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Specific vulnerability of face perception to noise: A similar effect in schizophrenia patients and healthy individuals

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Face perception plays a foundational role in the social world. This perceptual ability is deficient in schizophrenia. A noise-filtering mechanism is essential for perceptual processing. It remains unclear as to whether a specific noise-filtering mechanism is implicated in the face perception problem or a general noise-filtering mechanism is involved which also mediates non-face visual perception problems associated with this psychiatric disorder. This study examined and compared the effects of external noise on the performance of face discrimination and car discrimination in schizophrenia patients ($n=25$) and healthy controls ($n=27$). Superimposing the external visual noise on face or car stimuli elevated perceptual thresholds (i.e. degraded performance levels) for both face and car discrimination. However, the effect of noise was significantly larger on face than on car discrimination, both in patients and controls. This pattern of results suggests specific vulnerability of face processing to noise in healthy individuals and those with schizophrenia.

1. Introduction

Schizophrenia patients have exhibited impairments in various aspects of face perception (Phillips and David, 1995; Mandal et al., 1998; Darke et al., 2014; Chen, 2011). While impairments in face perception must have profound impacts on social functioning (Barton, 2003; Duchaine and Nakayama, 2005), their underlying mechanisms remain murky. Previous studies have been focused on how different functional domains such as affective and non-affective processing of facial images are altered in schizophrenia patients (Heimberg et al., 1992; Gur et al., 2002; Butler et al., 2008; Chen et al., 2008, 2009; Silverstein et al., 2010; McBain et al., 2010; Lee et al., 2007, 2011; Yoon et al., 2006). Noise-filtering is essential for the processing of perceptual information including faces, and appears to be implicated in various aspects of deficient perceptual processing in schizophrenia (Chen et al., 2008, 2014; Kim et al., 2013). A recent study proposed heightened noise levels as a mechanism underlying abnormal facial processing in schizophrenia (Spencer et al., 2013). The premise of this empirically- and computationally-inspired proposal is that noise within the facial processing system is heightened in this psychiatric disorder and, as a result, the reduced signal-to-noise ratio degrades patients' capacity in face perception.

Noise is a critical limiting factor for information processing in the brain; yet it is unclear whether it plays a similar role across different brain systems. The brain system for processing face information is distinct from those for processing non-face visual information. For example, the fusiform face area (FFA) of the temporal cortex responds selectively to faces, but not to non-face visual objects (Kanwisher et al., 1997, 1998; Haxby et al., 2000). As to noise, the existence of the face-specific brain system bears a question whether face processing, compared to the processing of non-face visual objects, responds differently to signal-irrelevant inputs. This question has not been answered with respect to either schizophrenia patients or healthy individuals.

In this study, we examined the effects of external noise on face discrimination and car discrimination in healthy individuals and schizophrenia patients. Our working hypothesis was that imposing external noise would interfere with the performance of face discrimination task to a greater extent than of car discrimination task, assuming that face processing is more vulnerable to noise than non-face visual processing. Further, given that schizophrenia is associated with hypersensitivity to environment (with a tendency to register information of no intrinsic interest) (Bleuler, 1911), we hypothesize that imposing external noise would interfere with patients' performance of face discrimination task to a greater extent than among controls.

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2. Material and methods

2.1. Subjects

Participants included 25 schizophrenia patients and 27 healthy controls. These individuals were included based on the following criteria: (1) no history of any neurological disorders (such as seizure or stroke) or head injuries, (2) IQ > 70, (3) age between 18 and 60 years old, and (4) no substance abuse in the six months prior to participation.

Patients were recruited from McLean Hospital and the Greater Boston areas. Their diagnoses were established based on a structured clinical interview SCID-IV (First et al., 1994) conducted by experienced clinicians who were blind to the purposes of this study, and by a review of all available medical records. Thirteen of these patients had a diagnosis of schizophrenia and the rest had a diagnosis of schizoaffective disorder. All patients were medicated on antipsychotic drugs (mean CPZ=538.1 mg, SD=422.7 mg). The Positive and Negative Syndrome Scale (Kay et al., 1987) was administered to the patients (positive subscale=14.0, SD=6.9; negative subscale=10.8, SD=3.0; general subscale=24.9, SD=6.8). Healthy controls were recruited from the local community. They were screened for the absence of Axis I psychiatric disorders using a standardized interview based on the SCID-I/NP (First et al., 2002). The two groups of subjects were matched in terms of average age and gender composition.

The Wechsler Adult Intelligence Scale – Revised (verbal component) (Wechsler, 1981) was administered to all participants. The participants had normal or corrected to normal vision, as assessed by the Rosenbaum Pocket Vision Screener. Table 1 provides demographic information of the participants.

2.2. Procedures

Visual stimuli were photograph images of face or car, alone or with uniform visual noise superimposed. A series of additional face and car images were created by morphing between two original photographed faces (from two different individuals) or between two original photographed cars (from two different models) (Fig. 1). Morphing was implemented using FantaMorphPro (v5.0, 2012), which automatically detects visually salient points of two original images and generates new images with points transitioning from one original set to another. As such, the resultant images contained varying proportions of two original items. Paired images for comparison had five levels of differences in the proportion of two original items: 5%, 12.5%, 25%, 50%, 100%, generating five levels of signal strength for face or car identity comparison. For example, to achieve a 5% difference between two face identities, the two original face images would be morphed to create two images: one containing 47.5% of one identity and 52.5% of the other identity, and the other containing 52.5% of one identity and 47.5% of the other identity.

The noise was created by randomly selecting a half of the pixels across an image and assigning them a fixed luminance rather than the values defined by the image itself. These noise pixels were randomly but evenly distributed across space. A single level of uniform noise was added to the images, both the original ones and morphed versions of the original ones (Fig. 1).

Two types of visual discrimination tasks, one for faces and the other for cars, were used. The task was to discriminate between a series of paired face or car images, based upon their identities. Each trial included two sequential presentations with a 500 ms pause in between. The brief inter-stimulus interval ensured that patients' perceptual performance was evaluated independently of working memory constraints (Chen et al., 2009; Park and Holzman, 1992). The first presentation contained a single image (600 ms). The second presentation contained a pair of images side by side (1200 ms), one of which was identical to that in the first presentation, and the other of which differed to varying degrees. Subjects determined which of the two images in the second presentation was the same as the image in the first presentation. This two alternative force choice procedure was administered with and without the presence of noise. Four testing sessions were blocked according to image type (face or car) as well as noise status (presence or absence). The order of presentation of the four task conditions was counterbalanced across subjects. With five levels of identity comparisons, each repeated 8 times, all sessions contained 40 trials. The order of the trials in a testing block was randomized across 5 stimulus strengths within each trial. The percent of correct trials or accuracy was used as a primary measure of perceptual performance.

All stimuli and task procedures were programmed within VisionShell on a G3 Mac computer, which also recorded subjects' responses. Subjects received a general training which included instructions and practice time for each task prior to formal data collection. During the practice, four types of trials (regular face images, noisy face images, regular car images and noisy car images) were presented and were repeated if asked by a subject. The study protocol was approved by the Institutional Review Board of McLean Hospital, and written informed consent was obtained from all participants.

3. Results

Table 2 summarizes the performance accuracies and the perceptual thresholds of face discrimination and car discrimination for patients and controls.

Table 1
Demographic characteristics of the sample: group mean (standard deviation).

	Sex	Age (year)	Verbal IQ*	Education (year)	Parental education (year)
Controls (n=27)	13-M, 14-F	43.0 (15.2)	111.5 (12.7)	15.3 (1.8)	14.7 (3.7)
Patients (n=25)	15-M, 10-F	43.3 (9.6)	101.4 (11.4)	14.0 (2.1)	14.4 (3.0)

F – female; M – male.

* Statistically significant ($p < 0.05$).

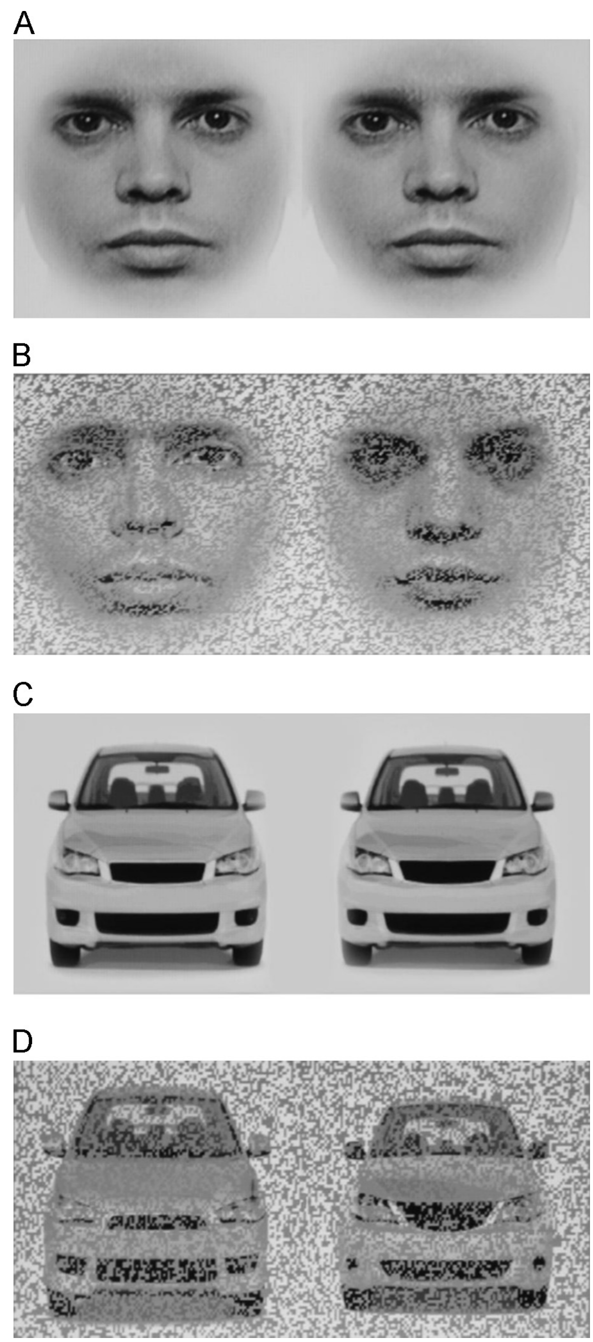

Fig. 1. Schematic illustration of face and car stimuli used in this study. Panels A and C show a pair of comparison original faces and original cars under the no-noise condition, respectively, whereas panels B and D show a pair of comparison original faces and original cars under the noise condition, respectively.

Table 2
Summary of face discrimination and car discrimination performance: mean (standard error).

	Stimulus strength	Patient		Control	
		Accuracy	Threshold	Accuracy	Threshold
Face (regular)	52.5	0.49 (0.02)	68 (2.0)	0.51 (0.02)	68 (2.0)
	55.0	0.57 (0.02)		0.56 (0.02)	
	62.5	0.72 (0.04)		0.78 (0.03)	
	75	0.86 (0.03)		0.91 (0.02)	
	100	0.95 (0.02)		0.98 (0.01)	
Car (regular)	52.5	0.58 (0.03)	63 (3.0)	0.61 (0.03)	69 (4.0)
	55.0	0.68 (0.04)		0.69 (0.03)	
	62.5	0.78 (0.04)		0.85 (0.03)	
	75	0.86 (0.03)		0.94 (0.02)	
	100	0.89 (0.03)		0.95 (0.02)	
Face (noisy)	52.5	0.48 (0.02)	83 (4.0)	0.48 (0.03)	82 (3.0)
	55.0	0.53 (0.02)		0.53 (0.03)	
	62.5	0.60 (0.03)		0.63 (0.02)	
	75	0.72 (0.03)		0.74 (0.03)	
	100	0.87 (0.03)		0.92 (0.02)	
Car (noisy)	52.5	0.52 (0.02)	68 (4.0)	0.58 (0.03)	71 (4.0)
	55.0	0.60 (0.03)		0.68 (0.03)	
	62.5	0.73 (0.04)		0.80 (0.04)	
	75	0.83 (0.03)		0.89 (0.04)	
	100	0.88 (0.03)		0.94 (0.02)	

3.1. Face discrimination

A three-way ANOVA (subject group (patient or control), signal strength (5 levels), and noise (presence and absence)) on performance accuracy revealed significant effects for signal strength ($F(1,\ 4)=212.5$, $p<0.001$), group ($F(1,\ 51)=4.7$, $p=0.031$) and noise ($F(1,\ 1)=59.1$, $p<0.001$). The interaction between signal strength and noise was significant ($F=5.5$, $p<0.001$) whereas the other interactions were not ($p>0.05$). This analysis indicates that the performance levels of patients were lower than those of controls and the presence of noise degraded the performance levels overall. It also indicates that the noise effect depended upon signal strength (Fig. 2).

To further evaluate the performance change of the two groups in relation to the presence of noise, separate two-way ANOVAs were used for the noise and the no-noise conditions. For the no-noise condition, the ANOVA (group and signal strength) revealed significant effects of signal strength ($F(1,\ 4)=81.7$, $p<0.001$) and group ($F(1,\ 51)=4.4$, $p=0.036$, Cohen's $d=0.36$). The interaction between group and signal strength was not significant.

For the noise condition, the ANOVA (group and signal strength) revealed a significant effect of signal strength ($F(1,\ 4)=81.7$, $p<0.001$). Neither the group effect (Cohen's $d=0.22$) nor the interaction between group and signal strength was significant.

3.2. Car discrimination

A three-way ANOVA (group, signal strength and noise) on performance accuracy revealed significant effects on signal strength ($F(1,4)=90.8$, $p<0.001$), group ($F(1,51)=19.2$, $p<0.001$) and noise ($F(1,\ 1)=6.9$, $p=0.009$). None of the interactions were significant. This analysis indicates that the performance levels of patients were lower than that of controls overall and the presence of noise degraded the performance levels (Fig. 2).

For the no-noise condition, a two-way ANOVA (group and signal strength) revealed significant effects on signal strength ($F(1,\ 4)=45.0$, $p<0.001$) and group ($F(1,\ 51)=6.9$, $p=0.009$, Cohen's $d=0.45$). The interaction between group and signal strength was not significant.

For the noise condition, a two-way ANOVA (group and signal strength) revealed significant effects on signal strength ($F(1,\ 4)=46.0$, $p<0.001$) and group ($F(1,\ 51)=12.7$, $p<0.001$, Cohen's $d=0.46$). The interaction between group and signal strength was not significant.

3.3. Comparison of face discrimination and car discrimination

Perceptual thresholds of face discrimination and car discrimination were derived as a unified performance measure for each subject. This measure was defined as minimum signal strength level at which a subject achieves the performance level of 80% accuracy, and was computed through fitting accuracy data to a psychometric function[1] (Chen et al., 2009). By taking into account the accuracies under all stimulus strengths, the derived perceptual thresholds provided a singular metric of performance in each task condition that could be used to compare between the performance of the two tasks and between the task performance and clinical variables.

A three-way ANOVA (group, noise and object type (car and face)) on perceptual threshold revealed significant effects on group ($F(1,51)=7.4$, $p=0.007$), noise ($F(1,1)=21.3$, $p<0.001$) and object type ($F(1,1)=13.8$, $p<0.001$). The interaction between noise and object was significant ($F=4.8$, $p=0.029$) whereas the other interactions were not significant. This pattern of analysis indicates differential noise effects on car and face discrimination (Fig. 3).

In controls, the perceptual thresholds for car discrimination did not differ significantly between the noise and the no-noise conditions ($t=0.84$, $p=0.41$). However, the perceptual thresholds for face discrimination were significantly lower (better performance) under the no-noise condition than under the noise condition ($t=5.04$, $p<0.001$).

In patients, the perceptual thresholds for car discrimination did not differ significantly between noise and no-noise conditions ($t=1.44$, $p=0.15$). However, the perceptual thresholds for face discrimination were significantly lower (better performance) under the no-noise condition than under the noise condition ($t=2.76$, $p=0.008$).

3.4. Relationship with clinical variables

Under the no-noise condition, perceptual thresholds of face discrimination in patients were not correlated with clinical measures, except for the negative PANSS scores. Under the noise condition, perceptual thresholds of face discrimination in patients were only correlated with the general PANSS scores. Correlation coefficients between face discrimination performances and clinical variables are listed in Table 3.

4. Discussion

This study found that the presence of external visual noise degraded the performance of visual identity discrimination (faces and cars). This noise effect was greater for face discrimination than for car discrimination. Schizophrenia patients showed reduced performance levels at baseline (i.e. in the absence of noise), but were similarly affected by noise, as compared to healthy controls; both groups showed greater degradation of performance by noise for face discrimination than for car discrimination. These results

[1] The psychometric function takes a form of $y=100-50*\exp((-a/x)\text{\wide-hat}b)$ (Weibull function). Here, y signifies accuracy, x signifies stimulus strength. a and b are the fitting parameters.

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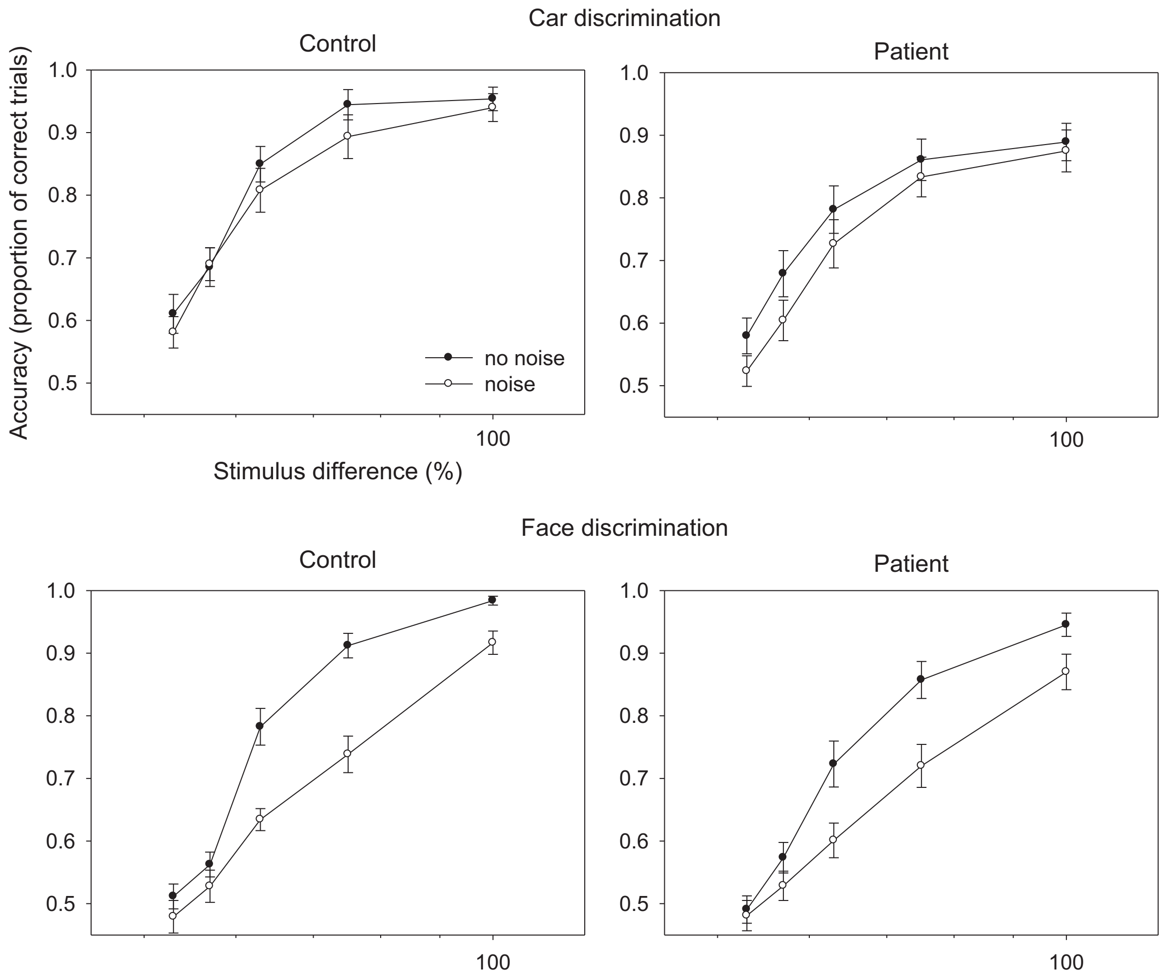

Fig. 2. Performance accuracies of visual discrimination. The top two panels are for car discrimination and the bottom two panels are for face discrimination. The panels on the left are for patients and the panels on the right are for controls. In each panel, the *x*-axis represents signal strength used for visual discrimination. The *y*-axis represents the percent of trials in which a correct response is produced. Error bars are for ±1 standard error.

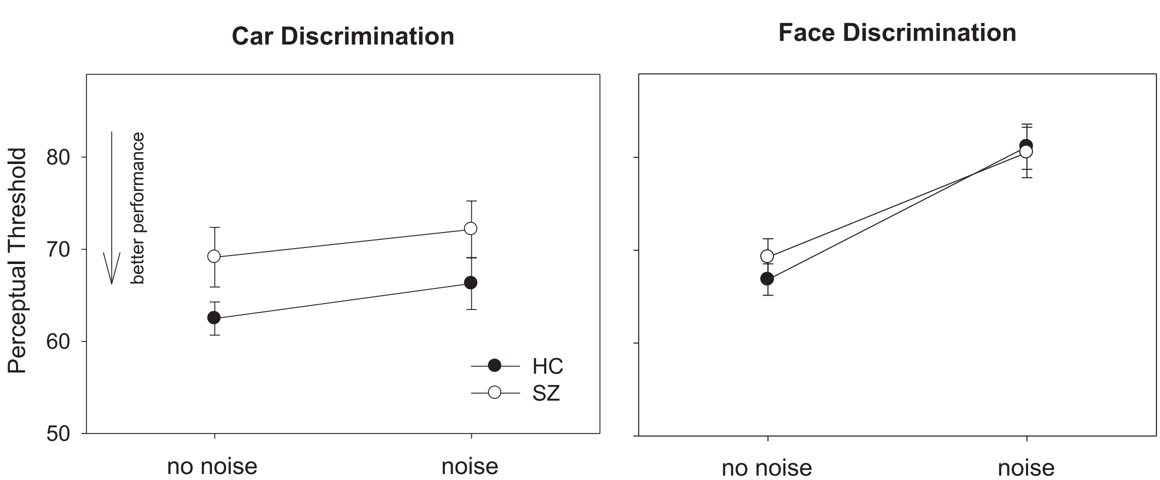

Fig. 3. Perceptual thresholds for car discrimination and face discrimination. In each panel, the *x*-axis represents the status of noise (absence or presence) during visual discrimination. The *y*-axis represents perceptual thresholds of car discrimination (the left panel) and of face discrimination (the right panel). The lower a threshold, the better the perceptual performance is. SZ stands for schizophrenia patient and HC stands for healthy control. Error bars are for ±1 standard error.

support the first hypothesis of this study – face processing is more vulnerable to noise than non-face visual processing – but do not support the second hypothesis – abnormal face processing in schizophrenia is more vulnerable to noise than face processing in health.

4.1. Noise effect on face vs. non-facevisual discrimination

While face recognition is established as a specialized perceptual process (Kanwisher et al., 1997; Bodamer, 1947; Yin, 1969; Duchaine and Nakayama, 2006), the issue of whether noise exerts

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Table 3
Correlation coefficients between face discrimination and clinical variables in patients.

	Verbal IQ	CPZ	Illness duration	PANSS (+)	PANSS (−)	PANSS (general)
Face discrimination (regular)	−0.33	0.22	0.03	−0.06	0.44*	0.22
Face discrimination (noisy)	−0.09	0.04	−0.03	0.09	−0.02	0.40*
Car discrimination (regular)	−0.39	−0.13	−0.05	−0.19	−0.33	−0.26
Car discrimination (noisy)	−0.49*	−0.09	0.18	−0.10	−0.22	−0.17

Not corrected for multiple comparison.

* Statistically significant ($p < 0.05$).

a specific effect on face processing as compared to non-face visual processing has seldom been addressed. One previous study showed that imposing external noise differentially degraded the perception of upright vs. inverted faces (Schneider et al., 2007). As inverted faces are presumably a non-face visual object, this result would be consistent with the notion that there are differential effects of noise on face vs. non-face visual processing. However, another study showed that face inversion did not change internal noise (Gaspar et al., 2008), a result that would be inconsistent with the notion of differential noise effects on face vs. non-face visual processing. The present study directly addresses this issue by examining and comparing noise effects on face vs. non-face visual discrimination. The significant interaction between the type of visual discrimination (face vs. car) and the status of visual noise (presence vs. absence), found in this study, indicates a larger effect of external noise on face discrimination than on car discrimination. This result suggests a larger role of external noise or a relatively smaller role of internal noise in the face processing system. Note that the property of a low level of internal noise would allow highly efficient processing of face information in the absence of external noise. Adding external noise may reduce the signal-to-noise ratio for face discrimination to a greater extent than for car discrimination, or face processing has greater vulnerability to noise than non-face visual processing.

4.2. The effect of noise among schizophrenia patients and healthy controls

The result of a significant noise effects for face discrimination but no significant interaction between noise and group suggests that adding external noise has a significant impact on face processing in both schizophrenia patients and healthy controls. First, in schizophrenia, high levels of internal noise in the face processing system have been suggested (Spencer et al., 2013). According to this suggestion, a smaller effect of external noise on face perception would be predicted for patients as their face processing system is presumably noisy. The similar degradation of face perception in patients and controls due to the presence of external noise, found in this study, suggests that face processing in schizophrenia, while impaired, may not be as noisy as suggested and thus imposing external noise yields similar interfering effects in the two groups. Second, the normal face processing system, maintaining a relatively low level of internal noise, is vulnerable to external noise. The face discrimination result contrasted with that in car discrimination, where the presence of external noise had a smaller effect in both patients and controls (Fig. 3). Taken together, these results highlight that face processing in the healthy and schizophrenic brains may be specifically vulnerable to noise.

4.3. Summary, limitations and future directions

Through examining and comparing face discrimination and non-face visual discrimination in the presence of noise, this study provides evidence suggesting a specific vulnerability of face processing system to external noise in schizophrenia patients and in healthy individuals. Results from car discrimination – showing significantly reduced effect of external noise – does not support the idea that the effect of internal noise similarly extends to other visual processes in this psychiatric disorder. Instead, it suggests that a smaller role of external noise or a higher level of internal noise in non-face visual processes is associated with schizophrenia.

The presence of external noise did interfere with non-face visual processing in schizophrenia patients (Chen et al., 2003, 2008, 2014; Kim et al., 2013;Stuve et al., 1997). While this study showed quantitative differences between the noise effects in face processing and in non-face visual processing, whether qualitative differences exist in schizophrenia remains unclear. For example, only a single level of external noise was used in the present study. It is thus unknown whether the differentiation of noise effects in face and non-face visual processing remains when a higher or a lower level of external noise is applied.

This study has several additional limitations. First, only one pair of facial identity and one pair of car identity were used for visual discrimination. Whether the results from this small set of face and non-face identities can be generalized to more identities needs to be examined. Second, although perceptual signals were presumably not identical between the face and car images, the perceptual thresholds for the two identity tasks were similar at baseline (Fig. 3). This justified the images being used for studying effects of identical external noise. Ideally, equating task difficulty levels should be considered when comparing performance levels of two tasks. Third, the noise used here was static in time and was evenly distributed in space. It remains to be examined whether or not other types of noise have similar effects on face processing in patients and controls. Fourth, the patient group had a lower average verbal IQ score than the control group. Although this variable was not significantly correlated with face discrimination performance in patients, it did show a significant correlation with car discrimination performance (Table 3). In a previous study, patients showed a significant correlation between verbal IQ and perceptual discrimination of a happy facial expression but not of a fearful facial expression (Norton et al., 2009). Further examination of how this neurocognitive factor influences face perception in additional patients is warranted.

A couple of moderate but significant correlations between face perception and selected clinical variables in patients warrant a follow-up. The relationship between regular face discrimination and negative PANSS scores implies an association between face processing and social functioning deficits that are part of schizophrenia. The relationship of noise-masked face discrimination and general PANSS scores, on the other hand, implies an association between face processing vulnerability to noise and general psychotic symptoms. At this stage, the two relationships, while potentially interesting, are only tentative due to the relatively moderate sample size.

One broad theory is that schizophrenia is associated with 'noisy' brain systems (Winterer and Weinberger, 2004). It would

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be interesting to see whether the specific vulnerability of face perception to noise is reflected in cortical responses during the processing of face signals in patients. A recent study found that patients' activations in multiple cortical regions, such as hippocampal, thalamic and temporal areas, are abnormally increased when listening to noisy auditory stimuli (Tregellas et al., 2009). Investigating how patients' abnormal cortical and perceptual responses to face and non-face visual objects are linked in the presence of external visual noise would help reveal brain mechanisms responsible for face-specific perceptual vulnerabilities in schizophrenia and in health.

One recent study showed that variability in cortical response (i.e. internal noise) can be modified by behavioral tasks (Garrett et al., 2014). This suggests the possibility of reducing heightened internal noise in a specific brain system (such as the one for face processing) through targeted behavioral interventions. Indeed, schizophrenia patients have already shown some promise in this regard, as a recent study demonstrated that training on visual motion discrimination provided patients with an increased tolerance for random motion noise (Norton et al., 2011).

In the social world, identifying facial identity and emotion expression can be a challenging task, as irrelevant visual signals are frequently present. Irrelevant signals may act like external noise interfering with the processing of relevant signals, i.e. facial information. This study found that the presence of external noise affected face discrimination to a greater extent. One implication of this specific vulnerability is that in order to achieve similarly effective interventions, enhancement of one's ability to attend relevant visual targets and to ignore surrounding irrelevant visual targets is particularly useful for improving face perception and social functioning in patients, although such enhancement could ostensibly benefit healthy people as well.

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