Contributions of Individual Face Features to Face Discrimination

Andrew J Logan[a], Gael E Gordon[b] and Gunter Loffler[b]

[a] School of Optometry and Vision Science, University of Bradford, UK.

[b] Department of Life Sciences, Glasgow Caledonian University, UK.

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Correspondence: Andrew J Logan; A.Logan@bradford.ac.uk

Gael E Gordon; G.Gordon@gcu.ac.uk

Gunter Loffler; G.Loffler@gcu.ac.uk

Abstract

Faces are highly complex stimuli that contain a host of information. Such complexity poses the following questions: (a) do observers exhibit preferences for specific information? (b) how does sensitivity to individual face parts compare? These questions were addressed by quantifying sensitivity to different face features.

Discrimination thresholds were determined for synthetic faces under the following conditions: (i) 'full face': all face features visible; (ii) 'isolated feature': single feature presented in isolation; (iii) 'embedded feature': all features visible, but only one feature modified.

Mean threshold elevations for isolated features, relative to full-faces, were 0.84x, 1.08, 2.12, 3.34, 4.07 and 4.47 for head-shape, hairline, nose, mouth, eyes and eyebrows respectively. Hence, when two full faces can be discriminated at threshold, the difference between the eyes is about four times less than what is required when discriminating between isolated eyes. In all cases, sensitivity was higher when features were presented in isolation than when they were embedded within a face context (threshold elevations of 0.94x, 1.74, 2.67, 2.90, 5.94 and 9.94).

This reveals a specific pattern of sensitivity to face information. Observers are between two and four times more sensitive to external than internal features. The pattern for internal features (higher sensitivity for the nose, compared to mouth, eyes and eyebrows) is consistent with lower sensitivity for those parts affected by facial dynamics (e.g. facial expressions). That isolated features are easier to discriminate than embedded features supports a holistic face processing mechanism which impedes extraction of information about individual features from full faces.

Keywords: face perception, psychophysics, unfamiliar faces, face features, holistic.

1. Introduction

Human faces share the same basic template (i.e. two eyes, above a nose, above a mouth). Therefore, in order to discriminate between them, humans have to be sensitive to subtle idiosyncratic differences in the positions and shapes of individual features. This process is made more complex by variations associated with facial dynamics used to express a wide range of emotions and communicate the direction of attention through variations in eye gaze. In order to use visual face information to accurately recognize individuals and to appropriately interpret dynamic facial information, the primate brain has evolved an interconnected network, including the occipital face area (OFA) (Gauthier et al., 2000), the superior temporal sulcus (Allison, Puce & McCarthy, 2000) and the fusiform face area (FFA) (Kanwisher, McDermott & Chun, 1997). The latter appears to be particularly important in the processing of face information which is used to discriminate between different identities (Grill-Spector, Knouf & Kanwisher, 2004, Kanwisher & Yovel, 2006).

1.1. Familiar vs unfamiliar face recognition

The way in which this network processes individual faces is dependent upon a number of factors. For example, it is well established that faces are processed differently depending on their level of familiarity (Johnston & Edmonds, 2009). Familiar faces can be recognized despite marked changes in lighting, contrast and viewpoint (Hancock, Bruce & Burton, 2000, Hill, Schyns & Akamatsu, 1997, Johnston, Hill & Carman, 1992), allowing for a degree of identity constancy. Unfamiliar face discrimination, on the other hand, is susceptible to errors resulting from incidental image artefacts, such as illumination or context changes (Bruce et al., 1999). Even a mere change in facial expression can impair unfamiliar face recognition (Bruce, 1982). fMRI has been used to show that adaptation of the BOLD signal within the FFA, which results from repeated viewing of the same unfamiliar face, can be released when the same face is shown from different viewpoints (Ewbank & Andrews, 2008). Viewpoint transformations, however, were not sufficient to remove FFA adaptation for familiar faces, suggesting that the same population of neurons responds to a particular familiar face irrespective of the direction from which it is viewed. Moreover, fMRI studies have found evidence of different cortical activation patterns in face-sensitive brain areas for familiar and unfamiliar faces (Eger et al., 2005, Rossion et al., 2001). A dissociation between familiar and unfamiliar faces is also seen in neurological conditions: some patients with prosopagnosia demonstrate preserved unfamiliar face discrimination, despite a marked impairment of familiar face recognition (Benton & Van Allen, 1972). There are also reports of the opposite; patients may be impaired for unfamiliar face matching yet can recognize familiar faces normally (Malone et al., 1982).

1.2. External and Internal Features

Faces contain a wealth of information. Previous research has investigated which information may be particularly important for the processing of face identity. A broad categorization has been made by dividing faces into external (e.g. head-shape) and internal (e.g. eyes) features. Physiologically, these sources of information are available at the level of FFA: fMRI response from the FFA is sensitive to manipulations of both external and internal face features (Andrews et al., 2010, Axelrod & Yovel, 2010).

Behaviorally, the relative importance of external versus internal features appears, once more, to depend on familiarity. Familiar face recognition accuracy is significantly higher when observers base their judgement on internal, compared to external features (Campbell, 1999, Clutterbuck & Johnston, 2005, Ellis, Shepherd & Davies, 1979, Haig, 1985, Longmore, Liu & Young, 2015, Osborne & Stevenage, 2008, Young et al., 1985). This reliable internal feature advantage for familiar faces may be a product of increased attention to features used for conveying emotions and intentions (Ellis et al., 1979). In addition, the relatively fixed nature and position of internal features, as opposed to variable external features such as hairstyles and facial hair, may make internal features a more reliable recognition cue in the long-term (Young, 1984).

Evidence regarding the relative contributions of external and internal face information to unfamiliar face perception, on the other hand, is inconclusive. An early report found that recognition of unfamiliar faces was most accurate when forehead and hairline information was utilized (Davies, Ellis & Shepherd, 1977). A number of subsequent studies have also identified an external feature advantage for unfamiliar face discrimination (Bruce et al., 1999, Fraser, Craig & Parker, 1990, Haig, 1986, Nachson & Shechory, 2002, Veres-Injac & Persike, 2009). Participants perform within normal limits on clinical tests of unfamiliar face recognition when all internal feature information has been removed (Duchaine & Weidenfeld, 2003). Further, learning to recognize an unfamiliar face is associated with a significant increase in the time spent viewing the external features (Henderson, Williams & Falk, 2005).

On the other hand, a number of reports have found no evidence of an external feature advantage for unfamiliar face perception (Clutterbuck & Johnston, 2002, Ellis, Shepherd & Davies, 1979, Hines, Jordan-Brown & Juzwin, 1987, Longmore, Liu & Young, 2015, Young et al., 1985). For example, Young and colleagues found no difference in the speed at which observers matched familiar and unfamiliar faces based on their external features. Similarly, it has been reported that unfamiliar face recognition accuracy was equivalent when observers were given either external or internal feature information (Ellis, Shepherd & Davies, 1979). The range of experimental approaches used (different memory demands, incidental photographic details) may partially account for these conflicting results (see 4.1 for details).

The first aim of the present study was to systematically investigate the relative weighting of a range of internal and external face features for unfamiliar face discrimination. We employed simplified synthetic faces in a discrimination paradigm with minimal memory requirements. The synthetic face metric allows performance to be measured in a way that facilitates direct comparison of sensitivity to different face components with each other and with that for full faces. The results will provide a formal quantification of the relative contributions of component features to unfamiliar face discrimination.

1.3. Holistic face processing

Holistic processing is generally understood to describe the integration of individual features into an interdependent representation (Maurer, Le Grand & Mondloch, 2002, Rossion, 2008). The processing of faces is considered to be holistic, rather than piecemeal (Maurer, Le Grand & Mondloch, 2002, Richler & Gauthier, 2014). Richler, Cheung and Gauthier (2011) have shown that face recognition accuracy is correlated with the degree to which individual observers engage holistic face processing and it has been proposed that impaired holistic processing may be a cardinal feature of acquired prosopagnosia (Ramon, Busigny & Rossion, 2010). As a consequence of holistic processing, the extraction of information about individual features from full faces is impeded (Sinha, Balas, Ostrovsky & Russell, 2006). This is perhaps best illustrated by the composite face effect: combining the top half of the face of one individual with the bottom half of the face of another impairs recognition of the component identities (Young, Hellawell & Hay, 1987).

Although recognition accuracy is significantly greater within full faces, observers can still recognize isolated features (Tanaka & Farah, 1993). In previous studies, masking paradigms have been used to elucidate the neural mechanisms which underlie face processing. Like other aspects of visual perception, face discrimination is impaired by a preceding mask (Loffler et al., 2005a). Although the strongest masking effect is seen for full face masks, isolated or scrambled face parts also significantly impair performance (Farah et al., 1998, Loffler et al., 2005a). These results suggest that, while holistic processing may be the dominant strategy, faces also recruit feature-based processing. This is consistent with evidence from a recent fMRI study which indicates that response patterns recorded from the OFA and FFA distinguish between isolated features (Henriksson, Mur & Kriegeskorte, 2014). A second aim of the present study was to quantitatively investigate the impact of holistic processing on individual feature discrimination for unfamiliar faces.

We addressed this aim in the following way. Discrimination sensitivity for individual face features was first measured with the features presented in isolation. The experiment was then repeated with the same features embedded within a fixed face context (see figure 2). In both conditions, the change to the task-relevant feature was identical and therefore the available information was the same, irrespective of whether the feature of interest was presented alone or alongside unchanged features. A comparison of discrimination sensitivity for individual features under these two conditions was designed to investigate the extent and nature of holistic and configural processing. We made three distinct predictions about the effect of embedding features, relative to presentation is isolation. Firstly, if unfamiliar faces recruit only part-based processing, it would be expected that discrimination thresholds are largely unaffected by the addition of a face context; performance for the isolated and embedded conditions would be comparable (see 3.2 for a discussion of the effects of spatial uncertainty and attention). Secondly, face computation might be driven by holistic processing: the integration of information across the face into a singular representation (Rossion, 2008). Holistic processing would be expected to reduce sensitivity to information about individual features when presented within a full face context (Leder & Carbon, 2005). Such a holistic hypothesis would predict that observers are less sensitive to changes made to individual features embedded within a face context, relative to the same features presented in isolation. Finally, configural processing (Maurer, Le Grand & Mondloch, 2002), the processing of the spatial relational information between component features (e.g. position of nose relative to eyes), would predict that placing a feature within a face context may improve discrimination sensitivity by providing cues about relative feature spacing and position (Vesker & Wilson, 2012). The present study directly tested these three predictions.

2. Methods

2.1. Synthetic faces

Most face studies have utilized photographs or digitally manipulated face images. The complexity of these stimuli makes it difficult to directly relate changes in sensitivity to specific face information. Synthetic faces (Wilson, Loffler & Wilkinson, 2002) are simplified stimuli which capture the major geometrical information (head-shape, hairline, feature size and position) of a face photograph. These face images have the advantage that they can be manipulated in a controlled and precise way, independent of face identity.

To create synthetic faces, the salient geometric face information was digitized from greyscale face photographs with neutral expressions (figure 1-top; Wilson, Loffler and Wilkinson (2002)). Specifically, a polar coordinate grid was superimposed on the face photograph, centered on the bridge of the individual’s nose. The external contour of the head was measured at 16 locations, angularly positioned at equal intervals of 22.5°. The positions of these points were used to define 7 radial frequencies (RFs) that describe the subject’s head-shape. Radial frequency patterns are closed contours (Wilkinson, Wilson & Habak, 1998) that can, in combinations, be used to capture the shape of animal torsos, fruit (Wilson & Wilkinson, 2002) and heads (Wilson, Loffler & Wilkinson, 2002). A further 9 points were utilized to define the shape of the subject's hairline.

The internal face features were defined by 14 additional measurements. The position of all features was idiosyncratic, as derived from the photograph. The shapes of the eyes and eyebrows were generic; those of the mouth and nose were individualized. In sum, each synthetic face is defined by 37 parameters and represented by a 37-dimensional vector (see Wilson, Loffler and Wilkinson (2002) for further details).

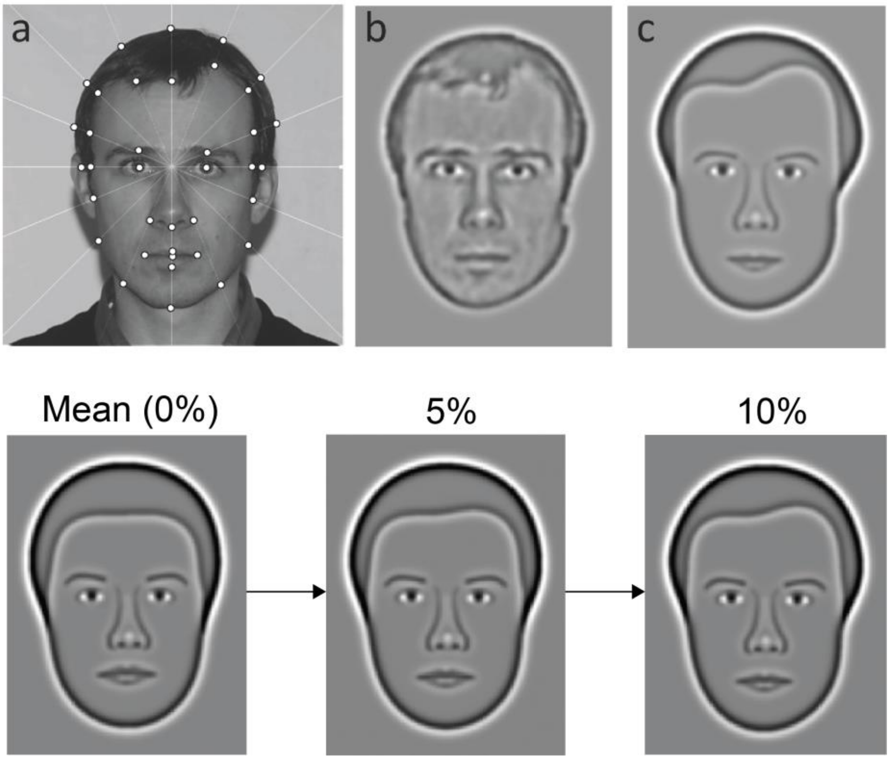

Figure 1. Synthetic faces. Top: (a) Greyscale photograph superimposed with polar coordinate grid centered on the bridge of the nose. The head-shape was measured at 16 locations around the external contour (outermost small white circles), 9 points in the upper half of the face captured hairline information. The location and shape of the internal face features were also digitized. (b) Photograph filtered with a 2.0 octave bandwidth DOG filter with peak spatial frequency of 10 c/face width. (c) Corresponding synthetic face. Bottom: Synthetic faces were adjusted by manipulating their distinctiveness, i.e. by how much they differ from the mean face (left). Increasing face distinctiveness results in individual faces becoming progressively more dissimilar (from middle to right) to the mean face. Distinctiveness is expressed as a percentage of mean head radius and quantifies the total geometric variation between the specified face and the mean face. Typical observers can discriminate a face from the mean at about 5% distinctiveness (Wilson, Loffler & Wilkinson, 2002).

The authors suggest 1 column width for figure 1. Greyscale.

The synthetic faces contain a minimal amount of information that has been shown to be sufficient to allow accurate identification (Wilson, Loffler & Wilkinson, 2002). For example, while colour (e.g. skin, hair and eye) and texture are present in real faces, faces can be identified without this information. As a result, the synthetic faces include neither colour nor texture.

All internal features carried positional information, relative to the centre of the face and the other features. This information is, of course, only available within a face context. The mouth and nose also carried shape information. Eyes and eyebrows were generic in shape but provided additional positional information that was independent of the other features because they were presented in pairs. Thus, each of the internal features (mouth, nose, eyes, eyebrows) carried one additional piece of information that was available without a face context (i.e. when these features were presented in isolation).

The face images were band-pass filtered at the spatial frequency which has been reported to be optimal for face identification (10 cycles/face width, circular difference of Gaussian filter with a bandwidth of 2.0 octaves) (Näsänen, 1999). While the optimal spatial frequency may be task-dependent, the resulting faces accentuate geometric information in the most important frequency band while omitting cues such as hair and skin texture, skin color and wrinkles. It should also be noted that synthetic faces only contain two-dimensional information.

All face measurements (i.e. the 37-dimensional vector representing each face) were normalized by the mean head size of the respective gender, resulting in faces that differed in terms of individual features (e.g. head-shape and eye position) but not overall size. A mean face was produced by averaging each of the 37 dimensions of all synthetic faces of the same gender. Within this framework, synthetic faces can be manipulated to have a defined difference from the mean face (figure 1-bottom). This geometric difference quantifies the distinctiveness of individual faces, expressed as a percentage of the mean head radius. It has been shown that this metric captures discrimination sensitivity independently of face identity (Wilson, Loffler & Wilkinson, 2002).

Synthetic faces from four different Caucasian male individuals were used. At the test distance of 1.20m, each face subtended 5.5° of visual angle in height.

2.2. Observers

One author (AJL) and three naïve observers (mean age = 22.5 years old, range = 19-26) completed experiment one. All four participants (one male) were in good health with normal, or corrected-to-normal, vision (visual acuity 6/6 or better, no visual abnormalities). No reimbursement was offered for participation. Participants gave informed consent in accordance with the Declaration of Helsinki, as approved by the Human Subjects Ethics Committee of Glasgow Caledonian University.

2.3. Apparatus

All trials were completed under binocular viewing, under an ambient illumination of 75 cd/m^2. Observers were seated at 1.20m from a computer monitor. Accurate viewing distance was maintained with a chin and forehead rest. Stimuli were created in Matlab (www.mathworks.com) and presented, using routines from the Psychtoolbox extension (Brainard, 1997, Pelli, 1997), on a LaCie high resolution monitor (1024 X 768 at 85 Hz) of 61 cd/m^2 mean luminance which was controlled by a Mac mini computer. 150 equally spaced grey levels were used to maximize contrast linearity. At the test distance, the computer monitor subtended 13.4° by 10.1° of visual angle; one pixel was 0.018°.

2.4. Procedure

Three different conditions were tested. The general procedure was identical in all of them. All employed a two-alternative forced choice (2-AFC) procedure using the method of constant stimuli. A target image was shown for 110ms, followed by a low-level noise mask and then a uniform grey screen, each for 200ms. The noise mask was used to remove any residual visual transient from the target exposure. Short target durations were used to minimize eye movements. Exposures of 90ms have previously been shown to be sufficient for a face discrimination task; any further increase in target duration did not improve accuracy (Lehky, 2000, Veres-Injac & Persike, 2009).

Following the offset of the grey screen, two images were presented side by side. One of them was the target. To adjust task difficulty, the other (distracter) varied from the target by a specific amount, dependent upon observer sensitivity and condition. The observer was asked to indicate the target via computer mouse click. Figure 2 provides an illustration of the experimental procedure. The two choices remained on the screen until the decision had been made. Participants were encouraged to respond quickly and guess when uncertain, no feedback was provided. A uniform grey screen (300ms) was displayed before the beginning of the next trial.

Discrimination thresholds were measured for four face identities, presented randomly within the same experimental block in an interleaved design. Discrimination accuracy for each identity was measured at 6 increments of facial distinctiveness. Each level of distinctiveness was randomly presented 20 times, resulting in 120 trials for each determination of threshold and a total of 480 trials per experimental run. Data were fit by a Quick function (Quick, 1974) using a maximum likelihood procedure (separately for each identity). Discrimination thresholds were subsequently extracted from the fitted functions and defined as the distinctiveness value which was associated with 75% accuracy.

2.4.1. Condition 1: Full Face Discrimination

In the ‘full face’ condition, observers were required to discriminate between the mean face and a face in which all of the features differed from the mean face by equal fractions (figure 2-top). The mean face was randomly assigned as the target face in 50% of trials.

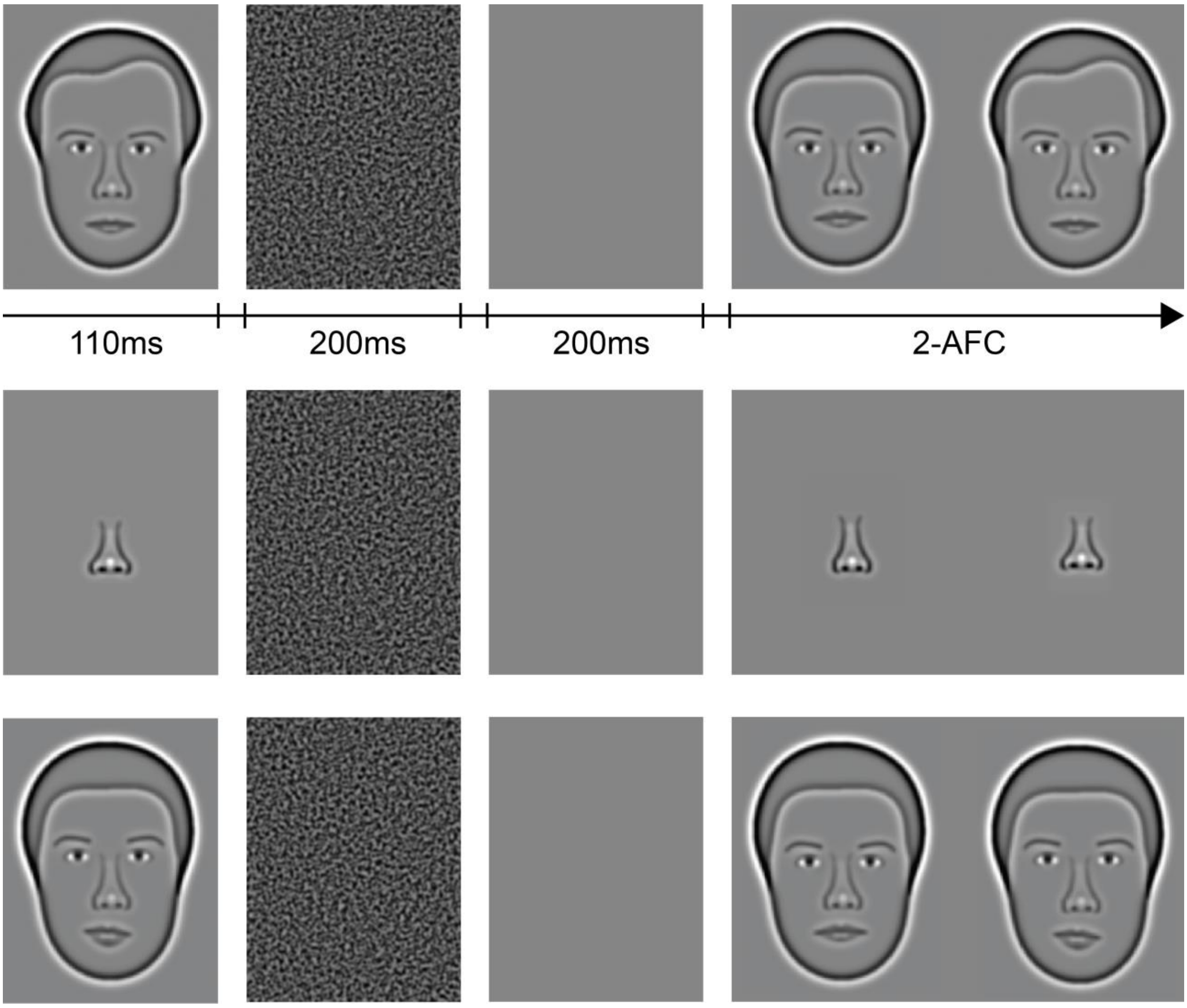

Figure 2. Procedure. Top: a single trial for the full face condition: a target face is shown for 110ms, followed by first a noise mask, then a blank screen (200ms each) and finally by two faces side-by-side. Observers have to select which of the two faces matched the target (two-alternative forced choice, 2-AFC). In this example, a non-mean face (right-hand side in 2-AFC) with a distinctiveness of 10% is the target, which has to be discriminated from the mean face (distracter). Middle: isolated feature condition. In this trial, a non-mean nose (right-hand side in 2-AFC) with a distinctiveness of 15% is the target and has to be discriminated from the mean nose (distractor). Bottom: embedded feature condition: the variable feature of interest (e.g.

mouth) is embedded within a mean face context where all other features are that of an average face. The difference between the target and the distractor is therefore restricted to the mouth.

The authors suggest 1.5-2 column width for figure 2. Greyscale.

2.4.2. Condition 2: Isolated Feature Discrimination

Six face features of interest were identified: head-shape, hairline, nose, mouth, eyes and eyebrows. The procedure was the same as for the full face condition, however, observers were now asked to match an isolated feature to one of two isolated alternatives (see figure 2-middle). The same four face identities were used as in condition 1. Note that the isolated condition (as well as embedded condition; see below) contained features that were identical to those at the corresponding distinctiveness level for the full face, i.e. an isolated nose at 5% distinctiveness was the nose extracted from a full face at 5% distinctiveness. Different features of different individuals at varying levels of distinctiveness were presented randomly within experimental runs in an interleaved design. This prevented observers from predicting which feature would be tested on individual trials. Thresholds were determined separately for each face feature (6) and each face identity (4), for a total of 24 threshold estimates per experimental run.

2.4.3. Condition 3: Embedded Feature Discrimination

This condition was identical to condition 2, apart from the addition of a task-irrelevant, fixed face context. Discrimination thresholds were measured for individual face features embedded within fixed features of the mean face. Only the feature of interest varied between the target and distracter, all others features were identical. For example, in figure 2 (bottom) the difference between the target and the distractor lies solely in the mouth, the other face features are the same. As in condition 2, an interleaved design was used in which face identity and face features were intermixed. Therefore, observers could not predict which feature was tested in any individual trial.

2.5. Statistical analysis

All statistical analyses utilized a one-factor, repeated measures ANOVA, unless otherwise specified. Where Mauchly’s test indicated that a violation of the sphericity assumption had occurred, the Greenhouse-Geisser correction was utilized. An alpha value of 0.05 was employed as the criterion for statistical significance.

3. Results

There was no significant effect of face identity on discrimination thresholds ($F_{3, 9} = 0.85$; p=0.50). Equally, there was no significant difference between observers ($F_{3,48} = 0.02$; p=0.968). Accordingly, face discrimination thresholds were averaged across face identity and observer and average data are presented and considered in all subsequent analyses.

3.1. Experiment 1: Sensitivity to different face features

3.1.1. Full faces

The average full face discrimination threshold across observers was 5.37%. This value is in line with results of previous investigations of synthetic face discrimination (Loffler et al., 2005a, Wilson, Loffler & Wilkinson, 2002). For example, Logan et al. (2016) reported a range between 3.33 and 8.84% for 52 typical observers.

The full face condition served as a baseline to which all other conditions were compared (figure 3). Data are therefore presented as threshold elevations, relative to the thresholds for the full face condition (threshold elevation of 1.00).

There was a main effect of face context [full face, isolated features, embedded features] on threshold elevations ($F_{2,6} = 63.14$; $p<0.001$). Pairwise comparisons (with Bonferroni correction) revealed that full-face discrimination thresholds were significantly lower than those for isolated (p=0.003) and embedded features (p=0.010). This result confirms the intuitive assumption that faces that differ in terms of all features are easier to discriminate than faces in which only one feature is different.

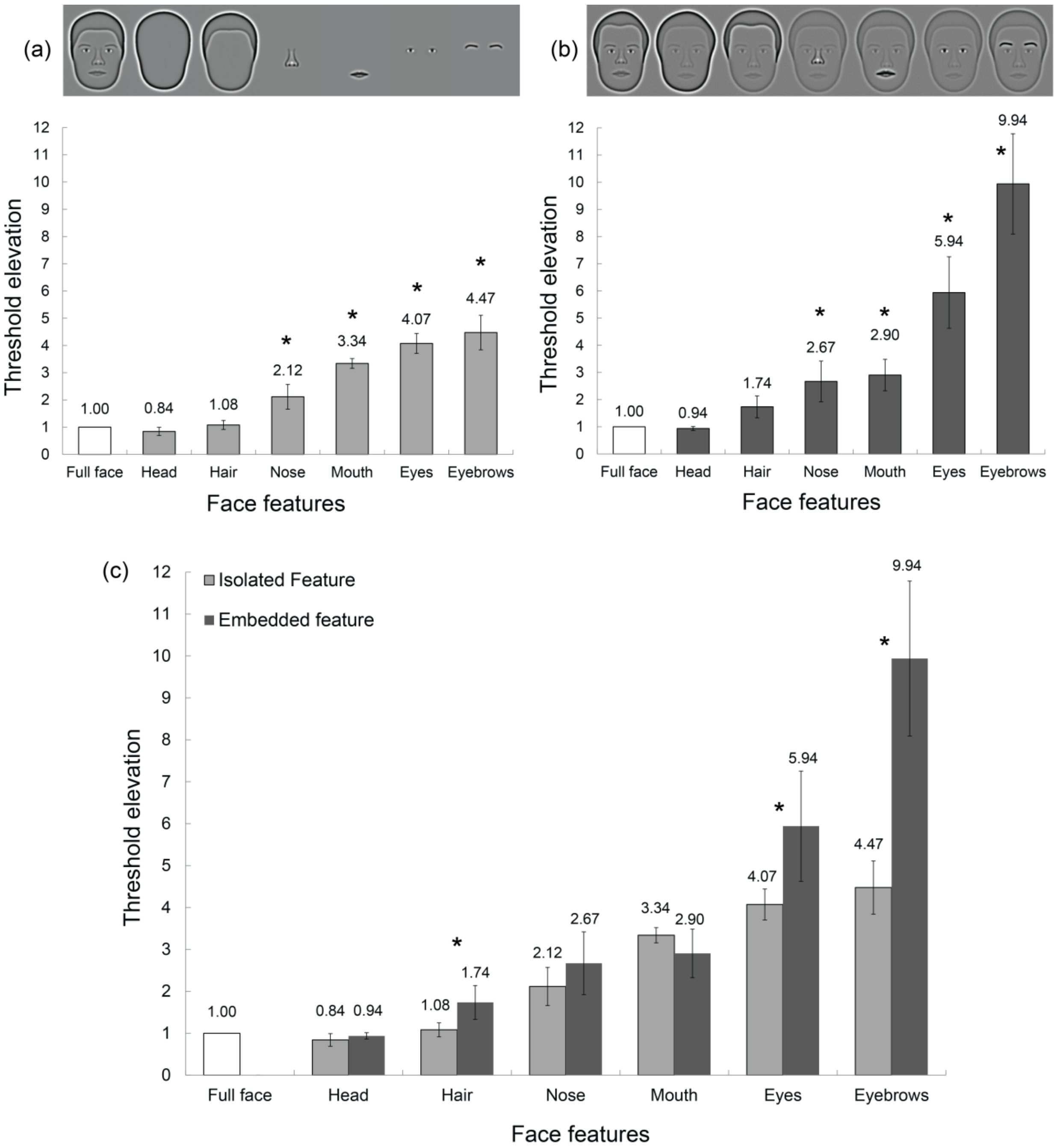

Figure 3. Discrimination thresholds for isolated and embedded features. Data are expressed as threshold elevations, relative to each observer's full face discrimination threshold (= 1.00; white bars). The numbers next to each bar are average threshold elevations. The error bars, here and elsewhere, denote 95% confidence intervals and include variability due to individual differences between observers. Based on the description of synthetic faces within a multi-dimensional vector space, sensitivities (expressed as threshold elevations, relative to the same baseline) can be directly compared across experiments. This allows the following three comparisons to be made: (i) comparing sensitivity to an isolated feature with that when the same feature is part of an overall changing full face (figure 3a), (ii) comparing sensitivity to a feature embedded within a fixed (unchanging) face with that when the same feature is part of

an overall changing full face (figure 3b) and (iii) comparing sensitivity to a feature when presented within, or outside of, a fixed face context (figure 3c). For example, a threshold elevation of 4.47x for isolated eyebrows (figure 3a) means that observers require a 4.47 times larger difference in the eyebrows when they are presented in isolation than when the eyebrows are part of a full face (in which all of the features changed by equivalent proportions). (a) Sensitivity for face features presented in isolation. Asterisks indicate significant ($p<0.001$) elevation of discrimination thresholds from the full face baseline (pairwise comparisons with Bonferroni correction). (b) Thresholds for discriminating faces based on a modification to one feature embedded within an otherwise fixed face. (c) A comparison of threshold elevations for the isolated (light bars) and embedded (dark bars) conditions. With the exception of the mouth condition, threshold elevations are larger when the variable feature is embedded within an otherwise fixed face than when it is presented in isolation. This reached significance (*; pairwise comparisons with Bonferroni correction) for the hairline (p=0.038), eyes (p=0.036) and eyebrows (p=0.009) conditions.

The authors suggest 2 column width for figure 3. Greyscale.

3.1.2. Isolated features

Figure 3a demonstrates that threshold elevations for isolated features depended strongly on the face features visible ($F_{1.6,4.9}= 109.91$; $p<0.001$). Pairwise comparisons (Bonferroni correction) revealed that threshold elevations for the two external features (head-shape: 0.84±0.15 and hairline: 1.08±0.17, mean ± SD) were not significantly greater than the full face baseline (both $p>0.05$). This suggests that observers were equally able to discriminate between full faces, in which all the features changed, and isolated head-shapes or hairlines.

Thresholds for all internal features (nose, mouth, eyes and eyebrows), on the other hand, were significantly greater ($p<0.001$) than baseline. Threshold elevations were 2.12±0.46, 3.34±0.18, 4.07±0.37 and 4.47±0.63 for the nose, mouth, eyes and eyebrows respectively. It is important to stress that the isolated feature conditions utilized features which were extracted from the same faces used in the full face condition. As a result, sensitivities to individual features can be directly compared. For instance, the mean threshold elevation for the isolated eye condition was 4.07. Therefore, a 4-fold increase in inter-pupillary distance was required to discriminate eyes in isolation, compared to where they were positioned within the full-face condition at threshold. Put another way, when two full faces can just be discriminated, the difference between the eyes is about a quarter of what is required when discriminating between isolated eyes.

3.1.3. Embedded features

A similar pattern of results was found when observers had to discriminate between two faces based on individual feature variations within an otherwise fixed face (figure 3b). Thresholds in the embedded condition again depended strongly on face features ($F_{1.6,4.9}$= 65.62; $p<0.001$). External feature discrimination thresholds were not significantly higher than baseline ($p>0.05$), whereas all internal feature thresholds were significantly elevated (all $p<0.001$).

3.1.4. Comparing isolated and embedded contexts

Although the pattern of threshold elevations is similar for the isolated and embedded conditions, the absolute values are not. A two-factor (context [isolated or embedded] and face features [head-shape, hairline, nose, mouth, eyes, eyebrows]), repeated measures ANOVA identified a significant effect of context on threshold elevations ($F_{1,3}$ = 24.15; p=0.016; η_p^2 = 0.889). Threshold elevations for embedded features were significantly higher than those for isolated features (figure 3c). This suggests that observers found it more difficult to discriminate between features when they were embedded within the same face than when they were presented in isolation.

There was also a significant interaction between context (isolated or embedded) and face features ($F_{1.9,5.8}$ = 25.04; p=0.001; η_p^2 = 0.893). This indicates that the detrimental effect of embedding is not equivalent for all face features. Pairwise comparisons (Bonferroni correction) showed that the face context disadvantage was particularly strong for the hairline (p=0.038), eyes (p=0.036) and eyebrows (p=0.009).

The finding that observers are poorer at detecting changes to individual features when they are part of a fixed face, compared to when they are presented in isolation, is consistent with the predictions of holistic processing outlined in the introduction. It appears that observers struggled to extract the relevant feature information from the surrounding face context. This full face disadvantage is interpreted as evidence of holistic processing which can limit the ability to extract featural information from a whole face (Tanaka & Farah, 1993). In turn, this argues against the notion of a configural advantage for unfamiliar face discrimination. Adding spatial relational information (e.g. position of nose relative to eyes and mouth) reduced, rather than improved, feature discrimination sensitivity.

3.2. Experiment 2: Priming the variable feature

Experiment one showed that feature discrimination sensitivity is significantly reduced when features were embedded within a face context, relative to presentation in isolation. It is possible that this reduction in sensitivity reflects the greater task difficulty of the embedded feature condition. Because the conditions were interleaved, observers were unaware of which feature differed between the target and distracter faces on individual trials. In the isolated feature condition, on the other hand, the target feature was obvious as it was the only visible feature. It is conceivable, therefore, that the increase in discrimination thresholds resulted from the requirement to spread attention across all face features in the embedded condition (Richard, Lee & Vecera, 2008) and/or spatial uncertainty (deciding which of many features was changing).

Experiment two was designed to investigate these possibilities by equalizing task difficulty and removing the additional attention requirement of the embedded feature condition and, with it, spatial uncertainty. Before viewing the target face, observers were informed, using clearly visible text at the fixation point, of the feature being tested in that trial. This featural priming directed the observer's attention towards the relevant feature.

3.2.1. Procedure

Each trial began with the presentation of the name of the trial-relevant feature (head-shape, hairline, nose, mouth, eyes or eyebrows). The text was black "Times" font and each letter measured 2cm in height, corresponding to 0.95° of visual angle at the viewing distance (approximate equivalent visual acuity = 6/70). The text was presented for 300ms and followed by a noise mask (300ms) to remove any residual visual transient. The remainder of the procedure was identical to that of the embedded condition in experiment 1 (figure 4-top). Two observers (one male) from experiment 1 completed experiment 2.

3.2.2. Results

As in experiment 1, there was no significant effect of face identity ($F_{3, 9} = 2.88$; $p=0.50$) or observers (univariate ANOVA, $F_{1, 10} = 0.65$; $p=0.438$). Accordingly, mean threshold elevations were calculated.

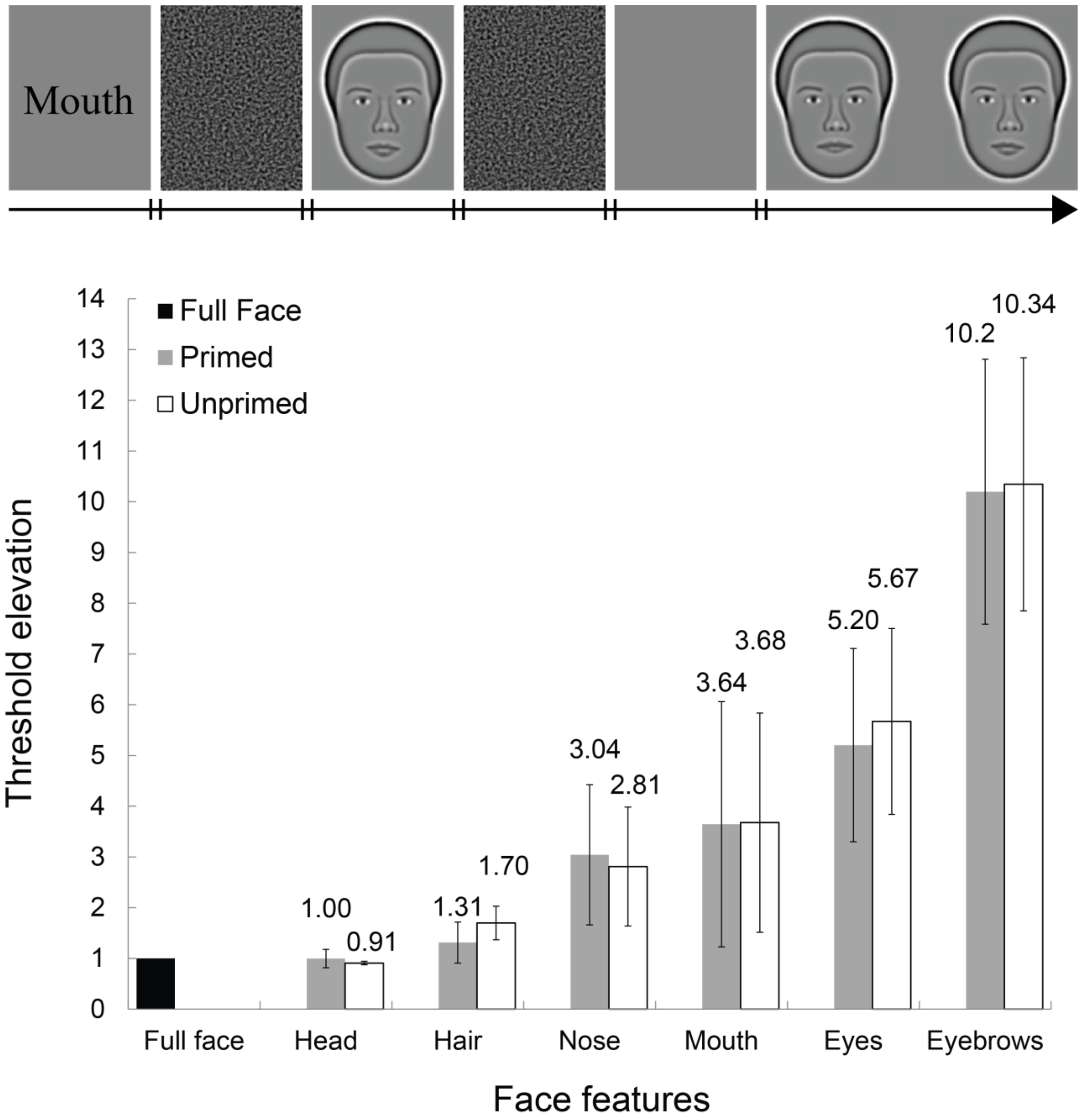

Figure 4. Results for priming the task relevant face feature. Data are for embedded conditions (one variable feature within an otherwise fixed face) with (grey bars) and without (white) prior priming to the relevant feature. There was no significant effect of priming on threshold elevations. Error bars denote 95% confidence intervals (*N* = 2). Note that the data for the unprimed condition are not identical to those in figure 3b because only two observers completed experiment two.

The authors suggest 1-1.5 column width for figure 4. Greyscale.

Visually priming the observer to the variable, task relevant feature did not alter discrimination thresholds ($F_{1, 11} = 0.40$; $p=0.539$). This suggests that the face context disadvantage identified in experiment one cannot simply be attributed to greater task difficulty, increased spatial uncertainty or enhanced attentional requirements for the embedded condition. Instead, this reaffirms the conclusion that the difficulty in extracting featural information from a full face is the result of holistic processing.

4. General Discussion

4.1. Internal versus external face features

The primary aim of this study was to quantify and directly compare sensitivity to individual face features. The results provide evidence of increased sensitivity to external, relative to internal, features in an unfamiliar face discrimination task. Quantification of the contributions of individual features to discrimination accuracy revealed a hierarchy of feature salience: sensitivity was highest for the head-shape and lowest for the eyebrows. Sensitivity to eyebrow changes was approximately 5 (presented in isolation) or 10 (embedded in an otherwise fixed face) times lower than that for the head-shape.

Previous evidence comparing internal with external features in unfamiliar face discrimination has been mixed. While some studies have reported an external feature advantage for unfamiliar faces (Bruce et al., 1999, Davies, Ellis & Shepherd, 1977, Fraser, Craig & Parker, 1990, Haig, 1986, Nachson & Shechory, 2002, Veres-Injac & Persike, 2009), in line with our results, others have not (Clutterbuck & Johnston, 2002, Ellis, Shepherd & Davies, 1979, Hines, Jordan-Brown & Juzwin, 1987, Longmore, Liu & Young, 2015, Young et al., 1985).

These conflicting results may be attributable to differences in experimental design. For example, in some studies, observers could use incidental photographic details (e.g. clothing and residual background) to discriminate between individual faces (Ellis, Shepherd & Davies, 1979, Nachson, Moscovitch & Umilta, 1995, Young et al., 1985). Secondly, some paradigms asked observers to match internal or external features with a target face photograph taken from a different viewing angle (Clutterbuck & Johnston, 2002, Young et al., 1985). It has been suggested that changing the viewpoint may underestimate sensitivity to the features of unfamiliar faces (Johnston & Edmonds, 2009). This highlights a further distinction between familiar and unfamiliar face perception: discrimination of familiar faces is substantially more robust to changes in viewing angle than that for unfamiliar faces (Hancock, Bruce & Burton, 2000, Hill, Schyns & Akamatsu, 1997). Other studies isolated the external and internal features by cropping face photographs (Ellis, Shepherd & Davies, 1979). This type of modification may disrupt typical face processing mechanisms by, for example, creating a false external head contour (Veres-Injac & Persike, 2009). The present study overcame these problems by using synthetic faces. Finally, while some studies employed a memory-free face matching task (Clutterbuck & Johnston, 2002, Nachson & Shechory, 2002, Young et al., 1985) others required observers to learn and later recognize individual faces (Ellis, Shepherd & Davies, 1979, Henderson, Williams & Falk, 2005, Longmore, Liu & Young, 2015). The latter paradigm investigates face recognition- a process that may be qualitatively different from face discrimination.

The results presented here extend the premise of an external feature advantage for unfamiliar faces. In one demonstration of this finding, the external features of police face composites were matched with suspect face photographs at an accuracy level close to that found for the whole full face composite (Frowd et al., 2007). Matching the internal features of face composites with a full face photograph, on the other hand, was performed poorly.

One possible explanation for an external feature advantage for unfamiliar faces is that the relatively large size of the head-shape and hairline information can preserve discrimination over long viewing distances. This explanation is appealing based on context: familiar faces are viewed in close range during social interaction whereas unfamiliar faces are often viewed from a distance. External face features are also less affected by facial dynamics (e.g. due to the portrayal of facial expressions or eye movements). Thus external features may be more reliable discrimination cues when humans have to discriminate between faces with which they are unfamiliar.

To our knowledge, the present study has provided the first direct and quantitative comparison of discrimination sensitivities for a wide range of face features. Analysis of the pattern of results supports the proposal that sensitivity is poorer for features which are affected by facial dynamics (eye, eyebrows and mouth). Specifically, the nose, a largely static feature during speech and changes in facial expression, was reliably found to be the internal feature to which observers were most sensitive. It has been argued that the nose may be used as a central reference point for face coding (Vesker & Wilson, 2012). Conversely, eyebrows were associated with the lowest sensitivity. This reduced reliance on eyebrow information may reflect the positional changes which the eyebrows undergo to express emotions and intentions (Tian, Kanade & Cohn, 2001). Eyebrows have previously been found to be important for face recognition (Sadr, Jarudi & Sinha, 2003) in a study using famous celebrities who were highly familiar to observers. This can be linked to the internal versus external feature advantage for familiar versus unfamiliar faces, which would predict an important role of internal features, such as eyebrows, in a familiar face recognition task. We found intermediate levels of sensitivity for the eyes. This is consistent with our interpretation; while dynamic cues in the eye region communicate direction of attention, the positional movements of the eyes are less varied than those of the eyebrows.

4.2. Holistic processing

The individual face features that we tested included variations in both featural (e.g. isolated nose shape) and configural (e.g. inter-ocular spacing) information. Both types of information have been found to contribute to face perception (Cabeza & Kato, 2000, Rhodes, 2013). Experiment one demonstrated that sensitivity to individual face features was significantly reduced when these features were embedded within a fixed face context, relative to presentation in isolation. Experiment two showed that the effects of feature context cannot be explained by task complexity (being confronted with multiple features), spatial uncertainty (deciding which of many features is modified) or attention (having to spread attention across an entire face rather than a single feature). We interpret our finding of a face-context disadvantage as evidence of holistic processing in an unfamiliar face discrimination task; holistic processing impedes the extraction of information about individual features when a feature is embedded in, and part of, a face.

The present study also revealed a differential influence of holistic processing for individual face features. This was evident in the significant interaction between context (i.e. isolated or embedded) and face features. Specifically, the effect of embedding features within a fixed face context was particularly strong for the hairline, eyes and eyebrows and less so for the nose and head-shape. Several previous investigations have collated results obtained for individual face features to calculate a mean value for holistic face processing (Tanaka & Farah, 1993, Tanaka, Kiefer & Bukach, 2004, Tanaka & Sengco, 1997). The results presented here suggest that the effect of holistic processing might not be equivalent for each face feature.

It should be made clear that this face-context disadvantage is not inconsistent with the established part-whole effect for familiar face recognition (Tanaka & Farah, 1993). Tanaka and Farah familiarized participants with a set of full face images. When recognition accuracy was assessed for the individual features of these learned faces, a clear advantage emerged for features embedded within a face context, relative to features presented in isolation. In the isolated condition of the present study, on the other hand, participants were always presented with isolated features, and there was no familiarization with full faces or individual features. In line with this result, Leder and Carbon (2005) reported that when observers were familiarized with isolated features, recognition accuracy was significantly higher when the learned features were presented in isolation, rather than embedded within a full face context. The present study has therefore extended the finding of a face-context disadvantage to unfamiliar, unlearned face discrimination.

4.3. Do synthetic faces engage normal face processing mechanisms?

Synthetic faces are reduced, simplified stimuli that do not contain all of the information present in face photographs. In order to generalize the results of the present study to everyday face processing tasks, one must show that synthetic faces engage the same processing mechanisms as real faces. Despite being simplified, there is ample evidence which shows that synthetic faces engage the same cortical processes as face photographs. Firstly, Wilson, Loffler and Wilkinson (2002) have demonstrated that synthetic faces contain sufficient information to permit individual identification which is robust to changes in face viewing angle. Secondly, synthetic faces demonstrate behavioral hallmarks of face processing including a face inversion effect (Logan et al., 2016, Wilson, Loffler & Wilkinson, 2002) and left-over-right visual field bias (Schmidtmann et al., 2015). Thirdly, a comparable BOLD fMRI signal in the FFA for face photographs and synthetic faces suggests that the brain processes both stimuli in a similar way (Loffler et al., 2005b). Finally, two recent studies (Lee et al., 2010, Logan et al., 2016) identified impairments of synthetic face discrimination in patients with developmental prosopagnosia. In one of them, synthetic faces were employed within a new test of face discrimination (the Caledonian face test; Logan et al. 2016). The synthetic face test, in agreement with two established face tests, identified an impairment of face perception in a case of suspected developmental prosopagnosia, but the test utilizing synthetic faces enjoyed a higher sensitivity than the established tests. Consistent with the premise that synthetic faces engage face-specific processing mechanisms, this patient demonstrated no comparable impairment of non-face object discrimination (e.g. cars).

It is less clear if isolating face parts may result in stimuli that do not engage face processing mechanisms in the same way as full faces. We found no evidence of a qualitative difference in the pattern of featural reliance when features were presented in isolation and embedded within a fixed face context. This would appear to suggest that face processing mechanisms were engaged when individual face features were isolated in our experiments.

As the experiments were based on four face identities, the following question arises: could our experiments have promoted an atypical reliance on featural differences? We believe that our experimental design and results argue against a feature-based strategy. Firstly, observers were confronted with a sizeable number of different face images (4 face identities, each at six different distinctiveness levels). Secondly, faces were presented in a random order using an interleaved design so that the observer could not anticipate which face (or feature) would be shown on any trial. This makes it unlikely that observers would adopt a strategy which relied upon the detection of specific featural cues. Thirdly, presenting the target image for 110ms precluded the use of atypical eye movement strategies. Our results suggest that these measures were sufficient to avoid a feature-based strategy: we found no effect of identity on face discrimination thresholds, suggesting that the results are not dependent upon the specific identities used or their individual features. Further, we interpreted our finding of elevated thresholds for embedded, relative to isolated, features as evidence of holistic processing. This finding is inconsistent with the suggestion that observers used a feature-based strategy in our experiments.

As noted above, the present study used four specific face identities. Can our results be generalised to other identities? By testing a large set of faces with different identities and distinctiveness levels, we have shown in previous work that thresholds for synthetic face discrimination show a dependence on face distinctiveness but not identity (Wilson et al., 2002; Logan et al., 2016). We can therefore be confident that the results presented here can be generalised to other face identities. This is reflected in our results: we found no effect of identity on face discrimination thresholds, indicating that the conclusions are not dependent upon the specific identities tested.

It is possible that an experiment which presents numerous faces within a block may introduce some degree of unintended face adaptation (Leopold et al., 2001). Such adaption may shift the percept of some of the presented faces and could, in turn, add noise to the data. We tried to mitigate the effect of adaptation by interleaving face identities, features and distinctiveness within experimental blocks, limiting target presentation time (110ms) and including a low-level noise mask in order to remove visual transients and counteract the build-up of adaptation. Moreover, as adaptation would act on the percept of both distractor and target face, one may not expect this to influence discrimination thresholds. In support of this, we found a reliable pattern of sensitivity across observers, face identities and conditions. This suggests that any adaptation effect was small and did not significantly influence our results.

It is also possible that this type of discrimination task could encourage observers to engage image-based, rather than face-specific, processing strategies. One way to distinguish between image and face-specific discrimination is the face inversion effect (Rossion, 2008), where sensitivity to faces, relative to other objects, is disproportionately reduced by inversion. In previous work, we found a significant inversion effect for synthetic face discrimination (Logan et al., 2016), which provides convincing evidence that these stimuli engage face-specific processing mechanisms.

5. Conclusions

The results of the present study are indicative of a significant external feature advantage for unfamiliar face discrimination. Using a novel metric, the contribution of each face feature to face discrimination was quantified. Discrimination thresholds for external features (head-shape and hairline) were not significantly different from those for faces in which all of the features changed. Conversely, discrimination thresholds for the internal features - nose, mouth, eyes and eyebrows - were all significantly higher than those for full faces. Sensitivity was lowest for features (eyebrows, mouth, eyes) affected by face dynamics (e.g. expression, speech).

Embedding features within the context of a face significantly decreased sensitivity, relative to presentation in isolation. This result is interpreted as evidence against a configural advantage for unfamiliar faces, which would predict improved sensitivity to features embedded within a face, and for holistic processing that impedes extraction of information about individual features.

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