recognition (e.g., Bower & Karlin, 1974; Patterson & Baddeley, 1977).

Against this background of laboratory research suggesting that it is difficult to identify an unfamiliar face from their photograph and that brief periods of exposure produce relatively little facilitation it is noteworthy that Mundy, Honey, and Dwyer (2007) reported that as few as 5 two-second exposures to a pair of similar morph-created faces facilitated subsequent discrimination between them (see also Dwyer, Mundy, Vladeanu, & Honey, in press). Why was this brief exposure effective? Mundy et al. (2007) demonstrated that it was not the absolute amount of time that the faces were exposed that was important but rather the schedule of that exposure: For example, alternating or simultaneous exposure to two similar faces was more effective in promoting subsequent discrimination between them than was the same amount of exposure given in separate blocks for each face. One key aspect of these schedules was that they permitted direct comparison between the stimuli—a factor highlighted by Gibson (1969) as being the key to perceptual learning. This idea that comparison facilitates the effects of exposure to faces is also consistent with an experiment by Clutterbuck and Johnston (2005) in which 10 two-second, but not 5 four-second, exposures to each of a set of 12 previously unfamiliar faces was sufficient to improve performance on a face-matching task

and that this was selective to the internal features of the face. While both exposure conditions allowed the same overall exposure time to the target faces, larger numbers of shorter exposures would have allowed more opportunities to compare each face to the others in the exposure set.

Unfortunately there is one critical problem that prevents a direct application of Gibson's (1969) idea that perceptual learning is underpinned by comparison to the current problem of learning to recognize an unfamiliar face. Gibson explicitly argues that exposure to similar stimuli will facilitate discrimination between the exposed stimuli but is silent on the issue of whether this exposure will facilitate processing of each individual stimulus per se. Moreover, evidence from the animal literature suggests that while alternating exposure to two similar stimuli improves discrimination between them it does not support a similar improvement in discriminating the exposed stimuli from equally similar stimuli that were not exposed in alternation to the targets (e.g., Blair & Hall, 2003). This problem is highlighted by examining the designs of the experiments reported by Mundy et al. (2007): Although they show that comparison between two similar faces facilitates discrimination between them they do not examine whether such comparison also facilitates the discrimination of either of those faces from other nonexposed faces.

Thus the main aim of the current studies was to examine whether relatively brief exposure to a target would facilitate test performance in which the target face has to be discriminated from faces not seen during exposure. These studies also addressed the question of whether providing the opportunity to compare the target face to other similar faces during exposure contributed to the facilitatory effects of exposure.

EXPERIMENT 1

As noted above, people find matching between a target and a face in a choice array much simpler when the target faces are familiar. Therefore Experiment 1 examined whether relatively brief exposure to a target face (twelve 2-s exposures)

would facilitate performance on a matching task. The data presented by Mundy et al. (2007) indicated that comparison between stimuli facilitated the effects of exposure on subsequent discrimination performance. Thus in the current experiment one target face was presented in alternation with similar comparator faces (the exposed condition) while a second target face was not presented during the exposure phase (the control condition). In order to hold participants' interest in the exposure phase blocks of exposure to the male target face and its similar comparators were separated by blocks of exposure to dissimilar (female) nontarget faces. During test the participants were shown one of the target faces and were asked to select it from an array consisting of the target plus four similar foils. Table 1 shows the design for the training and test phases of Experiment 1, and Figure 1 shows the target faces used in Experiments 1 and 2. It should be noted that in the exposed condition the foils for the test session were different from the faces used as similar comparators during the exposure phase. So if the effects of exposure are limited to facilitating discriminations between the exposed stimuli then there should be no effect of exposure. The target face was always presented facing forward but the test arrays were presented under three conditions: frontal (i.e., the same as the target), degraded (25% noise filter applied with Adobe Photoshop), and angled (30 degrees). Thus in the degraded and angled conditions the target and choice arrays differed in format, which would prevent the use of any simple feature-matching processes. Figure 1 shows an example of how the stimuli were presented in the angled test condition (note that the layout was the same for all test conditions). This figure also shows examples of the similar and dissimilar comparator faces (note that the dissimilar comparator faces were used as the exposure-phase fillers in the current experiment).

Method

Participants and apparatus

A total of 49 participants, 37 female and 12 male (mean age 19.7 years, range 16–50 years), visiting

Table 1. Design of Experiments 1 and 2

		Training sequence	Test arrays
Experiment 1	Exposed	A, A1, A, A2, A, A3, A, A4	Select A from array of A and A5, A6, A7, A8
	Not exposed		Select B from array of B and B5, B6, B7, B8
Experiment 2	Similar	A, A1, A, A2, A, A3, A, A4	Select A from array of A and A5, A6, A7, A8
	Dissimilar	B, X1, B, X2, B, X3, B, X4	Select B from array of B and B5, B6, B7, B8
	Alone	C, C, C, C	Select C from array of C and C5, C6, C7, C8
	Not exposed		Select D from array of D and D5, D6, D7, D8

Note: A to D are target faces while Versions 1–8 (e.g., A1 to A8) are similar comparator faces made by morphing away from the target face of the same letter. X1 to X4 are dissimilar comparator faces made by morphing away from a seed face that was different in sex and identity to the male target faces. Each training exposure sequence detailed here was presented as a block and was repeated three times: In Experiment 1 a block of four female faces was presented after each target block while in Experiment 2 there were no stimuli interleaved between blocks. During training exposure each stimulus was present for 2 s with a 1-s inter-stimulus interval (ISI). As shown in Figure 1 the test involved matching the presented target to the appropriate stimulus in a choice array. Each target face was tested with the faces in the choice array in one of three conditions: frontal, degraded, and angled (the sample version of the target face was always presented facing forward). Each of these test conditions was presented three times per target face.

the School of Psychology at Cardiff University for an open day, took part in the experiment as an example of a psychological study. All had normal or corrected-to-normal vision. IBM-compatible PCs displayed the stimuli in an evenly lit, quiet room and recorded responses. Participants were tested in groups of 9 to 21 people.

Stimuli

Stimuli were created using a face generation package (SI FaceGen Modeller 3.1; Singular Inversions, Toronto, Canada). Two male target faces were created for use in Experiment 1, and a further two were created for use in Experiment 2. Each target face was random generated as a whole using the “Generate” function with the constraint that the “Symmetry” and “Caricature” sliders were kept at “Average” and “Typical” in order to control for distinctiveness effects. For each target face eight similar comparators were created. These similar comparators were created by morphing away from the target face in a random direction, but by a set amount, using the “Genetic” tool (with the “Similarity” slider set to 0.3) in FaceGen Modeller. Dissimilar comparators were created by using a female seed face and the same random morphing process. This process ensured that the similar comparators were all

more similar to the target than the dissimilar comparators because the similar comparators had the target face as the seed while the dissimilar comparators did not (in addition to the fact that the similar comparators were of the same sex as the target face while the dissimilar comparators were not). In order to remove any nonface cues, the faces were generated without hair or accessories such as moustaches, eyeglasses, or piercings. Each face could be presented in three conditions: frontal, degraded (25% noise filter applied with Adobe Photoshop), and angled (30 degrees). Stimuli were 14 × 13 cm (height × width) during exposure and 7 × 6.5 cm during test.

Exposure and test procedure

Participants were seated 70 cm from the screen and were instructed to examine the faces carefully and try to memorize them and their names. During exposure a target face was presented, along with a name, in alternation with the presentation of similar comparator faces (condition exposed). The name was simply used to make instruction easier as participants were asked to remember the named individuals as opposed to the unnamed comparators. Memory for the face–name pairs was never assessed, and the names were not present during the test phase matching task. The

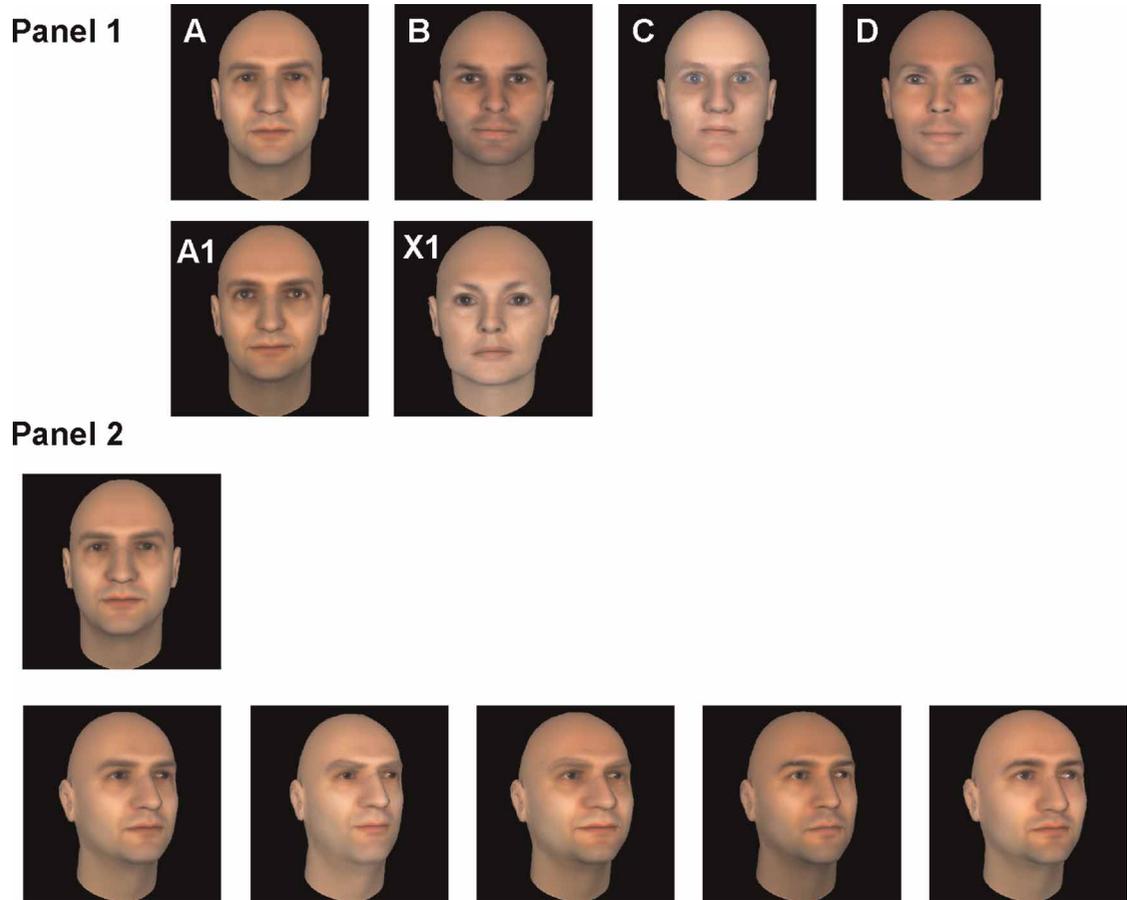


Figure 1. Panel 1 shows examples of stimuli used in Experiments 1 and 2. Faces A–D are the four target faces (Faces A and B were used in Experiment 1 while Faces A–D were used in Experiment 2). They were shown in this orientation during training and during test in the frontal condition. Faces A1 and X1 are examples of similar and dissimilar comparators, respectively, for Target Face A. Panel 2 gives an example of a test trial in the angled condition: Participants were asked pick the face from the array at the bottom that matched the target presented at the top left of the screen (in this case the face on the extreme right is correct). To view a colour version of this figure, please see the online issue of the Journal.

target face was presented four times in a block for two seconds each time. Four different comparator faces were presented in each block, also for two seconds, and there was a one-second interval between stimuli. Participants were given three blocks of exposure to the target face; in between these blocks they were presented with four female faces (once each for 2 s with a 1-s interstimulus interval, ISI) that were dissimilar to the male target faces and similar comparators. A second target face was not presented during the exposure

phase (condition not exposed). The assignment of faces to condition was counterbalanced across participants.

During test a target face was presented frontally in the top left corner of the screen, and an array consisting of the target and four similar foils was presented below. These were created by the same method as that for the similar comparators. The stimuli used as training comparators and test foils were counterbalanced across participants. Thus, across participants, the training comparators

and test foils were equivalently similar to the target face. Participants were required to choose the face in the array that matched the target. Choice arrays were presented in three conditions: frontal, degraded, and angled. Each target face was presented three times in each of the three test conditions. The order of testing was constrained so that participants received one test trial with each target face before moving onto a second trial with any other target face. The order in which the three test conditions were presented for a given target faces was randomized. Thus this experiment was performed fully within subject with all participants being tested with an exposed and a nonexposed target face, and each target face was presented in all test conditions.

Results and discussion

Responses were collated as the percentage of correct identifications per condition for each participant. These scores are shown in Figure 2 and were analysed using analysis of variance (ANOVA) with within-subject factors of exposure type (exposed, not exposed) and test condition (frontal, degraded, angles). All statistical tests

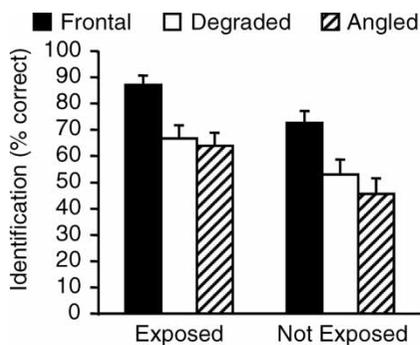


Figure 2. Matching performance as percentages (with SEM) from Experiment 1. Participants were presented with a target face (presented front on) and were asked to match it to one of five faces in an array below. Frontal, degraded, and angled refer to the condition in which this choice array was presented. Stimuli in the exposed condition had been shown in alternation with similar comparators prior to test. Stimuli in the not exposed condition were seen for the first time on test.

reported here used a significance value of $\alpha = .05$. There were significant effects of exposure, $F(1, 48) = 9.53, MSE = 1.65, p = .003$, and test condition, $F(2, 96) = 21.39, MSE = 0.73, p < .001$, with no interaction ($F < 1$). Pairwise comparisons confirmed that performance in condition frontal was better than that in conditions angled and degraded, $F(1, 48) = 38.25, MSE = 0.73, p < .001$, and $F(1, 48) = 25.46, MSE = 0.70, p < .001$, respectively, which did not differ, $F(1, 48) = 1.51, MSE = 0.76, p = .226$. Table 2 shows the mean inspection times on test for Experiment 1. ANOVA revealed no significant effect of exposure, $F(1, 48) = 3.14, MSE = 25.86, p = .083$, a significant effect of test condition, $F(2, 96) = 12.57, MSE = 25.13, p < .001$, and an interaction between them, $F(2, 96) = 23.16, MSE = 16.45, p < .001$. Although there were some significant differences in the time spent inspecting the test stimuli it is unlikely that this can have produced the differences in accuracy by way of a speed/accuracy trade-off as inspection times are not the mirror image of

Table 2. Mean inspection times during the discrimination test for each condition in Experiments 1 and 2

		Inspection time (s)	SEM
Experiment 1			
Exposed	Frontal	11.8	0.9
	Degraded	11.6	0.5
	Angled	9.5	0.6
Not exposed	Frontal	8.3	0.7
	Degraded	15.4	1.1
	Angled	12.4	0.7
Experiment 2			
Similar	Frontal	8.1	0.5
	Degraded	11.8	0.8
	Angled	9.8	0.6
Dissimilar	Frontal	9.5	0.7
	Degraded	10.7	0.7
	Angled	8.8	0.7
Alone	Frontal	8.9	0.8
	Degraded	10.4	0.6
	Angled	9.0	0.6
Not exposed	Frontal	9.6	0.6
	Degraded	10.8	0.7
	Angled	8.6	0.6

accuracy scores: For example, the degraded condition had the longest inspection times but also resulted in poor accuracy, and the exposed condition was more accurate and tended to show shorter inspection times.

Unsurprisingly performance was best when the target and choice arrays were presented in the same format (i.e., facing forward and not degraded with noise); however, changing the test conditions did not affect the basic finding that accuracy in selecting the target face was better when that target face had been exposed. Thus Experiment 1 demonstrates that, in an extension of previous studies, a limited amount of exposure to a target face can improve the recognition of that face rather than simply facilitating the discrimination between exposed faces. Furthermore, this cannot be attributed to nonface-processing strategies as the same result was seen when the target and choice arrays differed in format thus preventing any simple feature-matching process.

EXPERIMENT 2

In Experiment 1 presentation of the target face was alternated with presentation of similar comparator faces. Comparison between similar stimuli is anticipated to contribute to perceptual learning (e.g., Gibson, 1969) but the results of Experiment 1 are not uniquely consistent with this idea as performance in this comparison condition was examined relative only to a nonexposed control. Therefore Experiment 2 sought to replicate the effect seen in Experiment 1 and went on to ask whether exposure to the target with similar comparators produced better subsequent performance than did exposure to the target with dissimilar comparators or no comparators at all. Four target faces were used: One was presented in alternation with similar comparator faces (condition similar: This replicates the exposed condition from Experiment 1), a second face was presented in alternation with very different comparators (condition dissimilar), and the third face was presented alone (condition alone), while the final target face was not presented before test

(condition not exposed). See Table 1 for the design of Experiment 2. If exposure to similar comparator faces contributes to the learning of the target face then performance should be better in condition similar than in all other conditions.

Method

Participants, stimuli, and apparatus

A total of 48 participants, 31 female and 17 male (mean age 22.9 years, range 18–43 years), recruited from the School of Psychology at Cardiff University, were paid £3 for their participation. All had normal or corrected-to-normal vision. An IBM-compatible PC displayed the stimuli in an evenly lit, quiet room and recorded responses.

The two target stimuli from Experiment 1 were used along with two further stimuli created in the same fashion. The stimuli were the same size and were presented under the same test conditions as those in Experiment 1.

Exposure and test procedure

Participants were seated 70 cm from the screen and were instructed to examine the faces carefully and try to memorize them and their names. During exposure each of the three target faces was presented, along with a name, in blocks consisting of 4×2 -s exposures to the target face. Participants were given three blocks of exposure to each target face. In condition similar each exposure to a target face was alternated with presentation of similar comparator faces, which were also presented for 2 s. In condition dissimilar exposure was alternated with dissimilar comparators, which were also presented for 2 s. In condition alone no comparators were presented. Throughout training there was a 1-s ISI between stimuli, and so the interval between target stimulus presentations within a block was shorter in the alone than the similar and dissimilar conditions. The order in which these blocks of exposure were given was randomized with the constraint that no target face was presented in two consecutive blocks. A fourth target face was not presented during the exposure phase (condition no exposure). The assignment of faces to condition

was counterbalanced across participants. The same testing procedure was used as that in Experiment 1. Thus this experiment was performed fully within subject with all participants being tested with a target face in each of the similar, dissimilar, alone, and not exposed conditions, and each target face was presented in all test conditions.

Results and discussion

Responses were analysed as percentage of correct identifications and these data are shown in Figure 3 as a factor of both exposure and test condition. ANOVA revealed effects of exposure, $F(3, 141) = 9.39$, $MSE = 1.42$, $p < .001$, and test condition, $F(2, 94) = 9.65$, $MSE = 0.76$, $p < .001$, with no interaction ($F < 1$). Pairwise comparisons confirmed that identification was better in condition similar than in conditions dissimilar, $F(1, 47) = 4.54$, $MSE = 1.13$, $p = .038$, alone, $F(1, 47) = 7.67$, $MSE = 0.70$, $p = .008$, and no exposure, $F(1, 47) = 20.22$, $MSE = 1.31$, $p < .001$. Conditions dissimilar and alone did not differ ($F < 1$) and were both better than

no exposure, $F(1, 47) = 17.03$, $MSE = 0.49$, $p < .001$, and $F(1, 47) = 8.11$, $MSE = 0.99$, $p = .007$, respectively. With respect to the effect of test condition, frontal was better than conditions angled and degraded, $F(1, 47) = 9.49$, $MSE = 0.45$, $p = .003$, and $F(1, 47) = 22.04$, $MSE = 0.30$, $p < .001$, respectively, which did not differ ($F < 1$). Table 2 shows the mean inspection times on test for Experiment 2. ANOVA revealed no significant effect of exposure ($F < 1$), a significant effect of test condition, $F(2, 94) = 17.24$, $MSE = 13.26$, $p < .001$, and an interaction between them, $F(2, 94) = 2.31$, $MSE = 10.12$, $p = .035$. As with Experiment 1 it is unlikely that this can have produced the observed differences in accuracy by way of a speed/accuracy trade-off as inspection times are not the mirror image of accuracy scores: For example, the degraded condition had the longest inspection times but also displayed very poor accuracy.

The crucial result here was that exposure to the target face, along with similar comparators, produced the best accuracy when the target face was picked from the choice array on test. This facilitation in performance cannot be attributed to nonface-processing strategies as the same result was seen when the target and choice arrays differed in format thus preventing any simple feature-matching process. Importantly, the differences between conditions in test performance are not due simply to differences in the intervals between each presentation of the target face during exposure: Performance in the dissimilar and alone conditions did not differ despite the fact that the interval between exposures to the target faces was shorter in the alone condition, while there was a difference in test performance between the dissimilar and similar conditions despite the intervals between target exposures being the same. It is also true that simple exposure to the target faces also improved test performance to some degree compared to nonexposed faces even though the amount of exposure was relatively small. An inspection of the target faces in Figure 1 shows that they are all somewhat similar. As participants received interleaved blocks of exposure with each target face then they would have had

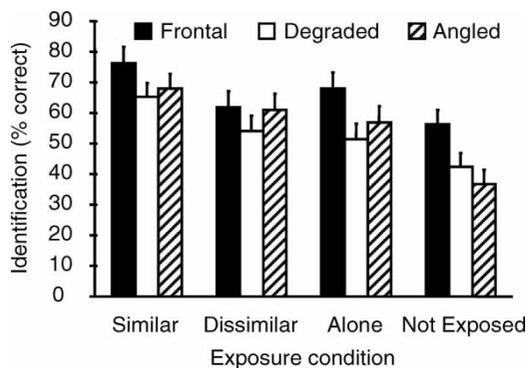


Figure 3. Matching performance as percentages (with SEM) from Experiment 2. Participants were presented with a target face (presented front on) and were asked to match it to one of five faces in an array below. Frontal, degraded, and angled refer to the condition in which this choice array was presented. Stimuli in the similar condition had been shown in alternation with similar comparators prior to test. Stimuli in the dissimilar condition had been shown in alternation with dissimilar comparators, while stimuli in the alone condition were exposed without comparators. Stimuli in the not exposed condition were seen for the first time on test.

some opportunity to compare each of the exposed faces to other, relatively similar, faces. Unsurprisingly performance was best when the target and choice arrays were presented in the same format (i.e., facing forward and not degraded with noise); however, the absence of any interaction between test condition and exposure confirms that test condition did not affect the critical finding that accuracy in selecting the target face was better when that target face had been exposed than with similar faces.

GENERAL DISCUSSION

The current experiments confirm that exposure to a target face in comparison to other similar faces facilitates performance on a matching task with that face. This extends previous results by demonstrating that the improvement is not simply due to an improved discrimination between the exposed faces. Although not widely explored in the previous face-processing literature the idea that comparison makes a significant contribution to perceptual learning has a long history (e.g., Gibson, 1969). The importance of comparison might also explain why only some previous studies were able to show facilitation based on brief exposure. For example, discussion of the exposed faces with a partner could have encouraged them to make explicit comparisons between faces (Bruce et al., 2001; see also Clutterbuck & Johnston, 2005). Similarly, the fact that prior studies have shown that exposure to multiple views of a face facilitates recognition (e.g., Lander & Bruce, 2003; Pike, Kemp, Towell, & Phillips, 1997) might also be partially based on the fact that this treatment also allows comparison between multiple two-dimensional representations of the same face supporting the development of a viewpoint-independent three-dimensional representation. It should be noted that although we have shown that comparison facilitates learning a new face it is unlikely that processing of these faces would be equivalent to that of a highly familiar face. Indeed, Tong and Nakayama (1999) show that extensive laboratory exposure

fails to completely remove the difference between a previously unfamiliar face and a face that had previously become familiar under natural circumstances. That said, the fact that natural exposure to a face over an extended period of time would allow for a comparison between that person and others, as well as a comparison between different views of the face, makes it possible that comparison processes could contribute to the formation of the sort of "robust" representation that Tong and Nakayama (1999) suggest is formed of highly familiar individuals.

There is abundant evidence (e.g., Jenkins, Beaver, & Calder, 2006; Leopold, O'Toole, Vetter, & Blanz, 2001; Rhodes & Jeffery, 2006; Webster, Kaping, Mizokami, & Duhamel, 2004; Webster & MacLin, 1999) that exposure to a face produces adaptation effects, which can affect both general perception (e.g., viewing a face results in an identity after-effect in which perception is biased towards the opposite identity) and the perception of individual face features (e.g., viewing one gaze direction results in a shift of perceived gaze in the opposite direction). Rhodes et al. (2005) interpret these after-effects in terms of an adaptive coding model whereby in each dimension in face-space there are two pools of neurons. One pool responds to values high on the dimension, and the other responds to values low on the dimension, with the value of a face on any given dimension coded by the relative activation of these two neuronal populations. The strong activation of either of these neuronal populations produces a temporary reduction in their response and so produces a shift in the perceived value on the dimension in the opposite direction. In other words, the response to nonadapted features will be relatively higher than the response to adapted features. Mundy et al. (2007) argue that this adaptation-dependent change in the response to the features of faces could provide a mechanism to explain why comparison is so effective in facilitating perceptual learning with faces. Briefly put, they noted that when two similar stimuli are presented in alternation the features that are common to both are present on every trial and thus should be subject to more adaptation

than the features that are unique to one stimulus. Because the activation strength of the unique features will be higher they should come to feature more prominently in the representation of the stimulus as a whole, thus focusing the representation of the stimulus on its unique features. In the current experiments similar comparison faces should have many features in common with the target and thus drive the adaptation of these common features. This should focus the representation of the target face on its unique features, thus facilitating subsequent processing of that face. In contrast, when the comparison faces are dissimilar they will not produce selective adaptation of the target unique and nonunique features, so the representation of the target will not be so focused on its unique features. Therefore brief-acting adaptation effects might drive longer term changes in the representation of the target face. Importantly, the account described by Mundy et al. (2007) does not actually depend on any particular idea of how faces are represented as it was actually developed in the context of domain-general mechanisms for perceptual learning and assumes only that exposure to a given feature will produce a transient decrease in the response it elicits (see Wagner, 1981, for an example of a very general instantiation of this idea).

The idea that some process of perceptual learning might contribute to face processing is certainly not novel (e.g., Bruce & Burton, 2002; O'Toole, Abdi, Deffenbacher, & Valentin, 1995; Valentine, Chiroro, & Dixon, 1995).¹ One way in which this process of perceptual learning has been envisaged is via the application of a principal component analysis (PCA, e.g., Burton, Bruce, & Hancock, 1999a; Furl, Phillips, & O'Toole, 2002; O'Toole et al., 1995). PCA is a statistical procedure for producing an efficient representation of a set of correlated variables in terms of a number of factors or principal components

(PCs). Any particular case in the original data can be described as a weighted sum of these PCs. One feature of this approach is that the factors extracted depend entirely on the statistical structure of the faces used to train the system, and so the extraction of factors is seen as a perceptual learning process whereby the features used by the system are developed by contact with the faces themselves. Principal component analyses are generally presented as static models (see Burton et al., 1999a for a discussion of this issue): A set of faces is presented to the system, factors are extracted, and these factors used to represent the original data (and other examples of the same form). However, the current experiments demonstrate that the efficiency with which faces can be recognized can be changed with only brief exposure and that it is not simply the amount of exposure that determines the accuracy of recognition. This suggests that, in addition to the extraction of general factors on which faces may be represented, models of face processing need to include a dynamic learning component in order to explain the process by which a face becomes familiar. Interestingly, some models (e.g., Moghaddam & Pentland, 1998; Zhao, Krishnaswamy, Chellappa, Swets, & Weng, 1998) have added a second stage to the PCA-based feature extraction where the PCA derived space is warped to improve the discrimination between individuals represented. This class of models has recently been shown to give a better account of the other race effect than do purely PCA-based models (Furl et al., 2002). The improvement in representation highlights the fact that simply extracting the relevant dimensions on which face stimuli vary might not be a complete description of perceptual learning in face processing and that modifications in the relative weights given to these factors in the representation of an individual face might also play an important role.

¹ Interestingly, the fact that people show deficits in recognition memory when faces from another race are used (for a review of this other-race effect see Meissner & Brigham 2001) has been cited as an example of perceptual learning (e.g., Valentine et al., 1995). While the other-race effect reflects the amount of contact with different race faces it may be mainly the exposure to a particular category or class of faces that is important. The current experiments focus on how exposure to individual faces affects their subsequent identification, and so the mechanisms explored here may not be directly relevant to those underpinning the other-race effect.

One simple model of face learning was presented by Burton (1994) as an addition to the interactive activation and competition model of face recognition. The model assumed faces to be represented as a combination of 12 different parameters, each of which could take on a number of different values. While this is a deliberate simplification of the representational processes involved in face processing, a more recent discussion (Burton et al., 1999a) has suggested that a realistic representation based on PCA extracted factors should not change the basic working of the model. These input factors were fully connected to a number of face recognition units (FRUs) and the weights of these connections initially set randomly. The FRUs themselves had mutually inhibitory links. Using a Hebbian process the model could learn to link a particular pattern of input to a particular FRU and thus learn to "recognize" a new face. However, in order to learn multiple faces each had to be presented repeatedly so that it was learnt well before the learning of the next face. Burton (1994) noted that this feature of the model was essentially arbitrary, and the results of the current experiments suggest that any revision of this model should address the fact that simple exposure to a single face does not appear to be the best way to train humans to recognize faces. One possible revision would be to allow for a process of short-term habituation in the input layer in order to model the suggestion made by Mundy et al. (2007). If this change was sufficient to improve the learning of new faces by the model it would support the idea that short-term adaptation effects allow for the improved processing of faces (and other stimuli) over longer periods by influencing the features that are used to represent the face.

Returning to the forensic concerns raised in the introduction, recognition of a person from their photograph can be vital, and yet exposure to a picture of a face alone was remarkably ineffective in supporting subsequent recognition of that person in prior field studies (e.g., Kemp et al., 1997; Logie et al., 1987) although simple exposure did produce at least some improvement in Experiment 2 here. The current results imply

that this problem may be at least partially overcome by allowing the opportunity to compare the picture of the target face to pictures of other similar people (although the current results should be replicated outside the laboratory before this strategy is recommended for adoption). Given that there is evidence for strong perceptual learning effects in a wide range of other real-life situations such as viewing X-ray images (e.g., Sowden, Davies, & Roling, 2000), wine tasting (e.g., Solomon, 1997), and chick sexing (e.g., Biederman & Shiffrar, 1987), there is every reason to expect that the beneficial effects of comparison in learning a new face should extend beyond the laboratory. Regardless of the cognitive mechanisms that underpin perceptual learning in face processing, perhaps the most important implication of our results is that the best way to learn to reliably identify an individual from their photograph is to view that photograph in comparison with photographs of similar people.

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