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Probing the magnocellular and parvocellular visual pathways in facial emotion perception in schizophrenia

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ABSTRACT

Schizophrenia patients have well-established deficits in facial emotion perception, which contribute to their poor social functioning. A number of studies have related these deficits to a differential dysfunction in the magnocellular (M) versus parvocellular (P) visual pathway. We assessed 35 schizophrenia patients and 35 healthy individuals on an emotion identification task, in which facial stimuli were either unaltered (broad spatial frequency, BSF) or manipulated to contain only high (HSF) or low (LSF) spatial frequencies, thereby respectively biasing the visual system toward the P- or M- pathways. As expected, patients were less accurate and slower in recognizing emotions across all conditions, relative to controls. Performance was best in the BSF condition followed by the HSF and finally the LSF condition, in both groups. A significant group by spatial frequency interaction reflected a smaller magnitude of impairment in the HSF condition, compared to the other two conditions that preferentially engage the M-system. These findings are consistent with studies showing a differential M-pathway abnormality in schizophrenia with a less pronounced impairment in P-function. The current study suggests that patients have less difficulty extracting emotional content from faces when LSFs are attenuated and supports the need to remediate basic visual processing deficits in schizophrenia.

1. Introduction

Individuals with schizophrenia have well-established perceptual and social cognitive deficits that contribute to their poor social functioning (Green et al., 2012). In the visual domain, they have difficulties perceiving simple visual information, such as spatial frequency (O'Donnell et al., 2002), and more complex stimuli, such as facial expressions (Kohler et al., 2010). The patients' impaired emotion recognition ability has been shown to be related to their deficits in basic, early-stage visual processing (Norton et al., 2009). Facial affect recognition involves the processing of facial features and emotional cues, which are conveyed from the retina to the visual cortex through two major cortical processing streams: the ventral and dorsal pathways dominated by parvocellular (P) and magnocellular (M) input, respectively. These pathways have differential psychophysical properties. The M-pathway consists of neurons that process large, low-spatial frequency (LSF) stimuli, whereas the P-pathway consists of neurons that respond preferentially to small, high-spatial frequency (HSF) stimuli (Merigan and Maunsell, 1993).

Faces are initially detected by rapidly conducting M-neurons that provide gross information about shape and coarse emotional cues, and subsequently by the more slowly conducting P-neurons that convey fine grained information about facial properties (Obayashi et al., 2009; Silverstein et al., 2010). Therefore, LSFs contain rough configural information and are generally processed more quickly than HSF components, which convey details of the face, such as wrinkles and exact contours of the eyes and mouth. LSFs are thought to be important for the rapid processing of emotional information, whereas HSFs are needed for the precise recognition of gender and facial identity (Calder et al., 2000; Schyns et al., 2002). This dissociation between fast subcortical processing of coarse emotional LSF information and cortically mediated perception of fine-grained HSF facial information has been demonstrated in neuroimaging studies (e.g., Vuilleumier et al., 2003).

Many studies to date have attempted to bias processing towards the M- versus P-pathway by changing the contrast level (Butler et al., 2009)

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or spatial frequency composition (Calderone et al., 2013) of visual stimuli. The majority of reports that employed LSF and HSF stimuli to differentially activate the M- or P-pathway suggest that schizophrenia patients have deficiencies in both pathways, with a more pronounced impairment in the M-pathway (e.g., Martinez et al., 2008; Butler and Javitt, 2005). Using faces and objects as stimuli, Silverstein et al. (2010) and Calderone et al. (2013) found impaired LSF processing, in addition to increased processing of HSF information in schizophrenia.

Spatial frequency information has been shown to have a direct impact on facial emotion recognition in schizophrenia (McBain et al., 2010). Several studies reported that patients required more visual information to correctly discriminate between facial expressions, compared to controls (Lee et al., 2011), and underutilized facial information presented at the lowest levels of spatial frequency (Clark et al., 2013). Conversely, Laprevote et al. (2010) found that patients preferentially used LSF information to perform a rapid emotion categorization task, suggesting a deficit in the integration of information across spatial frequencies. Therefore, it remains unclear whether the facial emotion perception impairments in schizophrenia are due to a deficient ability to process LSFs.

The goal of the current study was to examine whether biasing the visual system toward the M- versus P-pathway has a differential effect on the ability to recognize emotions in schizophrenia. More specifically, we wanted to assess the influence of spatial frequency filtering on the accuracy and speed of facial emotion processing in schizophrenia patients, compared to healthy controls. We hypothesized that patients will make more errors and will be slower identifying facial expressions regardless of the spatial frequency composition of the stimuli. They will also perform more poorly in the LSF condition, which is most strongly biased toward the M-pathway, compared to the two other conditions.

2. Method

2.1. Participants

Participants included 35 patients with schizophrenia or schizoaffective disorder and 35 healthy controls. Patients were recruited from an inpatient psychiatric unit at a major metropolitan hospital in Bat Yam, Israel. Diagnoses were made by a staff psychiatrist and confirmed using the Structured Clinical Interview for DSM-IV (SCID-I; First et al., 1997). Patients were excluded if they had a current diagnosis of substance abuse or dependence. All patients were clinically stable and receiving antipsychotic medications (10 typical, 10 atypical, and 15 both) at the time of testing.

Healthy controls were recruited from hospital staff and the local community through advertisements. Control participants were excluded if they had any history of Axis I disorders or paranoid, schizoid, or schizotypal personality disorders, according to SCID-I and SCID-II (First et al., 1996). Exclusion criteria for both groups also included a history of a head injury or neurological illness, full-scale IQ estimate less than 70 based on the Test of Nonverbal Intelligence (TONI-3; Brown et al., 1997), and corrected visual acuity estimate (via Snellen wall chart) worse than 20/40. This research was carried out in accordance with *The Code of Ethics of the World Medical Association (Declaration of Helsinki)* for experiments involving humans. All participants provided written informed consent in accordance with the institutional review board.

2.2. Emotion identification task

After completing informed consent and diagnostic interviews, participants were administered the facial emotion identification task, which we have used in previous studies (Rassovsky et al., 2013, 2014). Stimuli consisted of black and white still photographs (2×3 cm) displaying faces with four emotional expressions (happy, sad, angry, and afraid), derived from the Karolinska Directed Emotional Faces set (KDEF, Lundqvist, D., Flykt, A., and Ohman, A.; Dept. of Neurosciences, Karolinska Hospital, Stockholm, Sweden, 1998). We randomly selected 10 actors (5 males and 5 females) displaying the four different emotions from the KDEF set, resulting in a total of 40 different face stimuli. The face pictures were trimmed to exclude the hair and non-facial contours. This task was programmed and run using e-prime software (Psychology Software Tools Inc., USA) and was administered on a Dell Pentium computer with a 17 in. (43 cm) Sony Multiscan 200PS monitor, driven at 160 Hz. Stimuli were centrally presented (3.76°×5.64° eccentricity) as dark on a light background. Participants were asked to identify the emotional expression of face stimuli by pressing one of four labeled keys on the keyboard, such that chance level performance was 25%.

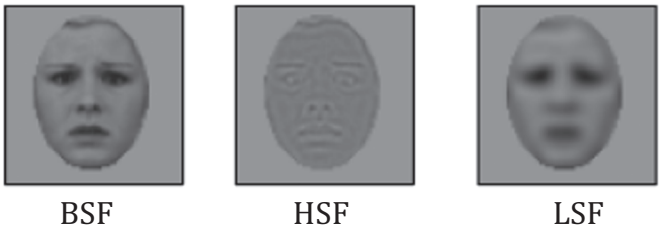

Fig. 1. Example of facial emotion stimuli. The facial image (BSF) was either filtered to a high-spatial frequency (HSF) or low-spatial frequency (LSF) image.

For the high-spatial frequency (HSF) face stimuli, the normal broad-spatial frequency (BSF) faces were filtered using a high-pass filter (≥10 cycles/image), attenuating lower spatial frequencies. Conversely, for the low-spatial frequency (LSF) face stimuli, a low-pass filter (≤6 cycles/image) attenuated higher spatial frequencies (see Fig. 1). Filtering was performed in Matlab (The Natworks, Natick, MA) using second-order Butterworth filters. HSF stimuli bias the system toward the P-pathway, whereas LSF faces bias the system toward the M-pathway. The contrast and luminance of the images resulting from the filtering process were equalized across pictures in two steps. First, by reducing the minimum value from all voxels and then dividing it by the maximum value, the values were transformed to range between 0 and 1. This ensured that the contrast was the same for all pictures. Second, each pixel was multiplied by the median luminance of all pictures and then divided by the mean luminance of the picture. This ensured that the luminance was the same for all pictures.

Participants were seated 1 foot (30.5 cm) from the monitor, received instructions, and practiced the task. For the experimental trials (120 total), the order of stimuli administration was fully randomized across the ten actors, four emotions, and three spatial frequencies. Each face was presented for 500 ms, followed by four emotion labels (“happy”, “sad”, “angry”, “afraid”) presented for 10 s. Participants were instructed to select the facial affect displayed by pressing a number on a keyboard, which triggered the subsequent trial. If the participant did not press any button within 10 s, the next trial was presented.

2.3. Data analysis

For demographic variables, independent samples *t*-tests and chi-square tests were used to assess group differences for continuous and categorical variables, respectively. A 3×2 repeated-measures ANOVA with spatial frequency (BSF, LSF, HSF) as the within-subject factor and group as the between-subject factor was performed to examine the effects of frequency manipulation on the ability to correctly identify emotions depicted in faces (percent correct). The same analysis was repeated with reaction time as the dependent variable. Given the small

number of trials per emotion, we examined the performance of both groups, averaged across all four emotions, in each condition. Bonferroni-corrected *t*-tests were conducted to follow up on significant main effects and interactions. Examination of the data revealed no significant outliers, but the dependent variables were positively skewed. A log transformation did not change the pattern of the results. We therefore report the analyses with the non-transformed data.

3. Results

3.1. Demographic and clinical characteristics

The sample consisted of 35 patients (29 with schizophrenia and 6 with schizoaffective disorder; 51% male) and 35 healthy controls (54% male). The gender distribution was similar for the two groups ($\chi 2$=0.06, p=0.81), but there were significant group differences in age (t [68]=−2.10, p=0.04) and education (t [68]=2.81, p=0.006). The schizophrenia group was significantly older (M=40.0, SD=12.4) and had fewer years of education (M=12.0, SD=2.62) than the control group (M=33.8, SD=12.1 and M=13.5, SD=1.92, respectively). Patients' age of illness onset ranged from 13 to 58 years (M=26.4, SD=10.2), and illness chronicity ranged from 1 to 52 years (M=13.5, SD=13.5). Patients' average positive and negative symptoms, based on the Positive and Negative Syndrome Scale (PANSS; Kay et al., 1992) were 18.5 (SD=9.05) and 23.6 (SD=10.6), respectively.

3.2. Accuracy

Table 1 displays the participants' performance on the emotion identification task. The repeated-measures ANOVA for accuracy revealed significant main effects of group (F [1,68]=9.99, p=0.002, partial η^2=0.13) and condition (F [2136]=282.40, $p < 0.001$, partial η^2=0.81), as well as a significant group by condition interaction (F [2136] =3.19, p=0.04, partial η^2=0.05). Averaged across conditions, the patient group's percentage of correct responses (M=59.90, SD=13.07) was significantly lower than that of the control group (M=69.81, SD=13.07). Averaged across groups, performance was significantly different among all three conditions (all p's < 0.001), with accuracy best in the BSF condition (M=84.71, SD=19.49) and worse in the LSF condition (M=51.71, SD =12.05), with the HSF condition (M=58.14, SD=11.80) in between. Paired samples t-tests within each group revealed statistically significant differences between HSF and LSF performance (p=0.001 in the HC group and $p < 0.001$ in the SZ group) as well as between BSF and both HSF and LSF (p's < 0.001 in both groups). Although schizophrenia patients performed worse than controls in all three conditions (see Fig. 2), the interaction was due to the magnitude of the group difference being smaller in the HSF condition (p=0.03) relative to the other two conditions (p=0.004 for BSF and 0.001 for LSF).

Table 1
Emotion recognition performance.

	Patients (n=35) Mean (SD)	Controls (n=35) Mean (SD)
Accuracy (% correct)		
BSF	77.86 (23.52)	91.57 (14.44)
HSF	55.00 (14.04)	61.29 (9.10)
LSF	46.86 (14.86)	56.57 (8.47)
Reaction Time (in seconds)		
BSF	2.63 (0.88)	1.66 (0.56)
HSF	2.77 (1.01)	1.70 (0.55)
LSF	2.89 (0.92)	1.65 (0.54)

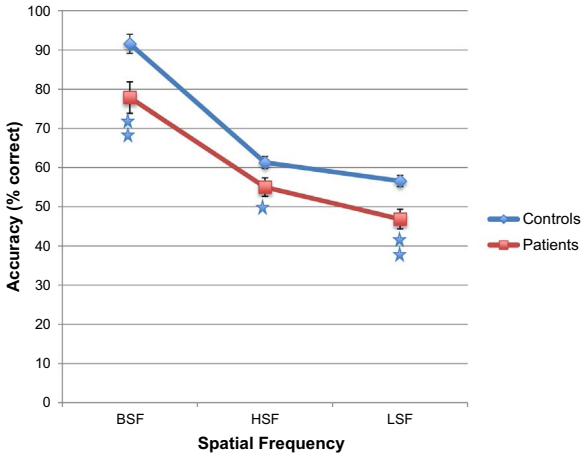

Fig. 2. Effect of spatial frequency on accuracy of facial emotion identification. Percentage of correct responses for each group in each condition: BSF=broad-spatial frequency; HSF=high-spatial frequency; LSF=low-spatial frequency. The vertical bars indicate standard errors. The stars indicate significant differences: * $p < 0.05$; ** $p < 0.005$.

3.3. Reaction time

The repeated-measures ANOVA for reaction time revealed a significant main effect of group (F [1,67]=42.61, $p < 0.001$, partial η^2=0.39), with patients (M=2.76, SD=0.70) being significantly slower than controls (M=1.67, SD=0.70) across conditions. However, the condition main effect (p=0.16) and group by condition interaction (p=0.15) were not significant.

4. Discussion

In this study, we investigated the role of spatial frequency information in the perception of facial expressions in patients with schizophrenia compared to healthy individuals. Only a few other behavioral studies (Butler et al., 2009; Laprevote et al., 2010; McBain et al., 2010) have systematically altered the spatial frequency composition of facial stimuli to examine how it affects emotion perception in this population. As expected, patients were significantly less accurate and slower in recognizing emotions from faces across all three spatial frequency conditions, relative to controls. The same pattern of performance was observed in both groups: patients and controls were most accurate identifying emotions in the BSF condition, in which faces were unaltered, and their performance was significantly better in the HSF compared to the LSF condition. Similar to results from Laprevote et al. (2010)'s control experiment, the speed of identifying emotions from faces was not modulated by spatial frequency manipulation in either group.

Consistent with the large body of literature suggesting M-pathway impairment in schizophrenia (e.g., Butler and Javitt, 2005; Calderone et al., 2013), patients performed worse in the LSF relative to the HSF condition. The most important finding, however, was the significant group by spatial frequency interaction, which was due to patients having less severe impairment in the HSF condition relative to the other two conditions. The effect size difference between patients and controls was large for BSF (Cohen's d=0.70) and LSF (Cohen's d=0.80), and medium for HSF (Cohen's d=0.53). Therefore, the magnitude of the group difference was smaller in the condition that capitalizes on the P-system. Patients' ability to correctly identify emotions was more seriously affected in the LSF and BSF conditions, both of which engage the M-system (M-neurons are strongly activated by LSF stimuli but also respond to BSF stimuli, which contain both high and low spatial frequency elements). These findings replicate previous behavioral and neuroimaging studies (e.g., Bedwell et al., 2013; Butler et al., 2009;

Kim et al., 2015) showing a selective M-deficit in schizophrenia with a less pronounced deficit in P-function, and have implications for the patients' ability to navigate their social environment. As there is a clear evolutionary benefit from using LSFs in emotion processing, having intact M-pathway is crucial for the rapid and accurate extraction of emotional information from faces, especially when making approach-avoidance decisions based on crude facial features.

Contrary to expectations, present results revealed that similar to patients, healthy participants were more accurate in identifying facial expressions in HSF compared to LSF stimuli. These unexpected findings contrast the predominant view that face emotional processing is selectively tuned for LSF (Fusar-Poli et al., 2009; Rohr and Wentura, 2014). Nonetheless, they are in line with those of another study (Laprevote et al., 2010), in which both healthy controls and schizophrenia patients performed better when presented with HSF than with LSF faces (across neutral, angry, and happy expressions). It is possible that there is a differential bias towards LSF and HSF face stimuli, depending upon the type of facial expression being processed.

This study has several limitations. First, due to the relatively small number of trials per emotion, participants' performance was averaged across the four emotions. Consequently, we could not assess if patients and controls processed each type of emotion (happiness, sadness, anger, fear) differently under different spatial frequency conditions. Previous research has shown that generally schizophrenia patients have more difficulty detecting fear (Norton et al., 2009) and anger (Laprevote et al., 2010) than happiness, and utilize spatial frequency information aberrantly to identify certain facial expressions (Lee et al., 2011). It would have been useful to analyze responses to each emotion separately and characterize the pattern of mistakes that patients make. For example, McBain et al. (2010) has shown that patients were more likely than controls to perceive facial images with LSF information as more fearful than images without this information. Therefore, more studies are needed to determine if the selective M-pathway impairment in schizophrenia is specific to some emotions and not others.

Second, we did not assess parental education and our groups were not matched on age and education. Due to early onset of the illness, individuals with schizophrenia usually have fewer years of education than healthy controls. Thus, as education level is considered to be part of the illness, this variable is not typically controlled for in the analyses. However, because of the group difference in age, we examined associations between age and our dependent variables and found age to be negatively correlated with performance (accuracy) in the BSF condition, only in the control group. Including age as a covariate did not change the pattern of the results (for both accuracy and reaction time), yielding significant main effects of condition and group, yet a somewhat reduced group x condition interaction effect for accuracy ($p=0.07$).

Third, our sample consisted of schizophrenia inpatients who were receiving antipsychotic medications at the time of testing. However, visual processing deficits have been found in both medicated and unmedicated schizophrenia patients (e.g., Butler et al., 2002; Cadenhead et al., 1997). Thus, we expect our findings to generalize to an outpatient or unmedicated population.

In summary, the current study expands the existing literature supporting a differential M-pathway abnormality in facial emotion recognition in schizophrenia. Although the study could not disentangle the effects of SF manipulation on the recognition of individual emotions, it showed that across a broad range of facial expressions, schizophrenia patients were less impaired in their ability to accurately identify emotions in HSF stimuli than in BSF and LSF stimuli. The results suggest that patients have difficulty recognizing emotions from faces in general, yet tend to perform better when the low spatial frequency information in faces is attenuated or filtered out. Remediating basic visual processing deficits in schizophrenia patients might therefore improve their ability to accurately perceive others' facial expressions, and in turn, facilitate their social interactions.

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