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The respective role of low and high spatial frequencies in supporting configural and featural processing of faces

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Abstract. One distinctive feature of processing faces, as compared to other categories, is thought to be the large dependence on configural cues such as the metric relations among features. To test the role of low spatial frequencies (LSFs) and high spatial frequencies (HSFs) in configural and featural processing, subjects were presented with triplets of faces that were filtered to preserve either LSFs (below 8 cycles per face width), HSFs (above 32 cycles per face width), or the full frequency spectrum. They were asked to match one of two probe faces to a target face. The distractor probe face differed from the target either configurally, featurally, or both featurally and configurally. When the difference was at the configural level, performance was better with LSF faces than with HSF faces. In contrast, with a featural difference, a strong performance advantage was found for HSF faces as compared to LSF faces. These results support the dominant role that LSFs play in the configural processing of faces, whereas featural processing is largely dependent on HSFs.

1 Introduction

The processing of human faces relies both on local features (eg eyes, nose, and mouth) and on the configural relations between these features (eg the metric distance between the eyes—Collishaw and Hole 2000; Rhodes et al 1993; Sergent 1984). To support the important role of configural relations for processing faces, it has been found in early studies that the recognition of faces is disproportionately impaired when faces are presented upside down, as compared to other categories (Diamond and Carey 1986; Yin 1969; for reviews, see Rossion and Gauthier 2002; Valentine 1988). Presumably, face inversion impairs configural information more than featural information. Several recent studies further support the view that face inversion disrupts configural processing, and that configural information is critical for face processing (Bartlett and Searcy 1993; Barton et al 2001; Freire et al 2000; Kemp et al 1990; Leder and Bruce 1998, 2000; Leder et al 2001; Rhodes et al 1993; Searcy and Bartlett 1996). For example, it has been shown that a facial feature (eg eye) is better recognised when presented in a whole face than when presented in isolation (Tanaka and Farah 1993), or when presented in a whole face with a different feature (eg nose) displaced from the original position of that feature (Tanaka and Sengco 1997). Overall, these findings suggest that the ability to extract configural cues is at the heart of our visual expertise for face recognition (Diamond and Carey 1986; Gauthier and Tarr 1997; Tanaka and Gauthier 1997; for a review, see Maurer et al 2002).

In the present study, we asked what primitive visual information supports the extraction of configural and featural cues during face processing. To address this question, we examined the role of low spatial frequencies (LSFs) and high spatial frequencies (HSFs) for recovering configural and featural information. Indeed, the analysis of the spatial frequency spectrum of an image is an early step in visual processing (for reviews, see De Valois and De Valois 1988; Morrison and Schyns 2001). Importantly, different spatial frequencies encode different aspects of faces and objects.

For example, cells sensitive to HSFs encode fine edges (ie fast luminance variations) in the image, whereas cells selective for LSFs encode coarse cues (ie regions of slow luminance variations). For faces, these cues could potentially play very different roles. Moreover, these roles may depend on the demands of the task at hand (Goffaux et al 2003a; Schyns and Oliva 1999; Sergent 1986).

Therefore, LSFs and HSFs may differentially support configural and featural processing. This proposal is not new: in the mid-eighties, Sergent (1986) argued that the gradual blurring of a photograph degrades features of the face more rapidly and fully than its configural information. However, previous studies have failed to demonstrate that configural cues are mostly carried by LSFs as compared to HSFs (Boutet et al 2003; Wenger and Townsend 2000). One possible problem is that these investigators used cutoff frequencies that did not maximise the difference between the ranges of spatial frequencies used for face processing. Here, to maximise the difference between our conditions, we exploited spatial frequency (SF) bands that excluded intermediate frequencies (8 – 16 cycles per face width, abbreviated henceforth as cpf). This frequency band is thought to be the best compromise between coarse and fine cues for face recognition (Costen et al 1994, 1996; Fiorentini et al 1983; Gold et al 1999; Morrison and Schyns 2001; Näsänen 1999; Parker and Costen 1999).

To tease apart the role of LSFs and HSFs in configural and featural processing of faces, we presented faces that could only be discriminated on the basis of either configural relations, local features, or both configural and featural information. We then compared subjects' performance on this task when the faces to be discriminated were presented with only LSFs available (low-pass filtered), only HSFs available (high-pass filtered), or all spatial frequencies available (full spectrum). LSFs should support the extraction of configural information but remove fine details that are necessary to recover useful facial features. Thus, we hypothesised that faces would be better discriminated when presented in LSFs than in HSFs if they differed by a configural rather than a featural change. By comparison, we hypothesised that faces differing by fine featural changes would be better discriminated when presented in HSFs.

2 Methods

2.1 *Subjects*

Twenty-two undergraduate students (mean age: 20.2 ± 2 years; two males; three left-handed) from the Department of Psychology received course credit for their participation in the experiment. They all had normal or corrected-to-normal visual acuity.

2.2 *Stimuli*

We used 20 gray-scale images of faces, half of which were male and half of which were female. Individual faces were approximately 200 pixels in width and 264 pixels in height, and all faces were centred on a 296 pixels $\times$ 296 pixels gray background. The faces were transformed in two ways: (i) by configural/featural transformations and (ii) by spatial filtering (figure 1). First, we manipulated the configural and featural parameters, either separately (configural and featural faces), or simultaneously (configural + featural faces). The *configural* faces were made different from the originals either by modifying the interocular distances, or by changing the eye heights. In all cases, the eyes were displaced closer or further away from the nose by 3 mm (9 pixels), ie 0.19 deg of visual angle (see figure 1a; for similar examples of configural transformation through feature displacement, see Freire et al 2000; Hosie et al 1988; Kemp et al 1990; Le Grand et al 2001; Leder et al 2001). The *featural* faces differed from the original by a replacement of the original eyes by the eyes of another face (figure 1b). In order to preserve the original configuration as much as possible, the 'new' eyes were of same gender and approximately the same size as the original eyes; they were

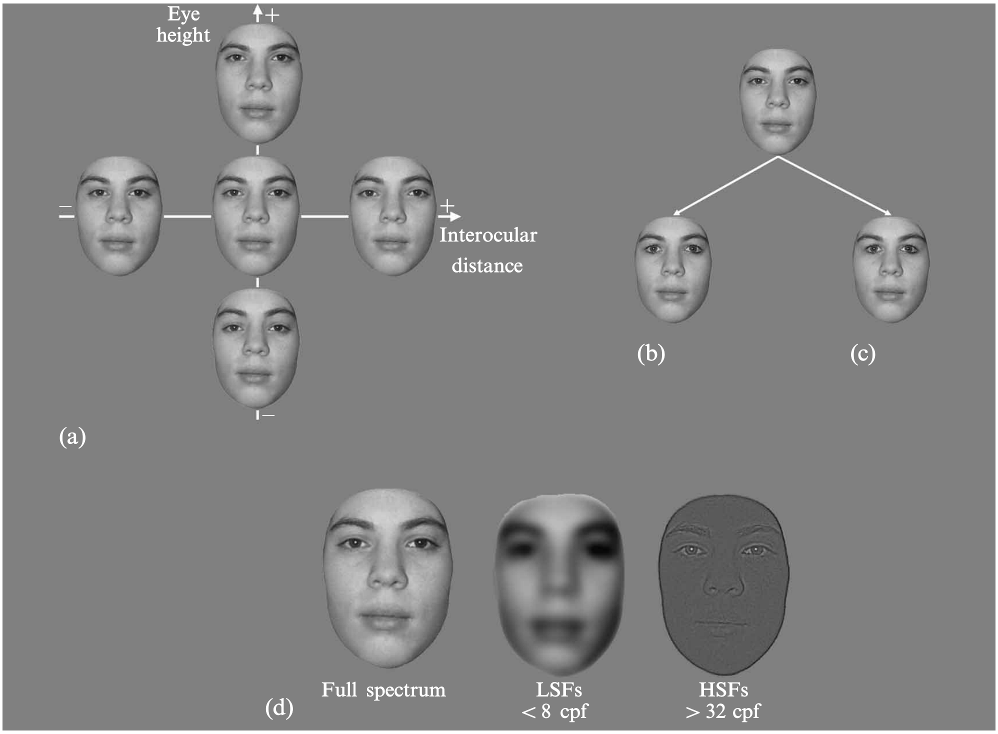

Figure 1. (a) Face stimuli from the configural set, where ocular spatial relations were manipulated. (b) Featural and (c) configural + featural transformations. (d) Illustration of a face in full spectrum, LSFs, and HSFs.

placed at the same location as the original eyes. Lastly, the *configural + featural* faces combined both configural and featural transformations (figure 1c). For a number of stimuli, we manipulated configural, featural, or configural + featural variations of the mouth or nose. These latter stimuli were only used on catch trials(1) so that subjects would not focus only on the eyes during the experiment.

Following the different configural and featural manipulations, faces (original, configural, featural, and configural + featural) were Fourier transformed into the frequency domain and multiplied by a low-pass or a high-pass filter to remove high or low frequencies, respectively. Specifically, we used a cutoff frequency of 8 cpf for LSF faces (ie maintaining all frequencies below 8 cpf), and a cutoff of 32 cpf for HSF faces (ie maintaining all frequencies above 32 cpf; see figure 1d). We used Gaussian filters with $\sigma = 10$ pixels for LSF faces and $\sigma = 38$ pixels for HSF faces to prevent 'ringing' artifacts in the filtered images. The product was then inversed-Fourier transformed and the resulting values were rescaled to the full 8-bit range [0 ... 255]. To assess possible interactions between our configural/featural transformations and SF filtering, we computed the power spectrum for the different distractors (configural, featural, and configural + featural) separately for LSF, HSF, and full spectrum faces. We did not observe any power-spectrum difference between configural, featural, and configural + featural manipulations.

(1) When faces differ only by subtle mouth and nose differences, be they featural, configural, or configural + featural, the error rates dramatically increase (see Pellicano and Rhodes 2003; Tanaka and Farah 1993; and Wenger and Townsend 2000 for similar observations).

2.3 *Procedure*

Faces were presented in triplets at the centre of a gray screen with a target face (approximately 4.3 deg × 3.1 deg) above two probe faces (approximately 3.9 deg × 2.8 deg each) in a triangle configuration (figure 2). One of the probe faces was the same image as the target face. The subject's task was to choose this probe face as quickly and as accurately as possible. We informed subjects that the distractor face (ie the other probe face) differed from the target face only slightly, but we did not inform them about the nature of these differences. Subjects responded by pressing a left or right key on a keyboard placed in front of them. The presentation of a triplet lasted until a response was made. After subjects responded, there was a 600 ms blank intertrial interval.

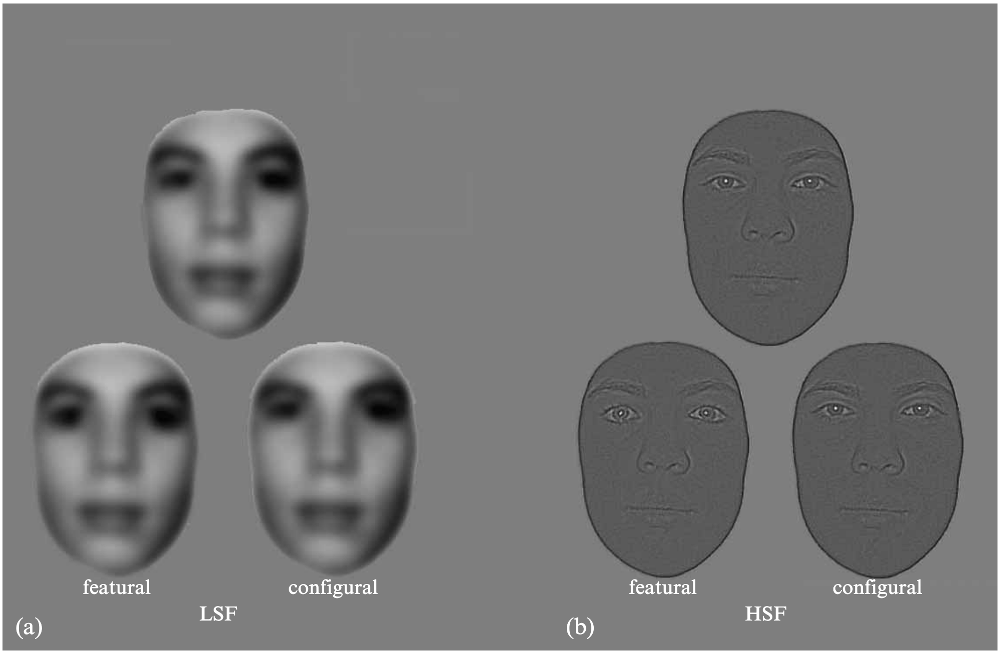

Figure 2. Featural and configural changes for (a) LSF and (b) HSF conditions.

The experiment consisted of 360 experimental trials and 60 additional catch trials (mouth and nose changes). These catch trials were not analysed. In the experimental trials, the distractor face differed from the target face either by a configural, a featural, or a configural + featural change. Faces on a given trial always appeared in the same SF band. In sum, we used a 3 (distractor type) by 3 (SF band) repeated-measures design, with 40 trials in each of the 9 conditions. The different conditions were randomly interleaved over the course of the experiment for each subject.

Note that both probe faces were slightly smaller than the target face (by a factor of 1.1). This was done to centre the overall display. Their size was decreased after filtering, but given the small size reduction, the probe and target faces contained approximately the same range of frequencies. Moreover, any differences in SF content were the same for all three distractor types (configural, featural, configural + featural).

Subjects sat in a dark room, where the only light source was the PC monitor (100 Hz refresh rate; 1024 × 768 pixels resolution; 0.24 mm dot pitch; gamma-corrected luminance profile). The experiment was programmed in E-Prime 1.1. The viewing distance was set to 90 cm. Subjects used a chin-rest to maintain this viewing distance.

2.4 *Analyses*

We first removed outlier trials from our data set, ie those trials in which the response time (RT) exceeded individual mean RT by more than three standard deviations. We then submitted the accuracy rates, correct RTs, and inverse efficiency scores (Akhtar and Enns 1989; Christie and Klein 1995; Kennett et al 2001; Townsend and Ashby 1983) to a repeated-measures analysis of variance (ANOVA) with distractor type (configural, featural, configural + featural) and SF band (LSF, HSF, full spectrum) as within-subject factors. The inverse efficiency score (expressed in ms) is equal to the mean RT divided by the proportion of correct responses, calculated separately for each condition and each subject. Lower values on this measure indicate better recognition performance. This measure is used to discount possible criterion shifts or speed–accuracy tradeoffs in performance.

3 Results

Figure 3 shows the mean ($n = 22$) error rates, correct response times, and inverse efficiency scores for the different experimental conditions.

3.1 *Accuracy and response times*

There was a main effect of distractor type for both accuracy rates ($F_{2,42} = 204.9$, $p < 0.0001$) and RTs ($F_{2,42} = 38.8$, $p < 0.0001$). This effect was due to lower accuracy rates and slower RTs for configural distractors as compared to either featural ($ps < 0.0001$) or configural + featural distractors ($ps < 0.0001$). Configural + featural distractors led to more accurate responses than featural distractors ($p < 0.045$), but RTs were similar across these conditions ($p > 0.08$). The main effect of SF band was also significant for both accuracy rates and RTs ($F_{2,42} = 104.5$, $p < 0.0001$; and $F_{2,42} = 4.9$, $p < 0.012$, respectively). A posteriori tests showed that accuracy rates decreased from full spectrum faces to HSF faces ($p < 0.0001$), and from HSF faces to LSF faces ($p < 0.0001$). For response times, HSF faces led to slower responses than full spectrum faces ($p < 0.001$), whereas response times did not differ significantly between LSF and full spectrum faces and between LSF and HSF faces ($ps > 0.08$).

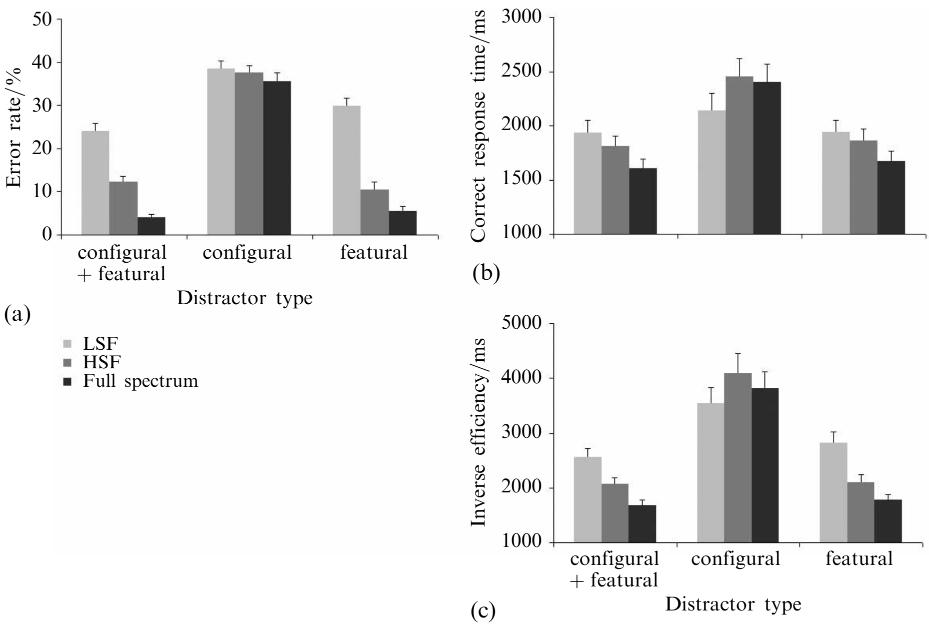

Figure 3. Mean error rates (a), RTs (b), and inverse efficiency scores (c) for the different SF bands and distractor types ($n = 22$).

Most interestingly for the purpose of this experiment, the interaction between distractor type and SF band was significant both for accuracy rates ($F_{4,84} = 21.29$, $p < 0.0001$), and RTs ($F_{4,84} = 19.18$, $p < 0.0001$). This interaction qualifies the main effects reported above.

When there was a difference between faces at the featural level (featural and configural + featural conditions), HSF faces led to more accurate responses than LSF faces (ps < 0.0001). However, full spectrum faces led to the highest accuracy rates, as compared with either LSF or HSF faces. This advantage for full spectrum faces was found for both featural and configural + featural distractors (ps < 0.009). Lastly, with configural distractors, accuracy rates were not affected by the SF content ($p > 0.43$).

Interestingly, the additional configural changes in the configural + featural condition led to better accuracy rates than featural changes alone, but only for LSF faces ($p < 0.008$; ps > 0.15 in HSF and full spectrum conditions).

When faces differed by their features, there were no RT differences between LSF and HSF faces (ps > 0.11). Subjects responded more quickly with full spectrum faces than with LSF and HSF faces in both the featural and configural + featural conditions (ps < 0.006). However, in the configural condition, LSF faces led to faster responses than HSF faces ($p < 0.0001$) and full spectrum faces ($p < 0.0007$). Both of the latter SF bands gave rise to similar RTs ($p > 0.5$).

To summarise: the accuracy data showed that HSFs support the extraction of facial features. Subjects performed better with HSF faces than with LSF faces in both the featural and the configural + featural conditions. In the configural condition, however, no difference in accuracy rates was evident across the different SF bands. By comparison, the RT data showed that subjects were faster with LSF faces than with HSF faces for configural distractors. Furthermore, the observation that subjects were more accurate with LSF faces in the configural + featural condition than in the featural condition suggests that LSF may provide the diagnostic cues for configural processing. Nevertheless, the lower accuracy rates in the configural condition suggest that configural differences were less salient than featural changes.

3.2 *Inverse efficiency scores*

To circumvent the possible criterion shift across distractor conditions, we analysed the inverse efficiency scores. A repeated-measures ANOVA revealed a main effect of distractor type ($F_{2,42} = 59.3$, $p < 0.0001$). Performance was worst (ie inverse efficiency scores were high) for configural distractors as compared with either featural or configural + featural distractors (ps < 0.0001). Configural + featural distractors led to slightly, but significantly, better performance than featural distractors ($p < 0.008$). The main effect of SF band also reached significance ($F_{2,42} = 17.62$, $p < 0.0001$). Subjects performed better for full spectrum faces than for either HSF or LSF faces (ps < 0.0001), but LSF and HSF faces differed only marginally ($p > 0.052$).

The ANOVA also revealed a significant interaction between distractor type and SF band ($F_{4,84} = 14.8$, $p < 0.0001$). On the one hand, subjects performed better with HSF faces than with LSF faces when there was a featural change (featural and configural + featural conditions, ps < 0.0002). On the other hand, an LSF advantage was observed with configural distractors ($p < 0.046$). Similar with regard to the accuracy data, configural + featural distractors led to better performance than featural distractors for LSF faces ($p < 0.02$), but not for HSF faces ($p > 0.44$). Full spectrum faces gave rise to better performance than either LSF or HSF faces in both the featural and configural + featural conditions (ps < 0.0004). Lastly, in the configural condition, efficiency scores for full spectrum faces did not differ significantly from either HSF or LSF faces ($p > 0.14$).

4 Discussion

The goal of the present study was to examine the spatial frequencies that are involved in processing configural versus featural cues of faces. To that end, we first systematically manipulated the effectiveness of configural as opposed to featural cues for face discrimination. In our study, subjects performed difficult identity judgments based on either local facial features, on the spatial configuration of these features, or on both local features and configuration of features. Second, we controlled the range of spatial frequencies available in our stimuli by selectively preserving the low, high, or full SF spectrum. These two manipulations enabled us to tease apart the relative contribution of different SF bands for extracting configural and featural cues.

Several authors have suggested that configural cues to facial identity are mostly carried by LSFs rather than HSFs (Collishaw and Hole 2000; Leder 1996; Sergent 1986). However, this proposal had not been directly demonstrated. Here, we show that:

(i) HSFs (> 32 cpf) support the extraction of local features for face recognition. When faces differed only by their local features, such as the shape and or the texture/luminance gradients of the eyes, subjects were more efficient at processing HSF faces than at processing LSF faces.

(ii) By comparison, subjects were more efficient with LSF faces (< 8 cpf) when faces differed by a configuration of features. This finding suggests that LSFs support the extraction of configural cues for face recognition. Moreover, even when subjects can use featural cues to discriminate faces, the addition of configural cues improves their performance if these cues are provided by the LSFs.

In summary, the accuracy and RT data point to a functional dissociation between LSFs and HSFs in supporting the extraction of configural and featural cues for face processing. It is important to stress that facial configurations can be extracted from both LSF and HSF faces (and full spectrum faces, of course). Given this, what might be the advantage for representing crucial cues to face identity, such as configuration of features, in LSFs? There are several possible reasons. First, LSFs are less vulnerable to different forms of degradation. For example, when a face is seen from a distance, fine featural details are blurred (ie the face is effectively low-pass filtered). Second, LSFs are thought to be processed by the magnocellular pathway. This implies that LSFs are processed at a faster rate than HSFs (Bullier 2001). This difference in processing speed suggests that LSFs are first used to extract configural information, resulting in a coarse description of a face. Subsequently, the accumulation of fine facial features, as conveyed by HSFs provides a progressively more accurate face representation (Hochstein and Ahissar 2002; Sergent 1986). Third, there may be developmental reasons for using LSFs to encode facial configuration. For instance, retinas of newborns have relatively low spatial resolution. Moreover, there is evidence that the initial LSF input for face processing shapes the ability to extract configural cues later in adulthood (Le Grand et al 2001).

Our data also show that face discrimination based on configural changes alone was very demanding, as compared to featural changes. As suggested previously by others, this may be due to the poor ecological plausibility of such variations (Leder and Bruce 2000). Nevertheless, several investigators have manipulated the position of facial features in previous studies and have obtained good overall performance. In these studies, however, the configural variations either were made explicit in the instructions to subjects (Haig 1984; Hosie et al 1988; Kemp et al 1990; Leder et al 2001), or were the only difference in the entire stimulus set (Freire et al 2000). In the present study, the addition of a condition where both configural and featural cues were modified and could be used to perform the task shows definitively that configural cues provide an advantage for LSF faces, but not for HSF or full spectrum faces.

As already raised by other authors (eg Hosie et al 1988; Leder and Bruce 2000; Rhodes et al 1993), the assumption that our experimental manipulations resulted in a 'pure' disruption of configural versus featural processing must be taken with caution. Configural and featural transformations have overlapping effects on face processing, since feature replacement also affects the metric relations with other features and feature displacement can distort the perception of feature shape. This line of reasoning also holds for SF filtering. Whereas blurring faces certainly eliminates fine featural cues (eg edges), caution is needed when considering HSF filtering. The information carried by HSFs is far more detailed and richer than the information carried by LSFs. In the present study, such a wealth of information is indicated by the fact that performance levels with HSF faces were close to the levels with full spectrum faces, even with an extreme cutoff frequency (32 cpf). Therefore, HSFs should not only enable the extraction of highly defined features, but also fine metric relations amongst feature cues (ie configural information). Nevertheless, our RT and efficiency data demonstrate that LSF and HSF filtering of faces impeded mostly one mode of processing.

Why might LSF information give rise to faster RTs for configural differences than either full spectrum or HSF faces, given that distances between features are also present for the latter two SF bands? The advantage for correct response times for LSF faces may arise precisely because HSF and full spectrum faces convey both configural *and* featural information, the latter being irrelevant on configural distractor trials. Given that subjects did not know in advance whether featural information was diagnostic or not on a given trial (as all trials were randomised), they might also encode and process featural information for HSF and full spectrum face trials. The correct RT and efficiency data therefore suggest that processing facial features is time-consuming and interferes with the processing of (diagnostic) configural information. In future work, a way to test whether this suggestion holds would be to run the conditions (configural, featural) in separate blocks. Alternatively, one could attempt to selectively suppress the impact of non-diagnostic HSFs when subjects have to judge configural changes in full spectrum faces (through facial adaptation techniques for instance, see Webster et al 2004).

In conclusion, by showing that LSFs and HSFs contribute differently to the configural and featural processing of faces, the present study suggests that facial configurations and features may be processed by different neurofunctional pathways. In support of this view, a recent event-related potential study showed that LSFs contributed to a larger extent than HSFs to shaping early visual differences between faces and objects, and between upright and inverted faces (Goffaux et al 2003b).

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