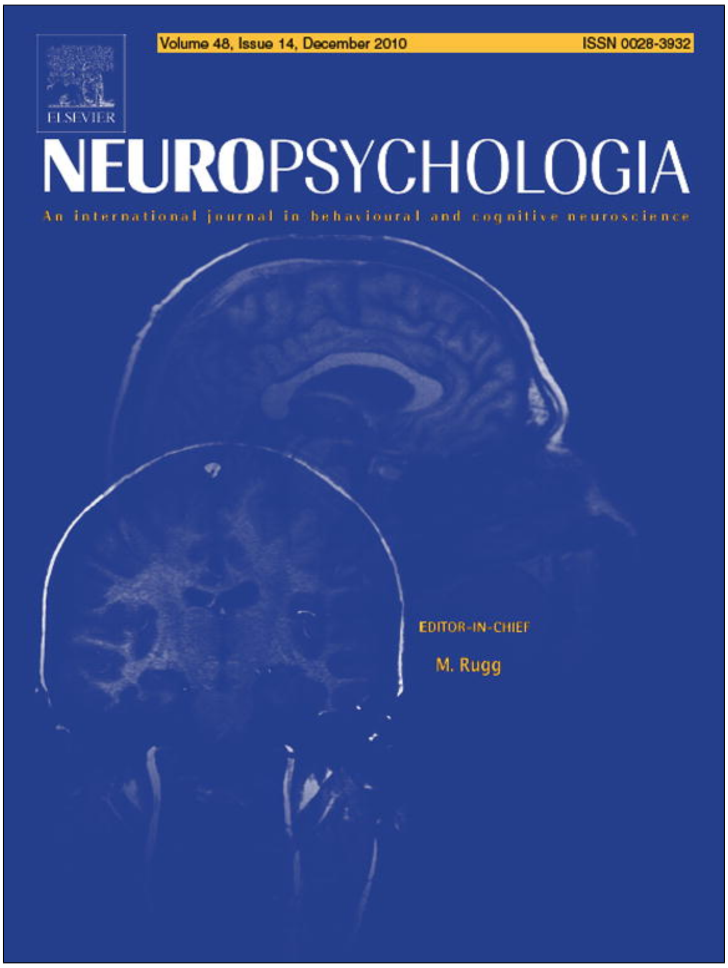
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Brief communication

# Patients with schizophrenia are biased toward low spatial frequency to decode facial expression at a glance

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## ABSTRACT

Whereas patients with schizophrenia exhibit early visual processing impairments, their capacity at integrating visual information at various spatial scales, from low to high spatial frequencies, remains untested. This question is particularly acute given that, in ecological conditions of viewing, spatial frequency bands are naturally integrated to form a coherent percept.

Here, 19 patients with schizophrenia and 16 healthy controls performed a rapid emotion recognition task with *hybrid* faces. Because these stimuli displayed in a single image two different facial expressions, in low (LSF) and high (HSF) spatial frequencies, the selected emotion probes which spatial scale is preferentially perceived. In a control experiment participants performed the same task with either low or high spatial frequency filtered faces.

Results show that patients have a strong bias towards LSF with hybrid faces compared to healthy controls. However, both patients and healthy controls performed better with HSF filtered faces than with LSF filtered faces in the control experiment, demonstrating that the bias found with hybrid stimuli in patients was not due to an inability to process HSF.

Whereas previous works found a LSF contrast deficit in schizophrenia, our results suggest a deficit in the normal time course of concurrently perceiving LSF and HSF. This early visual processing impairment is likely to contribute to the difficulties of patients with schizophrenia with facial processing and therefore social interaction.

While schizophrenia was first described more than 100 years ago, to date, we do not have a comprehensive understanding of how people with schizophrenia perceive the visual world. Beside altered high cognitive functions such as social communication, a large body of evidence has found that patients with schizophrenia have specific visual impairments at an early stage of processing (for a review, see Butler & Javitt, 2005), including a deficit in processing spatial frequencies.

Spatial frequency is one of the earliest features processed by the human visual system: the input signal is decomposed in bands of various spatial frequency ranges, from low (blur information) to high (sharp edges) spatial frequency (De Valois & De Valois, 1988). Several studies (Butler & Javitt, 2005; Martinez et al., 2008; O'Donnell et al., 2002) report a specific decrease in contrast sensitivity for low spatial frequency bands, and have related this to a sub-cortical magnocellular deficit in schizophrenia. However, a deficit of the magnocellular pathway in this population is still debated as it is difficult to isolate magno- and parvocellular processing with spatial frequency gratings (Skottun & Skoyles, 2007). Beside studies using simple stimuli, two recent studies have shown that visual dysfunctions may impair the capacity to recognize natural stimuli in schizophrenia. Norton, McBain, Holt, Ongur, and Chen (2009) found that patients' performance in contrast detection predicts the amount of difficulty they have in detecting facial expressions like fear. Similarly, Butler et al. (2009) found a correlation between a specific impairment of contrast sensitivity in low spatial frequency and diminished capacity to determine the emotion displayed on a face.

To date, we do not know to what extent the impaired visual processing found in schizophrenia directly affects natural image recognition, that is to say, which spatial frequency bands are naturally integrated to form a coherent percept. This is an important issue since in realistic conditions of viewing, visual objects – particularly faces – are perceived at several ranges of spatial frequencies; for instance, from far away, we only see low spatial frequencies and, as a person comes towards us, we integrate higher spatial frequencies and fine details into the initial blurry percept (Smith & Schyns, 2009). Specifically, how do patients with schizophrenia use the low

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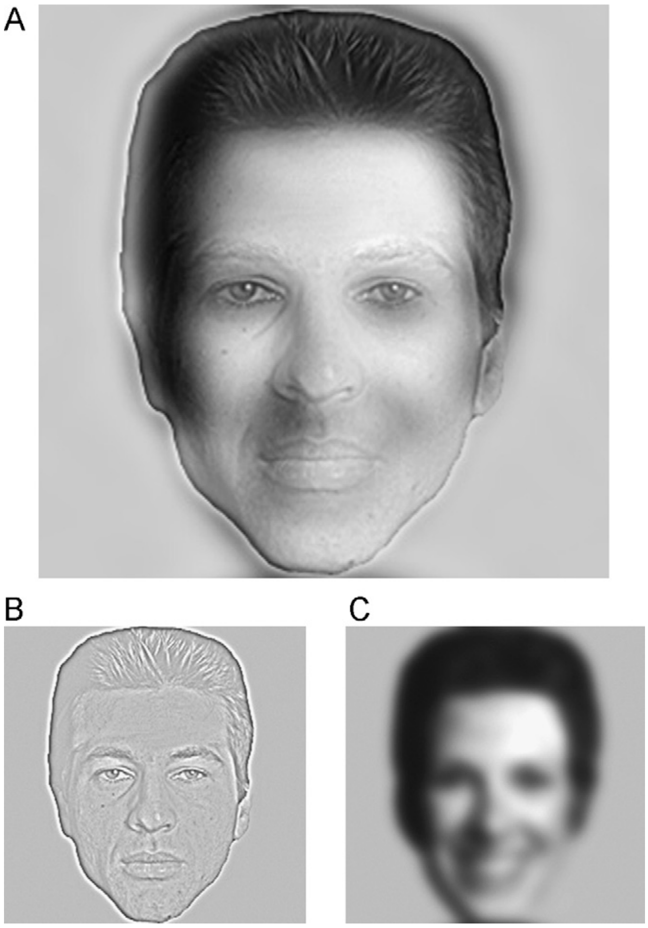

**Fig. 1.** Example of a hybrid stimulus (A). The hybrid combines the high spatial frequency information from the neutral man in image (B) with the low spatial frequency information from the happy woman in image (C). The high spatial frequency component of the hybrid can be seen more easily if you hold the image close to your eyes, and the low spatial frequency information can be better seen if you step away from the image or slightly blur your gaze. Images (B) and (C) are examples of filtered images that were used in the control experiment.

spatial frequency part or the high spatial frequency part of a natural image for face recognition? It has been shown, in healthy observers (Oliva & Schyns, 1997; Schyns & Oliva, 1999; Smith & Schyns, 2009) that different spatial frequencies are used depending on the task, context, and presentation conditions. For instance, low spatial frequencies are processed at a shorter time scale than high spatial frequencies, resulting in a coarse-to-fine analysis of information over the course of a glance (Legge, 1978; Schyns & Oliva, 1994). Low spatial frequencies therefore provide a coarse template, which is later refined by details contained in high spatial frequencies (Bar, 2004).

In the present study, we investigate the processing of high and low spatial frequencies for decoding the perception of facial expression in patients with schizophrenia. In a first experiment we used hybrid faces (Fig. 1A), which are visual stimuli made of two different superimposed faces: one face is composed of low spatial frequencies (LSF) and the other face is composed of high spatial frequencies (HSF). Stimuli of this kind are ideal to determine which spatial scale is used to perform a task, as they contain two different but coherent facial interpretations. In the experiment, observers were asked to determine the facial expression (if neutral, happy or angry) of these stimuli: because hybrid faces are composed by two emotions, each at a different spatial frequency range, the emotion perceived directly informs about the spatial scale perceived. Results show that, contrary to controls, patients with schizophrenia focus preferentially on the low spatial frequency, regardless of the emotion. A second experiment served as a control to first experiment: participants performed the same facial expression recognition task with single faces filtered either for high or low spatial frequency (Fig. 1B). This control experiment is mandatory to determine whether the bias to LSF observed in Experiment 1 is due to a specific deficit at processing a spatial frequency range or a deficit in processing concurrently HSF to LSF in images containing the spectrum of spatial frequencies (as in normal perception).

## 1. Hybrid faces

### 1.1. Aim

Here, we measured which spatial frequency band (high or low) from natural images is more frequently perceived at the beginning of the glance.

### 1.2. Method

#### 1.2.1. Participants

Twenty-five adult individuals suffering from schizophrenia were recruited in the Public Mental Health Institute of Flandres (Bailleul – France), Hope and Life Institute (Arras – France) and Department of General Psychiatry in Lille University Hospital (Lille – France). The inclusion criteria were an age of 18–55 years and a diagnosis of schizophrenia based on standard DSM-IV criteria. All participants' visual acuity was measured by Snellen chart. Only patients and controls with a normal or corrected-to-normal visual acuity (10/10 on Snellen chart) were included. The exclusion criteria were history of neurological illness, trauma occurring in the past six months, ophthalmic illness, and alcohol or drug abuse. All patients received antipsychotic medication and were clinically stable at testing time. Schizophrenia symptoms were assessed with the Positive and Negative Syndrome Scale (PANSS). Six patients were not included in the data analysis: four for misunderstanding of the instructions (when the percentage of incorrect responses was over 20%, see below) and two for failure to complete the experiment. Nineteen age and gender-matched healthy controls were recruited. They were free from DSM-IV axis-I diagnosis and reported taking no medication. Three healthy controls were excluded: two were excluded for misunderstanding the instructions (percentage of incorrect responses over 20%) and one failed to complete the experiment. The study was approved by the Ethics Committee of Lille University Hospital. A written consent was obtained from all participants. No participant was paid for taking part in the study.

#### 1.2.2. Stimuli

We used the image set of high and low filtered faces and hybrid faces of Schyns and Oliva (1999). In that set, faces from different individuals are aligned so that inner and outer face characteristics overlap (see Fig. 1). Images were 256 × 256 pixels size, in grayscale. Faces from 12 different individuals were used (six males and six females), each showing three different expressions: angry, happy or neutral. We created a low-pass version (below 8 cycles/image) and a high-pass version (above 24 cycles/image) of each face (see examples in Fig. 1), for a total of 36 HSF-only faces and 36 LSF-only faces. Then, 96 hybrid faces were created by overlapping a low-pass filtered face from one individual with the high-pass filtered face of another individual. Each hybrid was composed of two different individuals, one male and one female. One face displayed a neutral expression whereas the other face displayed either a happy or an angry emotion. Therefore, the expression determined by participants on a given hybrid image indicated which spatial scale was preferentially used, as seen in Fig. 1.

**Table 1**
Population characteristics.

| | Healthy controls ($N=16$) Mean ± SEM | Patients with schizophrenia ($N=19$) Mean ± SEM |
|---|---|---|
| Age (years) | 31.4 ± 2.09 | 31.6 ± 1.91 |
| Gender (male/female) | 14 M/2 F | 17 M/2 F |
| Antipsychotic medication (mg chlorpromazine Eq) | | 367.6 ± 61.8 |
| Benzodiazepine medication (mg diazepam Eq) | | 29.8 ± 9.7 |
| PANSS positive symptoms | | 18.9 ± 1.3 |
| PANSS negative symptoms | | 20.4 ± 1.6 |
| PANSS general psychopathology | | 30.6 ± 3.5 |

### 1.2.3. *Procedure*

Participants were seated in a darkened room with their head maintained by a chin-rest at a viewing distance of 140 cm. Stimuli subtended 2.5° of visual angle. A central fixation cross was shown for 1 s, followed by a face stimulus displayed for 100 ms. This presentation time was chosen to allow only one fixation on the stimulus, as average human gaze fixation is around 300 ms (Harris, Hainline, Abramov, Lemerise, & Camenzuli, 1988). Participants were asked to decide whether the facial emotion was happy, angry or neutral. Observers responded orally in a voice key, which recorded the response time. The verbal answer was coded by the experimenter on the keyboard of the computer.

### 1.2.4. *Statistical analysis*

Statistical analyses were conducted with STATISTICA 6.1 software (StatSoft Inc.). The main measure was the percentage of responses in each spatial frequency. Two repeated measure ANOVA were conducted, one for low spatial frequency and one for high spatial frequency, with "emotion" as within factor and "group" as between factor. As each stimulus contained a neutral face and an emotional face (angry or happy), the within factor "emotion" corresponds to the two emotions manipulated in the emotional face of the stimuli.

A proportion of incorrect responses can be calculated in this task because three responses are possible for the two faces of the hybrids. Due to the small number of incorrect responses, the proportion of incorrect responses in patients and controls was compared with a Mann–Whitney Test.

The reaction time was a complementary measure used to determine if the main result was obtained by a non-specific deficit of attention in schizophrenia. We compared reaction times of patients and healthy controls with a repeated measure ANOVA using "emotion" as within factor and "group" as between factor.

Ages of patients and healthy controls were compared with a two-tailed $t$-test. Two tailed Pearson correlations were used to check any relationship between percentage of responses in each spatial frequency or reaction times and antipsychotic daily dose, benzodiazepine dose, age and PANSS dimensions.

### 1.3. *Results*

The characteristics of the population are summarized in Table 1. Ages of patients and healthy controls were respectively 31.6 (SEM = 1.9) and 31.4 (SEM = 2.3) years. They did not differ significantly ($t(33) = 0.04$, $p = 0.96$).

Our main measure was the percentage of responses in each spatial frequency. Results are displayed in Fig. 2.

The percentage of responses based on the low spatial frequency face was respectively 58.3% (SEM 4.0%) for patients and 43.1% (SEM 3.9%) for healthy controls. This difference was significant. There was a main effect of group ($F(1,33) = 9.5$, $p < 0.005$) and also a main effect of emotion ($F(1,33) = 4.9$, $p < 0.05$). This effect reflected that low spatial frequency was more frequently chosen with happy faces than angry faces (respectively 27.7% SEM 9.4% vs 26.0% SEM 9.4%). The ANOVA failed to show any emotion × group interaction ($F(1,33) = 1.2$, $p = 0.28$).

The percentage of responses based on the high spatial frequency face was respectively 53.6% (SEM 4.0%) for healthy controls and 34.0% (SEM 4.0%) for patients. The ANOVA confirmed the main effect of group ($F(1,33) = 9.5$, $p < 0.005$) and a main effect of emotion ($F(1,33) = 4.9$, $p < 0.05$), indicating that high spatial frequency was more frequently chosen with angry faces than happy faces (respectively 23.9% SEM 5.2% vs 22.3% SEM 2.1%). The ANOVA failed to find any emotion × group interaction ($F(1,33) = 1.2$, $p = 0.28$).

The proportion of incorrect responses was 7.67% (SEM 0.8%) for patients with schizophrenia and 3.27% (SEM 0.5%) for controls. A Mann–Whitney test found a significant difference ($Z = 3.4$, $p < 0.001$). Healthy controls had 1.9% (SEM 0.4) incorrect responses with angry faces and 1.4% (SEM 0.3) with happy faces. Patients had 5.12% (SEM 0.8) incorrect responses with angry faces and 2.5% (SEM 0.6) with happy faces.

The mean reaction time was 1060 ms for healthy controls and 1170 ms for patients. The ANOVA conducted on RTs showed a main effect of emotion ($F(1,33) = 9.5$, $p < 0.005$), indicating that angry faces elicited longer RTs than happy faces. The analysis failed to find any group effect ($F(1,33) = 1.77$, $p = 0.19$) nor any emotion × group interaction.

We did not find any significant correlation between the percentage of responses or the reaction times in each spatial frequency and antipsychotic daily dose, benzodiazepine dose, age or any PANSS dimension.

## 2. Control experiment: high and low spatial frequency filtered faces

### 2.1. *Aim*

This control experiment assesses if the bias found with hybrid faces resulted from an inability to process a specific spatial frequency band. To do so, filtered images containing only LSF or only HSF are used.

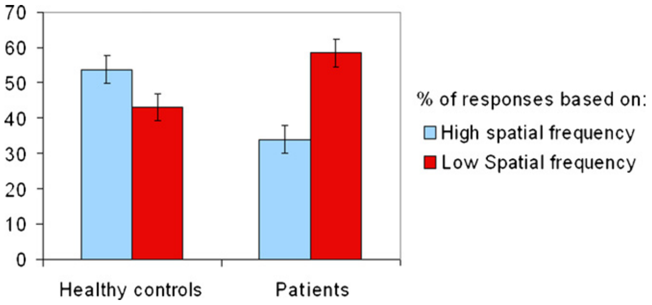

**Fig. 2.** Results with hybrid faces. The ANOVA performed on LSF responses showed a main effect of group, indicating that patients used more frequently LSF than healthy controls. The ANOVA on HSF showed a similar result.

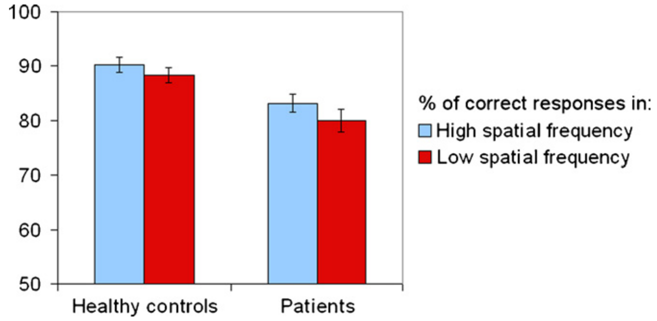

**Fig. 3.** Performance of healthy controls and patients on filtered faces. The ANOVA showed a main effect of spatial frequency, indicating that both patients and controls were more accurate with high spatial frequency faces. A main effect of group was also significant, indicating that patients were less accurate than healthy controls. There was no frequency × group interaction.

### 2.2. Method

#### 2.2.1. Participants

The same two populations were recruited for the control experiment.

#### 2.2.2. Stimuli

We used the same original faces set as in those used with hybrid faces. We created a low-pass version (below 8 cycles/image) and a high-pass version (above 24 cycles/image) of each face (see examples in Fig. 1), for a total of 36 HSF-only faces and 36 LSF-only faces.

#### 2.2.3. Procedure

This 72 image set was presented to participants in the same conditions as in Experiment 1 (distance = 140 cm, size = 2.5° of visual angle, stimulus display = 100 ms). Participants responded orally in a voice key, which recorded the response time. The verbal answer was coded by the experimenter on the keyboard of the computer.

#### 2.2.4. Statistical analysis

The main measure was the percentage of correct responses in each spatial frequency. This variable was analysed with a repeated measures ANOVA with "group" as between factor and "spatial frequency" and "expression" as within factors. The reaction time was a complementary measure analysed with a repeated measures ANOVA with "group" as between factor and "spatial frequency" and "expression" as within factors. The "expression" factor is here different of hybrid experiment: as each stimulus contained only one of three possible expressions (neutral, angry and happy), the three expressions could be included in both ANOVAs.

### 2.3. Results

The data are presented in Fig. 3.

The ANOVA showed a main effect of spatial frequency ($F(1,31) = 5.0$, $p < 0.05$): both patients and controls were more accurate for high spatial frequency faces (controls: 90.3%, patients: 83.2%) than for low spatial frequency faces (controls: 88.3%, patients: 79.9%). A main effect of group was also significant ($F(1,31) = 13.5$, $p < 0.001$), indicating that patients were less accurate than healthy controls. A main effect of expression was significant ($F(1,31) = 97.0$, $p < 0.001$). The exploration of this main effect by contrasts indicated that the expression "angry" was more difficult to detect than "happy" ($F(1,31) = 99.0$, $p < 0.001$) and than "neutral" ($F(1,31) = 119.1$, $p < 0.001$). An expression × group interaction was observed, indicating that the expression "angry" was more difficult to detect for patients compared to healthy controls, as explored by contrasts ($F(1,31) = 10.1$, $p < 0.005$). There was no frequency × group interaction ($F(1,31) = 1.0$, $p = 0.3$), nor any frequency × expression × group interaction ($F(1,31) = 0.05$, $p = 0.94$).

The mean reaction time was 933 ms (SEM 48 ms) for healthy controls and 1160 ms (SEM 87 ms) for patients. The ANOVA showed a main effect of expression ($F(1,31) = 21.7$, $p < 0.001$): happy faces elicited shorter reaction times than neutral faces ($F(1,31) = 12.9$, $p = 0.001$) which were more rapidly detected than angry faces as measured by contrasts ($F(1,31) = 7.6$, $p < 0.01$). There was a trend for a group effect ($F(1,31) = 3.1$, $p = 0.08$) but no main effect of spatial frequency ($F(1,31) = 0.04$, $p = 0.8$). Expression interacted with group ($F(1,31) = 3.4$, $p < 0.05$) indicating that patients had longer reaction times with angry faces ($F(1,31)) = 4.4$, $p < 0.05$) and with happy faces ($F(1,31) = 4.2$, $p < 0.05$) than healthy controls.

## 3. Discussion

Patients with schizophrenia and healthy controls performed an emotion categorization task on hybrid stimuli which combined two different faces, one in LSF and one in HSF. Patients exhibited a strong bias towards LSF compared to healthy controls. Importantly, the preferential use of LSF in schizophrenia was not due to a deficit in the perception of HSF information, since patients, as controls, performed the categorization task more accurately with the HSF-only faces than with the LSF-only in the control experiment with filtered images.

The patients' bias to select the LSF over the HSF face of the hybrid stimuli cannot be explained by overall task difficulty, as accuracy was high for both groups. Moreover, comparison of the response times between patients and controls when viewing the hybrid stimuli yielded no significant difference between the two groups, suggesting that the LSF preference was not due to a general deficit of attention.

Our stimuli were based on faces with various emotions. We observed that happy faces elicited an increased perception of LSF with hybrid stimuli in both patients and controls. This corroborates previous studies (Hayes, Morrone, & Burr, 1986; Nakashima et al., 2008), which found that positive expressions were better recognized with LSF stimuli than negative emotions. However, this effect did not differ between patients and controls in our experiment. Our results are also consistent with the literature showing a general deficit of emotion recognition in schizophrenia, particularly the detection of negative emotions (for reviews see Edwards, Jackson, & Pattison, 2002; Mandal, Pandey, & Prasad, 1998). However, schizophrenia patients' bias in emotion processing did not explain their tendency to select the LSF portion of the hybrid face.

The patients' overall preference for LSF selection in the hybrid face contrasts with the hypothesis of a subcortical magnocellular deficit in schizophrenia and a possible deficit in the processing of low spatial frequencies (Butler & Javitt, 2005). Our results suggest instead a possible impairment in the mechanism of information integration, a hypothesis in line with other results showing that the mechanism of feature integration into a coherent form is deficient in schizophrenia (Butler et al., 2008; Chambon, Baudouin, & Franck, 2006; Van Assche & Giersch, 2009). In schizophrenia, several works suggest a cortical level locus of visual dysfunctions, involving either the dorsal pathway (Foxe, Doniger, & Javitt, 2001; Lalor, Yeap, Reilly, Pearlmutter, & Foxe, 2008) or the interaction between dorsal and ventral pathways (Doniger, Foxe, Murray, Higgins, & Javitt, 2002; Ducato et al., 2008; Foxe, Murray, & Javitt, 2005; Schechter, Butler, Silipo, Zemon, & Javitt, 2003). For instance, an event-related potentials study (ERPs) based on illusory contours perception by Foxe et al. (2005) suggests that the processing of information in the ventral stream is normal in schizophrenia, however the guidance of ventral processing by the dorsal pathway is impaired. Our data fit with this proposal: in our study, the LSF information might be processed at a minima but may not properly integrate with the subsequent analysis of information performed by the ventral stream, hindering or masking the normal processing of HSF.

Another interpretation of our main result could be a delay in the processing of spatial frequencies. A 100 ms presentation time might be too short to allow a normal HSF processing in patients. Butler et al. (2007) have measured VEP with sinusoidal gratings and have shown a delayed P1 for LSF but not for HSF. In line with Butler et al. (2007) early LSF processing could be delayed which in turn would delay later processing of HSF. Whereas our control experiment suggests that HSF were well perceived in 100 ms and that both HSF and LSF stimuli were processed without reaction time delay, more studies will be needed to determine the spatial frequency time course of normal image processing in schizophrenia.

A possible limitation to our study is that patients were under medication at the time of testing. Benzodiazepines have been shown to impair contrast sensitivity, mainly for LSF (Haris & Phillipson, 1995). Also, antipsychotics have been shown to impair contrast perception for HSF and to increase contrast perception for LSF (Harris, Calvert, Leendertz, & Phillipson, 1990). While our analysis failed to find any significant correlation between spatial frequency preference and benzodiazepine or antipsychotics daily dose, further studies will be necessary to measure the impact of those treatments on spatial frequency preference.

Face understanding is a rich process that comprises multiple functional components: the processing of visual features, the perceptual grouping of information, a proper gaze scanning, and the understanding of facial identity, gender, expression, and intention. Integrating over time high- and low-spatial frequency information is a particularly important mechanism of ecological perception: as we move in the world, our percept moves in spatial frequency content. If we approach someone (or when someone comes towards us), we gain the details of the features of the face; as we move away, we lose details. Therefore, integrating high and low spatial frequencies at the correct time scale is a key mechanism for understanding the emotions and intentions of others in dynamic interaction. Our results suggest that while patients with schizophrenia perceive high spatial frequency details well in isolation, the normal time course of concurrently perceiving LSF and HSF is impaired, either because the mechanism of integrating HSF into LSF is altered, or alternatively because LSF processing is over-persistent. Therefore patients with schizophrenia more frequently use coarse visual information, which may contribute to their difficulties with facial processing and social interaction.

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## Conflict of interest

All authors declare that they have no conflicts of interest.

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