Research Report

Is high-spatial frequency information used in the early stages of face detection?

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ABSTRACT

The present study examined the role of high-spatial frequency information in early face processing, as indexed by the N170 face-sensitive ERP component. Participants detected 4 versions of famous faces, including full spectrum faces, and bandpass filtered faces containing predominantly high-spatial frequencies, low-spatial frequencies or both. The power spectra of all stimuli were balanced by superimposing the faces onto a visual noise background that included the spatial frequency information that was missing in filtered faces, e.g., high-spatial frequency faces were presented on a high- and low-spatial frequency background. An additional condition comprising of filtered visual noise only was also created to ensure that any observed effects were related to the processing of faces and not simply due to variations between spatial frequency information. Both behavioral and electrophysiological results replicated previous findings of a low-spatial frequency advantage for face processing. However, our results also show that faces containing both high and low-spatial frequency information are detected faster and more accurately than faces containing predominantly low-spatial frequencies. Furthermore, this advantage occurred with an enhanced amplitude of the N170. Together, these findings refute the suggestion that high-spatial frequencies are redundant in face perception.

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1. Introduction

Faces contain a wide spectrum of spatial frequency information. There are now several studies that have used spatial frequency filtering techniques to investigate the minimal spectral information required for face recognition. Variations among the spatial filtering techniques used, as well as differences in experimental design have often led to contradictory results and hence different conclusions about the relative importance of different spatial frequencies for face recognition. However, in general it is agreed that much of the information relevant for face recognition appears to be conveyed by spatial frequencies from middle (8–16 cycles per face) (Collin et al., 2004; Costen et al., 1994; Fiorentini et al., 1983; Grabowska and Nowicka, 1996; Morrison and Schyns, 2001; Näsiäinen, 1999; Parker and Costen, 1999) as well as lower spatial frequency bands (LSF) (Ginsburg, 1978; Harmon, 1973; Harmon and Julesz, 1973). For example, Harmon (1973) showed that removal of high-spatial frequency information (HSF) had little effect on participants’ ability to recognize faces and Ginsburg (1978) showed that faces containing only LSFs could be matched successfully against broad-spectrum face images. The results of these behavioral studies parallel those of more recent electrophysiological investigations demon-
recognising that the face-sensitive N170 event-related potential (ERP) component appears to be sensitive to LSF, but not HSF, information (Goffaux et al., 2003a,b). While the aforementioned studies have shown how variations in spatial frequency content affect recognition of faces other investigations have concluded that face recognition is more strongly affected by spatial frequency overlap (SFO) than by the actual spatial frequency content of face images (Collin et al., 2004; Kornowski and Petersik, 2003; Liu et al., 2000). For example, Liu et al. (2000) defined SFO as the range of spatial frequencies shared by a pair of filtered images and found that greater overlap between learned and test images yielded better performance on face matching tasks. Moreover, this effect appears to be confined to faces, as object recognition did not show the same sensitivity to SFO (Collin et al., 2004). However, since these studies did not examine the role of spatial frequency overlap in tasks other than face matching it remains to be determined whether or not these results are generalizable across other face perception tasks, e.g., detection, gender or emotional expression analysis etc.

The claim that face recognition is dependent on LSF information, with higher spatial frequencies contributing essentially redundant information has been refuted by some investigators. For example, Fiorentini et al. (1983) trained participants to identify (by name learning) nine originally unfamiliar male faces, and examined how recognition (name recall) was affected when faces were filtered so that they contained only LSF information or only HSF information or a combination of both high- and low-spatial frequencies. The results showed that both coarse and fine scale information can be used to identify faces, but the addition of HSFs to LSFs significantly improved face recognition. Based on this finding the authors concluded that HSF information is not necessarily redundant in face perception. In an attempt to resolve this controversy, Sergent and Hellige (1986) suggested that there is no “critical bandwidth” of spatial frequencies that is necessary for face perception. Rather the relative contribution of spatial frequencies is dependent on the kind of face judgement participants are being asked to make. This idea forms the basis of the “flexible usage hypothesis” proposed by Schyns and Oliva (1997, 1999). According to this hypothesis, distinct categorizations of an image will require different perceptual cues, which themselves could be associated with different regions of the spatial spectrum. In the case of faces, distinct spatial frequencies may convey face identity, gender and expression (Schyns and Oliva, 1999; Sergent and Hellige, 1986). For example, the age of a face is probably best conveyed by HSFs which represent information at a coarser scale. Thus, Schyns and Oliva (1999) suggest that scale usage for categorization may be flexible and determined by the usefulness (or diagnosticity) of cues at specific spatial scales. This view has received support from behavioral studies (Schyns and Oliva, 1999; Sergent and Hellige, 1986; Smith et al., 2005), as well as partial support from an ERP study in which the N170 was larger for LSF than HSF faces during a gender task, but not during a familiarity task (Goffaux et al., 2003b). However, since the predicted larger N170 for HSF than LSF in the familiarity task was not obtained, there is now increasing support for the idea that HSF are not critical at least for the early stages of face processing.

The aim of the current study was to further investigate whether HSF information has any influence in the early stages of face processing as indexed by the N170. In the following experiments the spatial frequency content of black and white photographic images of famous faces was manipulated so that the relative importance of LSF and HSF in the early stages of face processing could be assessed using a face detection task. We used a face detection task for two reasons (1) the N170 is thought to reflect early face processing mechanisms related to the structural encoding of faces (Bentin and Deouell, 2000; Bentin et al., 1996; Eimer, 2000a; Holmes et al., 2003) and has been found to be insensitive to changes in facial expression (Eimer et al., 2003; Holmes et al., 2003) or familiarity (Eimer, 2000b) and (2) face detection is not thought to rely heavily on HSF information, therefore using a detection task would be a particularly strict test to determine whether or not HSFs contribute to the processing of faces. Previous studies investigating the effect of spatial frequency on face recognition have typically used learning methods (such as name recall) to familiarize participants with previously unknown faces, we used famous faces as we thought this would involve a more naturalistic processing strategy. As mentioned, the N170 is thought to reflect the early stages of encoding of facial information (detection of the basic configuration of the face and/or of the eyes in particular (Bentin and Deouell, 2000; Bentin et al., 1996)). There is evidence to suggest that the perceptual mechanisms underlying the processing of featural and configural information differ and the difference may be related to underlying properties of channels involved in the processing of low- and high-spatial frequencies. The processing of configural (or global) information is thought to depend on its LSF content and the processing of featural information is thought to rely more on its HSF content (Boeschoten et al., 2005). Moreover, evidence from neuroimaging studies suggests that HSF and LSF information engage different brain areas. While some studies suggest the left hemisphere processing of HSF and right processing of LSF, others conclude that the processing of configural and featural information is mapped according to the spatial frequency, that is, the retinotopic map of the visual cortex (Boeschoten et al., 2005).

The general aim of this study was to investigate how varying the spatial frequency information depicted in faces affects (a) the amplitude and/or latency of the N170 and (b) the accuracy and speed with which faces are detected. The different face stimuli used were: (1) Original faces—these were unfiltered images of faces and hence contained a wide range of spatial frequency information. Inclusion of this condition allowed us to replicate the basic prior findings with the N170; (2) low-spatial frequency faces—these faces contained only low-spatial frequency information and therefore depicted information thought to be predominantly relevant to the overall configural properties of faces; (3) high-spatial frequency faces—these faces contained only high-spatial frequency information and therefore depicted
information predominantly relevant to the textural/featural properties of faces; and (4) high- and low-spatial frequency faces—these faces contained both low and high-spatial frequency information but differed from unfiltered faces in that they did not contain mid-band spatial frequency information. All the faces were superimposed onto a structured visual noise background that consisted of spatial frequency information that was missing as a consequence of bandpass filtering the faces i.e., both HSF and LSF faces were superimposed on a HSF and LSF noise background. In this way, we were able to ensure that the spectral energy of our stimuli were balanced allowing us to rule out early visual effects that might trivially arise due to power spectra variations amongst the different stimulus conditions. An additional condition was included that comprised of HSF and LSF structured visual noise only. The low-level physical properties of High-and-Low Faces and High-and-Low Noise are identical therefore any difference in the amplitude and/or latency of the N170 between these two conditions is attributable to the presence of face information.

We predicted that if HSFs contribute to the early stages of face processing the N170 should be (a) greater to HSF faces than to spatial frequency matched noise, and (b) greater to High and Low combined faces than to LSF faces. In addition, we predicted that if HSF information contributes to face detection then participants would be more accurate to detect High and Low faces compared to LSF faces.

2. Results

2.1. Electrophysiological data

2.1.1. N170 amplitude

Only those ERP trials in which participants made correct responses were included in the analysis of the amplitude of the N170. A repeated measures ANOVA showed that there was a main effect of condition on the amplitude of the N170 (F(4,44)=46.84, P<0.001) (relevant means and standard deviations are shown in Table 1). As predicted, the amplitude of the N170 was larger for HSF faces compared to noise (F(1,11)=36.14, P<0.001). The N170 was also larger for faces containing both high and low-spatial frequencies compared with faces containing only LSF information (F(1,11)=11.25, P<0.01). In addition, the N170 elicited by full bandwidth faces was larger than that elicited by faces containing both high- and low-spatial frequencies (F(1,11)=13.39, P<0.005). Finally, the N170 was larger for LSF faces compared with HSF faces (F(1,11)=14.15, P<0.005). There were no other main effects or interactions for the amplitude of the N170.

Table 1 – Mean and SD of N170 amplitude

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean N170 amplitude (μV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Face</td>
<td>-5.09 (3.34)</td>
</tr>
<tr>
<td>High–Low Faces</td>
<td>-4.75 (3.41)</td>
</tr>
<tr>
<td>Low Face</td>
<td>-4.20 (3.23)</td>
</tr>
<tr>
<td>High Face</td>
<td>-3.40 (3.14)</td>
</tr>
<tr>
<td>High–Low Noise</td>
<td>-1.42 (2.43)</td>
</tr>
</tbody>
</table>

2.1.2. N170 Latency

A repeated measures ANOVA showed that there was a main effect of condition on the latency of the N170 (F(4,44)=4.86, P<0.01) (relevant means and standard deviations are in Table 2). The N170 peaked more slowly for HSF faces compared with all other faces conditions (F(1,11)=12.46, P<0.005) and was the only face condition to differ significantly from noise (F(1,11)=14.05, P<0.01). The latency of the N170 did not differ between faces containing both HSF and LSF information compared with faces containing only LSF information (F(1,11)=276, P>0.05). The N170 peaked quicker for LSF faces compared with HSF faces (F(1,11)=15.13, P<0.005). In addition, full spectrum faces were processed quicker than faces containing only HSF and LSF information (F(1,11)=11.0, P<0.05). There were no other main effects or interactions for the latency of the N170.

2.2. Behavioral data

2.2.1. Response accuracy

A one-way repeated measures ANOVA showed that there was a significant main effect of condition on participants’ response accuracy (F(4,44)=10.13, P<0.001) (relevant means and standard deviations are shown in Table 3). Planned contrasts showed that response accuracy did not differ between HSF faces and noise (F(1,11)=0.30, P=0.59) and both were detected less accurately than all the other face conditions (F(1,11)=38.87, P<0.001). High–Low Faces were detected more accurately than Low Faces (F(1,11)=6.75, P<0.05) and LSF faces were better detected than HSF (F(1,11)=5.15, P<0.05).

2.2.2. Response latencies

A one-way repeated measures ANOVA showed that there was a main effect of condition on participants’ response latencies (F(4,44)=43.47, P<0.001) (relevant means and standard deviations are in Table 4). Participants were faster to detect HSF faces than noise (F(1,11)=21.76, P<0.001). They were also faster to detect LSF faces compared with HSF faces.

Table 2 – Means and standard deviations for latency of N170

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean N170 latency (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Face</td>
<td>148.7 (14.95)</td>
</tr>
<tr>
<td>High–Low Faces</td>
<td>151.67 (11.46)</td>
</tr>
<tr>
<td>Low Face</td>
<td>152.50 (13.37)</td>
</tr>
<tr>
<td>High Face</td>
<td>158.67 (14.95)</td>
</tr>
<tr>
<td>High–Low Noise</td>
<td>147 (22.79)</td>
</tr>
</tbody>
</table>

Table 3 – Mean number of correct responses and percentage correct responses

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean number (SD) of correct responses/88</th>
<th>%Correct responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Face</td>
<td>86.3 (1.8)</td>
<td>97.8</td>
</tr>
<tr>
<td>High–Low Faces</td>
<td>86.2 (1.2)</td>
<td>98.0</td>
</tr>
<tr>
<td>Low Face</td>
<td>84.3 (2.1)</td>
<td>96.0</td>
</tr>
<tr>
<td>High Face</td>
<td>75.8 (12.2)</td>
<td>87.0</td>
</tr>
<tr>
<td>High–Low Noise</td>
<td>73.4 (7.7)</td>
<td>83.8</td>
</tr>
</tbody>
</table>
Varying the spatial frequency content of faces affects the early encoding of faces as indexed by the N170. LSF faces elicited a robust N170 that was only somewhat smaller than that elicited by broadband faces, while HSF faces elicited a significantly smaller response. Our finding showing a larger N170 to LSF faces compared to HSF faces is consistent with previous event-related potential studies (Goffaux et al., 2003a, b), but is inconsistent with the results of a recent magnetoencephalography (MEG) study showing the opposite effect at the M170 (Hsiao et al., 2005). As Hsiao et al. (2005) suggested, the discrepant findings may be related to methodological differences and/or differences between the spatial frequency cut-offs used to create the filtered faces. In the present study, LSF was defined as <8 cycles/face and HSF was defined as >24 cycles/face. The LSF cut-off used by Goffaux et al. (2003a,b) was identical to ours, but the HSF cut-off was slightly higher (LSF <8 and HSF >32). In the MEG study, LSF and HSF were defined as <5 and >32 cycles/face, respectively. There is general agreement that face recognition is best supported by frequencies between 8 and 16 cycles/face (Collin et al., 2004; Costen et al., 1994; Fiorentini et al., 1983; Grabowska and Nowicka, 1996; Morrison and Schyns, 2001; Näsänen, 1999; Parker and Costen, 1999), and therefore <5 cycles may have given rise to the attenuated M170. Since low-spatial frequencies are thought to convey information related to the configurational property of faces the larger N170 to LSF supports the notion that the N170 is related to the structural encoding of the configurational property of faces (Eimer, 2000a).

Although the amplitude of the N170 was smaller for HSF faces than for LSF faces, our results suggest that HSF is not redundant in early face processing. Firstly, we observed that the N170 elicited by HSF faces was larger than that elicited by spatial frequency matched visual noise. Secondly, the N170 elicited by High-and-Low Faces was larger than that elicited by LSF faces. Since the spectral energy of our stimuli were balanced we are confident that these effects are due to the additional facial information conveyed by HSF. However, since we did not examine the role of spatial frequency in object processing we cannot say whether the increased amplitude of the N170 due to the addition of high-spatial frequency information to low-spatial frequency information is specific to faces or might also occur for objects as well. The causal factors underlying the processing difference between LSF and HSF faces remains undetermined. Some would argue that this difference arises from a coarse to fine scale processing strategy, inducing a bias to process LSF information first. Others might propose a more psychophysical explanation and suggest that differences in the spectral energy between the low and high frequencies might account for the reported differences. Both of these explanations need not be mutually exclusive. The finding that HSF does contribute to face processing is made even more compelling by the fact that these results were obtained even in a face detection task, which is thought to predominantly rely on LSF. We speculate that had an alternative task been used that requires the extraction of fine details of the face, e.g., identity, then the contribution of HSF information would be even greater and the present findings would have been enhanced. This conclusion was echoed in the behavioral results, where High-and-Low Faces were detected more quickly and accurately than LSF faces.

In the present study, the amplitude and latency of the N170 did not differ between the left and right hemisphere and the N170 effects of spatial frequency were consistent across the two hemispheres. These findings do not support a right hemisphere bias for face processing nor are they consistent with the idea of hemispheric processing advantages for different spatial frequencies. However, as Grabowska and Nowicka (1996) highlight when reviewing the role of the two hemispheres in processing spatial frequencies there numerous factors can effect whether or not one observes hemispheric differences and to conclude a dichotomous division of the two hemispheres may be an oversimplification. Rather they state that "hemispheric specialization has to be conceptualized as a complex, dynamic system of different asymmetrically represented components or modules tied by callosal pathways that serve to both integrate and modify output of the operations carried out by those components" (p. 446). One possibility is that early face detection processes, while showing sensitivity to spatial frequency, do not differently engage the two hemispheres, whereas later cognitively more complex processing of faces may involve mechanisms that differentially activate the left and right hemisphere. However, Goffaux et al. (2003b) did not report any spatial frequency related lateralization in both gender or familiarity tasks, suggesting that this explanation is unlikely to account for the lack of laterality effects seen in the present study.

Our results demonstrating the role of HSF in early face processing go beyond replicating the prior finding that full-spectrum faces elicited a larger and faster N170 than LSF faces (Goffaux et al., 2003b). This is because full-spectrum faces contain not only HSF information, but also additional ‘mid-band’ (8–24 cycles per image) information. In contrast, in the Goffaux et al. study the role of HSF remained unclear. This is important because some have argued that mid-band frequencies are critical for face recognition. For example, Costen et al. (1994, 1996) found that identification of faces was best supported by a band of intermediate-spatial frequency information, which was approximately 8–16 cycles per face (Costen et al., 1996). This finding was replicated in a more recent study in which Parker and Costen (1999) trained participants to identify six previously unfamiliar faces from one viewing angle, and tested subsequent recognition of these faces when viewed from five different angles. Based on

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### Table 4 – Means and standard deviations for response latencies of correct responses only

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean response latency</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Face</td>
<td>366.8</td>
<td>37.8</td>
</tr>
<tr>
<td>High–Low Faces</td>
<td>374.8</td>
<td>35.7</td>
</tr>
<tr>
<td>Low Face</td>
<td>397.2</td>
<td>36.8</td>
</tr>
<tr>
<td>High Face</td>
<td>416.4</td>
<td>49.6</td>
</tr>
<tr>
<td>High–Low Noise</td>
<td>419.2</td>
<td>72.3</td>
</tr>
</tbody>
</table>

(\(F(1,11)=4.98, P<0.05\)). There was no difference in reaction time between full spectrum faces and faces containing only HSF and LSF information (\(F(1,11)=2.56, P=0.13\)).

3. Discussion

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accuracy measures and response latencies the authors once again concluded that the middle range of spatial frequencies (8–16 cycles per face image) was most useful for a face identification task. Our results comparing the High and Low Face with the Full Face do also suggest a contribution for mid-band frequencies, as the N170 to Full Face was still larger than that to High and Low Face, and behavioral accuracies and response times quick for the former than the latter. Together the findings suggest that, although HSFs alone may be less effective for face detection, they are not redundant and can aid both the accuracy and speed with which faces are detected, and that these effects are observable from the early stages of face encoding. However, whether these effects are specific to faces or are generalizable to objects remains an open question.

4. Experimental procedure

4.1. Participants

Twelve paid volunteers (6 females, mean age 30.1 years, age range 23–42 years) participated in the experiment. All participants were right handed and had normal or corrected-to-normal vision.

4.2. Stimuli

The stimuli were derived from black and white images of 22 famous faces (see Fig. 1 for example of stimuli used). Four face types were used, including original (full spectrum), high (>24 cycles per image), low (<8 cycles per image) and High-and-Low Faces (superimposition of high and low faces). In order to maintain similar spectral energy all faces were presented against a noise background so that full spectrum faces had a full spectrum background and all other face conditions were superimposed onto a low and high noise background. The critical bandwidth cut-offs for high- and low-spatial frequencies were chosen on the grounds that they were outside of the mid-range (8–16 cycles per image) of frequencies previously identified as being crucial for face recognition (see Introduction) and would also be comparable to prior ERP investigations of spatial frequency and faces (Goffaux et al., 2003a,b). We also included a control condition that contained the same spatial frequency information as High-and-Low Faces but consisted of unstructured noise. A Butterworth filter was used to create the stimuli and they were 256×256 pixels on a 256 gray-level scale and subtended horizontal angle of 5.5° and a vertical angle of 5.5° when viewed from a distance of 1 m. A one-way repeated measures ANOVA suggested that averaged luminance (256 gray-scale level) differed between some of the stimuli ($F(4,105)=4.18$, $P<0.05$), however, post hoc $t$-tests with Bonferroni corrections did not yield any significant differences between the five conditions.

4.3. ERP recording

ERPs were recorded using a Geodesic Sensor Net consisting of 128 silver-silver chloride electrodes evenly distributed across the scalp (Tucker, 1993). A ground electrode was positioned on the forehead and the reference electrode was positioned at the

Fig. 1 – Example of stimuli used. (A=Full Face, B=High-and-Low Face, C=Low Face, D=High Face, E=Filtered Noise). Note that this is not the actual size of stimuli used.
vertex. Horizontal and vertical electro-oculograms (EOGs) were also measured to monitor eye blinks and eye movements. All bioelectrical signals were recorded using EGI NetAmps (Eugene, OR) with a bandpass filter of 0.1–100 Hz and with gain set to 10,000 times. Electroencephalogram (EEG) was recorded continuously throughout the test session with a sampling rate of 250 Hz. Stimulus duration was 120 ms with a random inter-stimulus interval (ISI) of 1–2 s.

4.4. ERP waveform analysis

The continuous EEG recording was divided to create segments from 100 ms pre-stimulus onset (used for baseline) to 500 ms post-stimulus onset (i.e., 600 ms segments). Data were then digitally filtered offline with a 30 Hz low-pass elliptical filter and edited for artifacts. Data from each electrode were removed if they contained artifacts created by movement or poor contact. The entire trial was excluded if data from more than 10 electrodes were excluded or if the trial contained an eye-blink. Data were baseline corrected and then individual participant averages were computed for each condition. Individuals with greater than 6 bad channels in their averages were excluded from further analysis. Missing data for participants with 6 or fewer bad channels were interpolated using spherical spline interpolation from the individual participant averages. Data were then re-referenced to the average reference (Fig. 2).

The effects of spatial frequency on the amplitude and latency of the N170 were tested by computing two measures: peak amplitude (μV) and peak latency (ms) within a time-window of 100–200 ms. These measures were analyzed in two separate 5×2 repeated measures ANOVAs with Condition (Full
Face, High Face, Low Face, High–Low Face, High–Low Noise) and hemisphere (right and left) as within subject factors. An alpha of 0.05 was used in all analyses and Greenhouse–Geisser corrected P-levels were used for within participant factors with more than two levels. To test specific effects t-tests were employed. Individual electrodes included in the analysis of the right hemisphere were 84, 85, 90, 91 and left hemisphere were 65, 66, 70, 71. These electrodes were chosen for further analysis because they are located over occipito-temporal scalp regions which is where the N170 has previously been shown to be most prominent and was also found to be most maximal in this study (Figs. 3 and 4).

4.5. Procedure

After the sensor net was applied, participants were seated 1 m from a 21 in. computer monitor which was situated in a dimly lit recording booth. Behavioral data were collected using a button press box which was situated on a small table directly in front of the participant. Participants were informed that they would see a series of stimuli that would appear quite quickly on the screen in front of them and that their task was to respond on each trial by pressing a green button if they saw a face in the stimulus and a red button if they did not. The hand used to press for the presence or absence of a face was counter balanced across participants. They were also told that some of the faces may be more difficult to see compared with others and that they should respond as quickly and accurately as possible to the presence or absence of a face. The test session consisted of 440 trials during which each of the 22 faces was randomly presented, four times for each of the five conditions. Faces were presented centrally on the screen for a duration of 120 ms with a random ISI (1–2 s), during which a white central fixation point appeared and served to keep the participants gaze as central as possible. The test session was approximately 25 min long and participants were given breaks when the experimenter could see that they were beginning to get tired or blink too much, usually only 2 breaks were needed by most participants.

REFERENCES


