



# Noise as a mechanism of anomalous face processing among persons with Schizophrenia

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There is substantial evidence that people with Schizophrenia (SCZ) have altered visual perception and cognition, including impaired face processing. However, the mechanism(s) underlying this observation are not yet known. Eye movement studies have found that people with SCZ do not direct their gaze to the most informative regions of the face (e.g., the eyes). This suggests that SCZ patients may be less able to extract the most relevant face information and therefore have decreased calculation efficiency. In addition, research with non-face stimuli indicates that SCZ is associated with increased levels of internal noise. Importantly, both calculation efficiency and internal noise have been shown to underpin face perception among healthy observers. Therefore, the current study applies noise masking to upright and inverted faces to determine if face processing deficits among those with SCZ are the result of changes in calculation efficiency, internal noise, or both. Consistent with previous results, SCZ participants exhibited higher contrast thresholds in order to identify masked target faces. However, higher thresholds were associated with increases in internal noise but unrelated to changes in calculation efficiency. These results suggest that SCZ-related face processing deficits are the result of a decreased noise-to-signal ratio. The source of increased processing noise among these patients is unclear, but may emanate from abnormal neural dynamics.

**Keywords:** Schizophrenia, face perception, internal noise, calculation efficiency, face orientation

## INTRODUCTION

People with Schizophrenia (SCZ) are impaired in recognizing and discriminating human faces in both upright and inverted orientations (Archer et al., 1992; Whittaker et al., 2001; Sachs et al., 2004). Moreover, although SCZ participants demonstrate visual processing deficits across a broad assortment of stimuli, face stimuli may be particularly problematic in this regard. For example, in a study by Chen et al. (2008), patients with SCZ were less accurate when locating or matching line drawings of faces compared to similar drawings of trees. This suggests that the ability to detect faces, compared to other visual stimuli, may be disproportionately impaired in this patient population<sup>1</sup>. Furthermore, when detecting trees, both patients with SCZ and healthy participants displayed similar stimulus inversion effects. However, stimulus inversion effects for faces were observed to be significantly reduced in people with SCZ<sup>2</sup>. The reduced face inversion effect observed in the patient population, in addition to the lack of

an inversion effect when detecting trees, suggests an impairment that is particular to face detection in SCZ. Moreover, SCZ-related deficits in face discrimination increased significantly as the duration of the interval between the initial and target faces increased, suggesting that face deficits may exist in working memory, as well as perception (Chen et al., 2009). These results, and others (Novic et al., 1984; Walker et al., 1984; Phillips and David, 1995; Gur et al., 2002) establish that SCZ participants are impaired when processing faces and suggest that this deficit is not likely to be fully accounted for by a general visual processing impairment across all classes of objects (e.g., trees).

Moreover, it is broadly accepted that faces convey an enormous range of socially relevant information about one's identity, gender, age, ethnicity, mood, attractiveness, level of interest, current focus of attention, and/or intentions (Haxby et al., 2002; Little et al., 2011). In turn, this information influences an array of social phenomenon including social categorization (Quinn and Macrae, 2011), discrimination, stereotyping and prejudice (Quinn et al., 2003), judgment of others' emotional state and empathy (Freitas-Magalhães, 2011; Eisenberger, 2012), and romantic attraction, attachment, and friendship (Gobbini et al., 2004; Wang et al., 2010). These observations are relevant to the investigation of

have shown intact face inversion effects within this population. While the reasons for these discrepancies are unknown, it is possible that methodological differences across studies may account for these findings.

<sup>1</sup>The study by Chen et al. (2008) is the only experiment known to the authors that directly compares the processing of faces to other objects with similar visual characteristics. It should also be noted, however, that detection accuracy rates from this study show that face processing is more difficult (lower accuracy in both SCZ and HC groups). Consequently, the group by object-type interaction may reflect a difficulty confound (Chapman and Chapman, 1973) and, in turn, could suggest that face processing is inherently more complex.

<sup>2</sup>It is noted that while many studies have shown a reduced face inversion effect among people with SCZ, others (e.g., Chambon et al., 2006; Butler et al., 2008)

SCZ since patients with this disorder also demonstrate prominent social deficits (Penn et al., 1997; Tulloch et al., 2006) and many researchers have directly linked SCZ-related alterations in face processing with social impairment (e.g., Marwick and Hall, 2008). Consequently, investigations aimed at understanding the mechanisms of altered face processing also hold the promise of elucidating determinants of social dysfunction among in persons with SCZ.

However, despite reliable evidence of impaired face processing among people with SCZ, few studies have assessed the mechanisms potentially responsible for this finding. A common speculation is that impaired face processing is a result of compromised neural functioning in the fusiform face area (FFA), or Brodmann's area 37. This suggestion is based on previous findings demonstrating reduced volume of the fusiform gyrus compared to other brain regions (Highley et al., 1999; Lee et al., 2002; Onitsuka et al., 2003). Additionally, reduced fusiform volume has shown to be associated with facial emotion recognition deficits in the population (Goghari et al., 2011). However, functional activation (as ascertained by fMRI) of the FFA has been indistinguishable between healthy and SCZ participants when performing face discrimination tasks (e.g., Yoon et al., 2006). These findings led Yoon et al. (2006) to suggest that other cortical mechanisms are likely responsible for impaired face processing in SCZ.

### CALCULATION EFFICIENCY AND INTERNAL NOISE

Signal detection theory (SDT) (Green and Swets, 1966) provides an alternative way of conceptualizing how face perception differs between healthy individuals and those with SCZ. According to SDT, observers make responses by comparing an internal response evoked by a stimulus to a decision criterion. In classic formulations of SDT, the internal response is unidimensional. However, it is not the case that SDT applies only to stimuli that vary along a single dimension (e.g., tones that vary in intensity); in fact, the theory has been applied successfully in many contexts using multidimensional stimuli (Swets, 1996). SDT casts an internal response as an abstract decision variable rather than a direct response to a simple stimulus attribute like intensity. According to this idea, the decision variable is an index of the information relevant to a particular decision (e.g., a stimulus is or is not present; the face belongs to person A or person B) that may be calculated from several stimulus attributes. The nature of this calculation—which stimulus attributes are encoded, and how they are distilled into a single decision variable—influences the amount of information conveyed by the decision variable and, therefore, constrains performance in perceptual tasks. In the current study, the degree to which a decision variable calculation captures the available stimulus information will be referred to as calculation efficiency. In the case of face identification, a great deal of information is concentrated near the eyes and eye brows (Sekuler et al., 2004; Gaspar, 2006; Keil, 2008), and therefore an efficient calculation would utilize a decision variable based on the distribution of contours in those regions. An inefficient calculation, on the other hand, would derive a decision variable based on subtle changes in contrast from other less informative face areas (e.g., the forehead). Under this assumption, a

proficient way to enhance the signal related to a target face (i.e., increase discrimination) is to use perceptual information from that face that best characterizes its uniqueness. Hence, one possible explanation for face perception deficits in people with SCZ is that they base their decisions on less informative aspects of faces (i.e., they have lower calculation efficiency). Evidence consistent with this idea has been described by Williams et al. (1999), who measured the eye movements of SCZ and healthy participants while they viewed human faces. Compared with healthy subjects, people with SCZ fixated less on the most informative regions of the face.

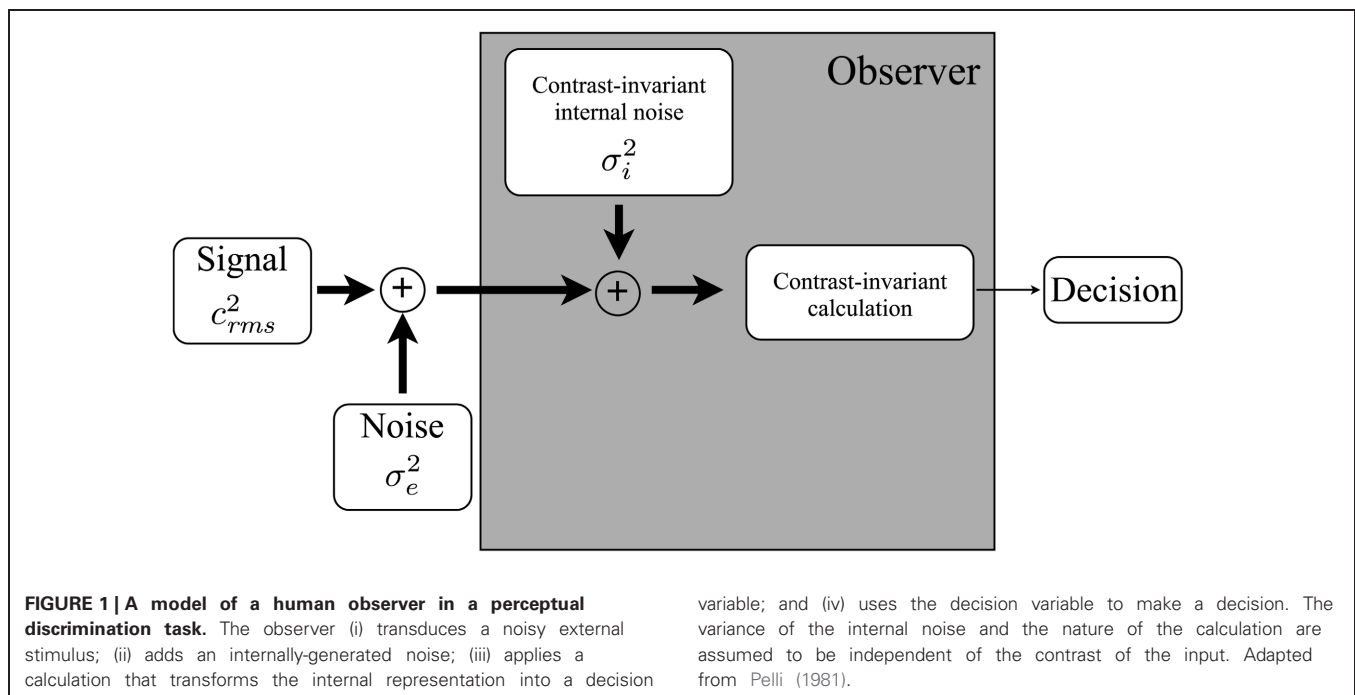
A second fundamental assumption in SDT is that internal responses are probabilistic: the internal response to an identical stimulus will vary across multiple presentations of the same stimulus. From a visual processing point of view, this internal variation, or noise, may arise from a variety of sources, such as jitter in eye position, fluctuations in attentiveness, or random fluctuations in the responses of sensory neurons. Obviously, internal noise degrades perceptual representations and limits performance in perceptual tasks. Hence, within the framework of SDT, poorer face perception in people with SCZ might be caused by elevated internal noise in face-processing mechanisms (Winterer et al., 2000; Rolls et al., 2008).

### NOISE MASKING FUNCTIONS

How can we estimate internal noise and calculation efficiency? In this section we describe a psychophysical framework for estimating these quantities. Consider a simple face discrimination task: on each trial a subject is shown one of two faces and must decide which face was presented. Across trials, face contrast is varied to estimate a discrimination threshold (i.e., the contrast necessary for an observer to respond correctly on 70% of the trials). Finally, in this hypothetical experiment we will measure discrimination thresholds for faces embedded in *external noise* (i.e., a noise mask). Specifically, a zero-mean random number is added to the brightness, or contrast, at each pixel in the visual display. If the noise is independent at each pixel, then the noise is said to be “white.” Moreover, if the random numbers are selected from a Gaussian distribution, then the noise is said to be Gaussian and the strength of the noise is related to the variance of the distribution. Our hypothetical experiment will measure discrimination thresholds with white Gaussian noise that varies in strength. The resulting threshold-vs.-noise curve is referred to as a *noise masking function*.

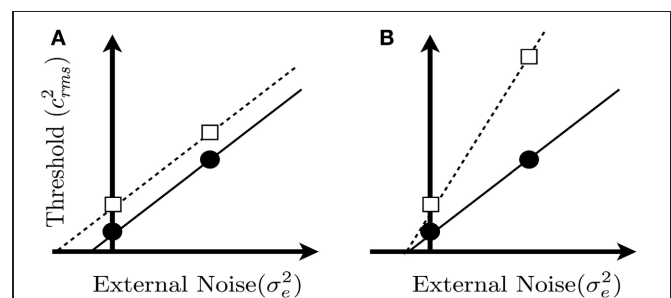
Pelli (1981) outlined a simple framework for interpreting noise masking functions (**Figure 1**): an observer receives a physical stimulus—in our case, a face embedded in external noise—which is transformed into an internal representation. An internal noise is added to the internal representation, and a calculation is performed that converts the internal signal-plus-noise variable into a decision variable. The variance of the internal noise and the nature of the calculation are assumed to be independent of stimulus contrast. Given this framework, discrimination threshold is related to the strength of the internal noise by the equation:

$$c_{\text{rms}}^2 = k(\sigma_e^2 + \sigma_i^2) \quad (1)$$



where  $c_{rms}^2$  is threshold expressed as the squared rms contrast, or contrast variance,  $\sigma_e^2$  is the variance of the external noise, and  $k$  and  $\sigma_i^2$  are free parameters. The parameter  $\sigma_i^2$  often is referred to as equivalent input noise because it is equal to the variance of the external noise that must be added to the stimulus to double the threshold relative to a no-noise baseline condition. In this framework, the threshold doubles when  $\sigma_i^2$  equals  $\sigma_e^2$ , and therefore the equivalent input noise can be used as an estimate of the level of internal noise. Parameter  $k$  indicates the rate at which the threshold increases with increasing external noise, assuming internal noise remains constant, and is related inversely to the efficiency of the observer's internal calculation. The values of  $k$  and  $\sigma_i^2$  are thought to reflect the influence of different processes and, therefore, measuring noise masking functions, as opposed to measuring a single threshold, provides more information about the processes that constrain perception.

Equation 1 predicts that threshold, expressed as  $c_{rms}^2$ , should be a linear function of the external noise variance. **Figure 2** illustrates the effects of the parameters  $\sigma_i^2$  and  $k$  on the masking functions predicted by Equation 1. In **Figure 2A**, the two masking functions differ only in terms of  $\sigma_i^2$ , and the resulting noise masking curves have the same slope but have different x-axis intercepts. In **Figure 2B**, the masking functions differ only in terms of  $k$ , and the resulting curves have the same x-axis intercepts but differ in terms of slope. Thresholds from a wide variety of tasks (Legge et al., 1987; Tjan et al., 1995; Doshier and Lu, 1998, 2000; Bennett et al., 1999; Gold et al., 1999, 2004, 2005; Pelli and Farell, 1999; Betts et al., 2007), including the discrimination of upright and inverted faces (Gaspar et al., 2008) are consistent with the predictions of Equation 1, including their linear relationship with masking noise.



**FIGURE 2 | Hypothetical noise masking functions predicted from Equation 1.** Each panel shows two noise masking functions for two groups, in which threshold is plotted as a function of the variance of the external noise mask. The two functions in each panel could represent thresholds measured from two groups of subjects, or under two different viewing conditions. The external noise is zero at the point where the x and y axes intersect. Panel (A) shows two masking functions that differ only in terms of equivalent input noise (i.e., parameter  $\sigma_i^2$  in Equation 1). Panel (B) shows two masking functions that differ only in terms of calculation efficiency, which is related to the reciprocal of parameter  $k$  in Equation 1. Note that thresholds in the zero noise conditions, represented by the square and circle, are the same in the two panels. Hence, a threshold difference measured in the no-noise condition could be produced by a change in internal noise or calculation efficiency (or a combination of both factors).

## OBJECTIVES OF THE CURRENT STUDY

Previous studies have shown that face perception is impaired in persons with SCZ. It is unclear, however, if these group differences in performance reflect differences in internal noise, calculation efficiency, or both factors. If the two groups differed primarily in terms of internal noise, then we would expect the noise masking functions in the two groups to differ like

those shown in **Figure 2A** (i.e., discrepant intercept parameters). On the other hand, if the two groups differed primarily in terms of calculation efficiency, then the masking functions for the groups should differ like those shown in **Figure 2B** (i.e., discrepant slope parameters). To investigate these issues, the current experiment measured noise masking functions with upright and inverted faces in both healthy subjects and those with SCZ.

## MATERIALS AND METHODS

### PARTICIPANTS

Twenty-three people with SCZ (11 females, 12 males) and 24 healthy participants (12 females, 12 males) participated in this study. All patients met criteria for SCZ, Schizoaffective Disorder, or Schizophreniform Disorder, as confirmed by the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID I) (First et al., 2001), but did not meet criteria for any other Axis I disorders, which was an exclusionary criterion. Healthy controls did not meet diagnostic criteria for any Axis I disorders. Structured clinical interviews were administered by either senior graduate students or research assistants, all of whom had received formal training in diagnostic interviewing. All participants had no self-reported history of neurological illness, brain injury, learning disability, current or past substance dependence, or medical conditions which could affect cognitive performance (e.g., coronary heart disease, type I diabetes). Participants also were excluded if they were taking psychotropic medication with known cognitive affects, including tricyclic antidepressants, anticholinergics, or benzodiazepines. Control participants were excluded if they reported having a first-degree relative with a SCZ-spectrum illness. Group means for healthy and patient participants were equivalent on age, years of education, an estimated Full Scale Intelligence Quotient (FSIQ)

from the Wechsler Adult Intelligence Scale (Matrix Reasoning and Information subtests), 3rd Edition (Wechsler, 1997) and Wide-Range Achievement Test-III Reading subtest (WRAT-III; Wilkinson, 1993). In contrast, patients scored significantly lower the Hopkins Verbal Learning Test (HVLT) compared to controls (Brandt and Benedict, 2001). Patients with SCZ were administered the Positive and Negative Syndrome Scale (PANSS; Kay et al., 1987). In addition, both patients and controls were administered several scales from the Personality Assessment Inventory (PAI), including the Depression (Dep), Alcohol Problems (Alc), Drug Problems (Drg), Positive Impression Management (PIM), and Negative Impression Management (NIM) scales (Morey, 1991). Patients demonstrated significantly higher scores on the Dep, Alc, Drg, and NIM scales, but a significantly lower score on the PIM scale. Mean scale indices, however, were all within normal limits. Additionally, no single subject scored in a range suggesting deliberate distortion of their responses across both validity scales (i.e., PIM and NIM). All patients were medicated on a single antipsychotic agent [mean chlorpromazine = 416.67 mg ( $SD = 267.86$ )]. Patients' mean number of years since diagnosis was 8.04 ( $SD = 8.05$ ) ranging from 1 year to 29 years. **Table 1** provides information characterizing the study participants.

### STIMULI AND APPARATUS

Stimuli were generated by a Macintosh G4 computer and displayed on a CRT monitor using MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The display had a frame rate of 85 Hz (non-interlaced) and a spatial resolution of 800 × 600 pixels, which from the viewing distance of 114 cm subtended 14.3° horizontally and 10.7° vertically. Face stimuli were based on digitized photographs of 10 frontal-view faces (5 males and 5 females), cropped to an oval window (width = 2.5°;

**Table 1 | Means (SD) for demographic, neuropsychological, and clinical characteristics of the sample.**

Variables	Initial		Upright condition		Inverted condition	
	Control ( $n = 24$ )	Patient ( $n = 23$ )	Control ( $n = 20$ )	Patient ( $n = 20$ )	Control ( $n = 19$ )	Patient ( $n = 17$ )
<b>DEMOGRAPHIC</b>						
Age (years)	36.13 (12.08)	33.17 (8.50)	35.4 (11.75)	33.15 (8.22)	33.95 (12.03)	33.12 (9.10)
Education (years)	14.62 (2.48)	14.87 (2.47)	14.65 (2.56)	14.75 (2.38)	14.21 (2.32)	15.06 (2.44)
<b>NEUROPSYCHOLOGICAL</b>						
Estimated FSIQ	113.17 (14.30)	110.30 (14.35)	114.4 (13.62)	110.3 (14.16)	112.42 (15.39)	112.65 (13.22)
WRAT-3 Reading	104.37 (10.19)	103.87 (7.31)	104.9 (9.90)	103.15 (7.51)	103.58 (10.54)	104.24 (7.24)
HVLT-R	46.33 (5.29)	35.61 (11.77)*	46.15 (5.64)	34.95 (10.89)*	45.95 (5.76)	36.00 (11.52)*
<b>CLINICAL</b>						
PAI-Dep	44.41 (7.21)	57.04 (12.04)*	43.45 (6.35)	58.5 (13.05)*	44.16 (7.59)	59.24 (12.67)*
PAI-Alc	45.50 (3.56)	48.14 (6.06)*	44.95 (3.47)	48.35 (6.36)*	45.53 (3.66)	46.82 (5.58)
PAI-Drg	46.54 (5.52)	50.27 (8.29)*	46.70 (5.36)	50.7 (8.57)*	47.67 (5.62)	49.29 (6.48)
PAI-PIM	56.98 (6.01)	48.95 (10.91)*	58.10 (6.81)	48.75 (10.98)*	58.68 (6.23)	46.18 (9.11)*
PAI-NIM	46.52 (5.06)	59.27 (13.32)*	45.85 (3.13)	61.95 (16.61)*	46.16 (5.17)	62.53 (15.48)*
PANSS-Pos	—	40.87 (7.83)	—	40.45 (8.24)	—	41.00 (8.30)
PANSS-Neg	—	35.65 (6.48)	—	35.95 (6.76)	—	35.00 (6.75)

\*Indicates significant ( $p < 0.05$ ) difference between controls and patients.

WRAT-3, Wide Range Achievement Test; HVLT-R, Hopkins Verbal Learning Test Revised; PANSS, Positive and Negative Symptom Scale.

height = 3.39°) that excluded areas showing chin, ears, and hair (see Gold et al., 1999 for details).

Thresholds were measured with a match-to-sample task. On each trial, two faces were selected randomly from the set of ten faces: one face was designated as the target, and the other as the distractor. A trial began with the presentation of a fixation cross at the center of the display. After a delay of 1 s, a noise-free version of the target face (rms contrast = 0.08) was presented for 200 ms centered at a location that was 2.29° above the fixation cross, and was followed by a high-contrast, static white noise mask that lasted for 200 ms. The offset of the mask was followed immediately by a 200 ms presentation of a pair of test faces—consisting of the target and distractor faces—centered 0.27° below and 2.29° to the left and right of the fixation cross. The target face could appear on the left or right with equal probability. The test faces were followed by the presentation (200 ms) of two high-contrast, static, white noise masks centered on the test faces (see **Figure 3** for an example of the experimental stimuli). The participant's task was to determine which one of the two test faces was the target face, and auditory feedback was provided after each trial to indicate correct and incorrect responses.

The contrast of the test faces was varied across trials using a 3-down/1-up staircase procedure to estimate face identification threshold, which was defined as the contrast necessary to achieve a correct response rate of 79%. A staircase ended after 12 reversals, and a threshold was calculated by taking the average of the last eight reversals. In separate blocks of trials, thresholds were measured with upright and inverted faces.

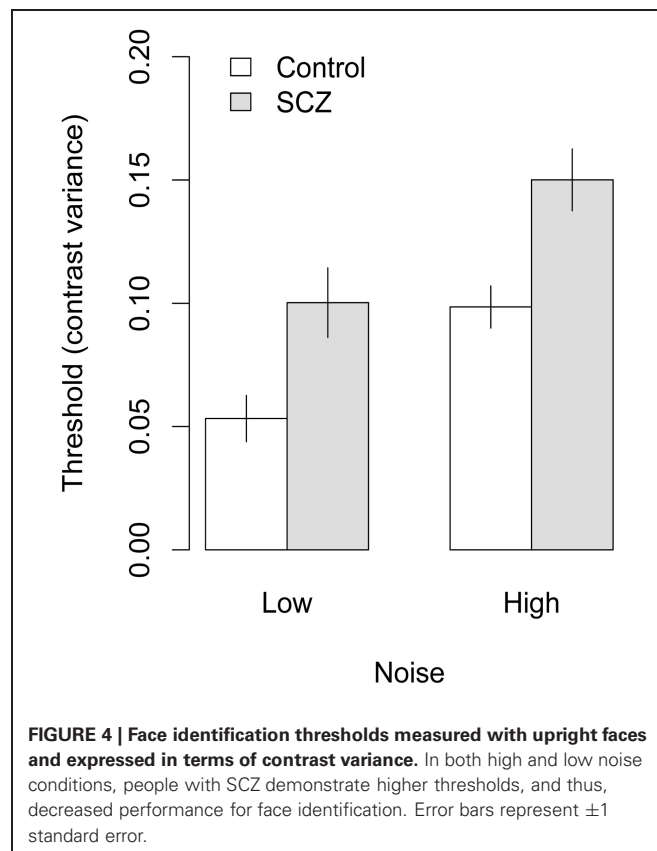
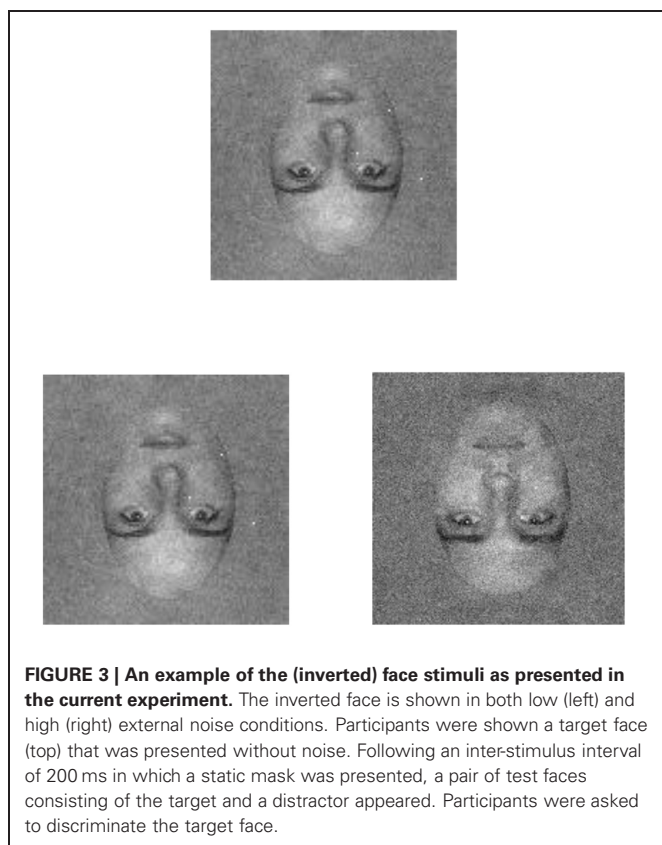
Within each block of trials, thresholds were measured in a low-noise condition, in which test faces were presented without noise, and a high-noise condition, in which faces were embedded in static white noise that had a contrast variance of 0.04. In the high-noise condition, a different noise field was computed for each test face on every trial. Note that in both conditions the test faces were *followed* by the presentation of high-contrast noise masks. Trials in the low- and high-noise conditions were intermixed randomly. Subjects were given 10 practice trials in each condition prior to starting the experiment.

## RESULTS

Statistical analyses were performed with R (version 2.8.1; R Development Core Team, 2007). Effect size was expressed as Cohen's  $f$  (Cohen, 1988) using formulae described by Kirk (1995). For ANOVA tests in which  $F < 1$ , the effect size was assumed to be zero (see Kirk, 1995, p. 180).

Face identification thresholds measured with upright and inverted faces, expressed in terms contrast variance, are shown in **Figures 4** and **5**, respectively. Thresholds were submitted to a 2 (group)  $\times$  2 (orientation)  $\times$  2 (external noise) analysis of variance (ANOVA). The ANOVA revealed a significant main effect of group,  $F_{(1, 45)} = 13.70$ ,  $p < 0.001$ ,  $f = 0.26$ , indicating that thresholds were higher in people with SCZ.

Significant main effects of orientation,  $F_{(1, 45)} = 28.17$ ,  $p < 0.001$ ,  $f = 0.34$ , and external noise,  $F_{(1, 45)} = 28.27$ ,  $p < 0.001$ ,



$f = 0.38$ , also were found, indicating higher thresholds were obtained in conditions that used inverted faces and higher levels of external noise. None of the interactions were significant,  $F$ 's  $< 1$ ,  $p > 0.33$ , all  $f$ s = 0.

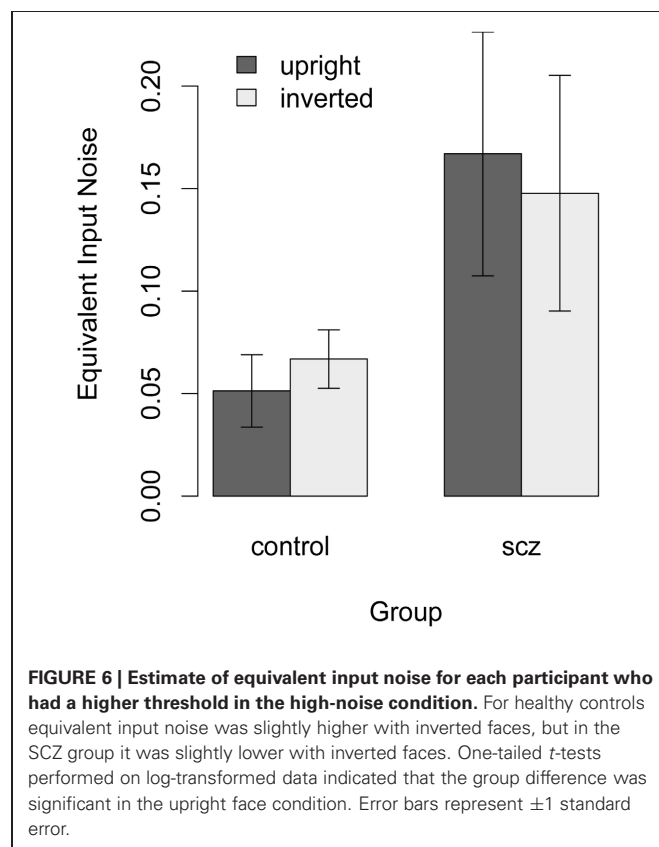
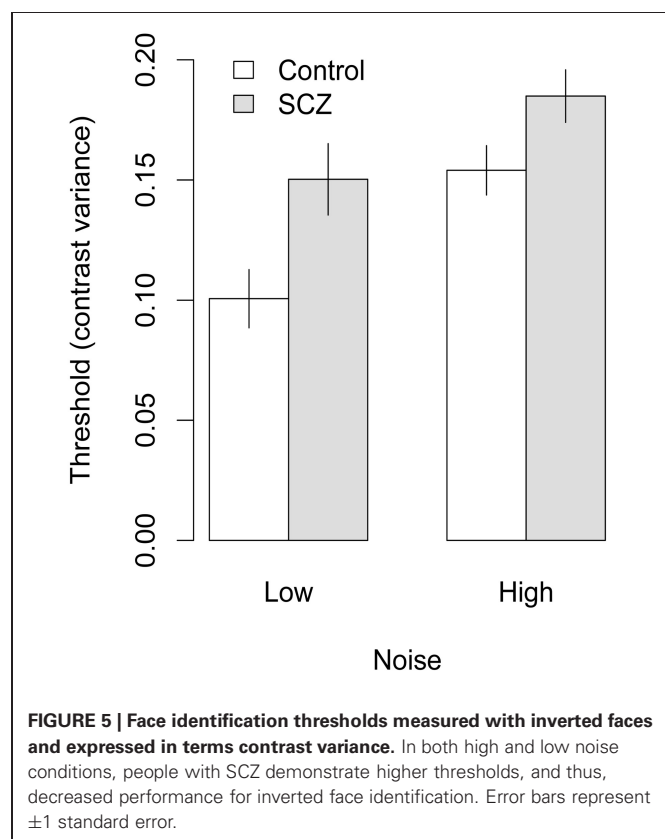
To use Equation 1 to calculate internal noise for an individual participant, the slope of the noise masking function must be greater than zero (i.e., threshold must be higher in the high-noise condition). Some participants did not display this result and, therefore, internal noise could not be estimated for those subjects. Consequently, subjects who did not have higher noise thresholds in the high-noise condition were removed from the data for further analysis. To minimize the number of subjects that were removed, we applied the criterion (i.e., higher threshold in the high-noise condition) separately in the upright and inverted conditions. This procedure yielded slightly different subsets of subjects in the upright and inverted face conditions, and therefore the two face orientation conditions were analyzed separately.

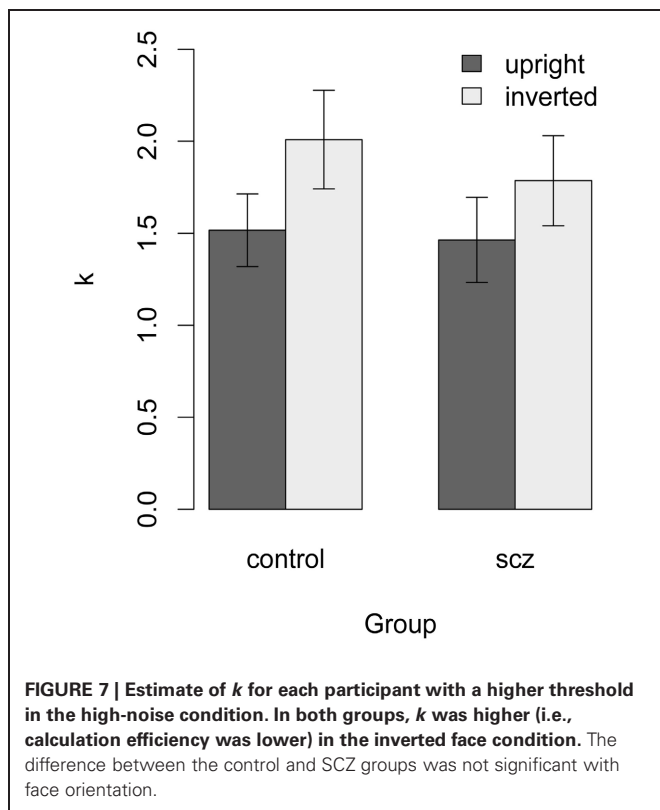
In conditions using upright faces, data from four participants in the control group and three in the SCZ group were removed. Thresholds from the remaining 20 participants in each group were analyzed with a 2 (group)  $\times$  2 (external noise) ANOVA, which revealed significant main effects of group,  $F_{(1, 38)} = 10.73$ ,  $p = 0.002$ ,  $f = 0.35$ , and external noise level,  $F_{(1, 38)} = 49.48$ ,  $p < 0.001$ ,  $f = 0.55$ . The group  $\times$  external noise interaction was not significant,  $F_{(1, 38)} = 0.03$ ,  $p = 0.86$ ,  $f = 0$ . In conditions using inverted faces, data from five participants in the control group and six participants in the SCZ group were removed.

A 2 (group)  $\times$  2 (external noise) ANOVA on the remaining subjects found significant main effects of group,  $F_{(1, 34)} = 7.45$ ,  $p = 0.01$ ,  $f = 0.30$ , external noise,  $F_{(1, 34)} = 63.8$ ,  $p < 0.001$ ,  $f = 0.66$ ; the interaction was not significant,  $F_{(1, 34)} = 0.37$ ,  $p = 0.54$ ,  $f = 0$ . These analyses indicate that (a) applying the criterion of having a higher threshold in the high-noise condition caused approximately equal numbers of participants to be removed from each group; and (b) the effects of group and external noise measuring in the subsets of subjects were similar to the effects obtained with the entire sample.

Equation 1 was used to estimate equivalent input noise and  $k$  for each participant who had a higher threshold in the high-noise condition. **Figure 7** shows that equivalent input noise did not vary systematically with face orientation: in the control group, equivalent input noise was slightly higher with inverted faces, but in the SCZ group it was slightly lower with inverted faces. In both the upright and inverted face conditions, however, average equivalent input noise was lower in the control group than in the SCZ group. One-tailed  $t$ -tests performed on log-transformed data indicated that the group difference was significant in the upright face condition,  $t_{(38)} = 2.63$ ,  $p = 0.006$ ,  $f = 0.38$ , and at trend level significance in the inverted face condition,  $t_{(34)} = 1.41$ ,  $p = 0.08$ ,  $f = 0.16$ .

Average values of  $k$  are shown in **Figure 6**. In both groups,  $k$  was higher (i.e., calculation efficiency was lower) in the inverted face condition. However, the difference between the control and SCZ groups was not significant with either face orientation





[upright:  $t_{(38)} = 0.17, p = 0.57, f = 0$ ; inverted:  $t_{(34)} = 0.61, p = 0.73, f = 0$ ].

## DISCUSSION

Consistent with previous research, this study found that SCZ participants are deficient in their ability to discriminate both upright and inverted faces compared to healthy observers. However, this study further sought to examine whether this effect was a result of increases in internal noise and/or decreased calculation efficiency. It was found that people with SCZ exhibit higher levels of internal noise when processing both upright and inverted faces; however, it is important to underscore that, while the group differences across the upright and inverted condition were of a similar magnitude, these differences were significant in the upright condition but trended toward significance in the inverted condition. In contrast, no between-group differences were observed on measures of calculation efficiency.

Our results suggest that internal noise is a substantive determinant of face discrimination deficits among people with SCZ. These results are also consistent with increasing evidence that signal-to-noise ratio is decreased among those with SCZ (Winterer et al., 2000; Winterer and Weinberger, 2004). Causes of increased internal noise in people with SCZ are unclear. Higher equivalent input noise could be caused by a variety of processes, such as jitter of the eyes or random fluctuations in the responses of sensory neurons. More recent work has suggested that increased noise in those with SCZ may be attributed to an alteration of brain dopamine levels, secondary to reduced NMDA and GABA receptors (Lang et al., 2007).

Although the source of internal noise is unclear, it has been hypothesized by Rolls et al. (2008) that neural noise underlies many of the cognitive and perceptual impairments associated with SCZ. According to the dynamical systems hypothesis, groups of neurons supporting a given behavior or cognition settle into a stable pattern, or attractor state. These attractors are then strengthened over time, and eventually partial activation of the neural network will be sufficient to activate the entire network. However, neural noise (i.e., random spiking) can destabilize the attractor state, and may even induce a sudden change from one attractor state to another, which may result in behavioral distraction or confusion. Rolls et al. (2008) propose that this noise-induced instability of attractor networks may be related to some of the impairments in SCZ, including impairments in memory and attention. While Rolls et al. suggest that the destabilizing of neural networks occurs in the prefrontal cortex, it is possible that the destabilization of neural networks may be a widespread general impairment in SCZ, and may explain much impairment, including face perception, in this population.

As noted above, results also indicate that there are no differences in calculation efficiency between healthy observers and those with SCZ. This is at odds with previously cited scanpath studies showing that people with SCZ direct their voluntary gaze at less informative regions of faces. A plausible explanation for this discrepancy is that scanpath studies actually do not only represent changes in efficiency, but also may be indicative of increased internal noise. In other words, scanpaths may be mediated by attentional processes, and as Rolls et al. (2008) suggest, attention may be deleteriously affected by the destabilization of neural attractor states. Although it is unknown how calculation efficiency and internal noise are related in this context, future research directed at examining this issue would be beneficial.

In the present study, we postulate that a decreased performance in face discrimination among people with SCZ may be a result of an increase in internal noise. It is plausible, however, that increased internal noise is not isolated to face processing, but may also underlie other visual perceptual deficits in SCZ. People with SCZ are also impaired in motion perception (Chen et al., 1999a,b; Clementz et al., 2007), visual context processing (Uhlhaas et al., 2005), and perceptual organization (Silverstein et al., 2006; Sehatpour et al., 2010). The methods as outlined in this study may also be used to disentangle whether increased internal noise contributes to deficiencies in other visual processes. In this context, many studies have demonstrated SCZ-related visual sensory processing deficits on tasks that preferentially involve the magnocellular visual system (Schechter et al., 2003; Butler et al., 2005, 2009; Keri et al., 2005; Martinez et al., 2008). More recently, Butler et al. (2009) investigated magnocellular and parvocellular contributions to emotion processing deficits using affective faces. Butler et al.'s results showed that deficits in low spatial frequency contrast sensitivity, thought to reflect magnocellular visual processing, correlated significantly with the ability to identify emotions from affective faces. Therefore, it is also plausible that SCZ-related performance deficits in affective face processing arise, at least in part, from magnocellular system dysfunction, which, in turn, may reflect greater internal (e.g., neural) noise.

The results from the current study also have clinical implications. As noted above, face processing is deficient among persons with SCZ, which may, in turn, underpin some of the social deficits associated with this disorder. In particular, important cues to others' emotional states and intentions are conveyed via facial expressions and facial affect recognition deficits are prominent features that appear early in the course of the illness and are stable over time (Penn et al., 2008). Deficits in this realm have been demonstrated using instruments such as the Reading the Mind in the Eyes Test (Köther et al., 2012) and the Mayer-Salovey-Caruso Emotional Intelligence Test (Dawson et al., 2012). Accordingly, several social cognitive remediation programs for patients with psychotic disorders have emerged, many of which explicitly train participants to decipher facial expressions as a means to understanding the emotional states of others (for a review see Fiszdon and Reddy, 2012). However, to the extent that such remediation efforts include explicit means for increasing visual focus on informative aspects of the face (e.g., eyes), these efforts may be somewhat misdirected. Although it may be the case that increased attentiveness to informative facial areas will positively influence discrimination or recognition performance across all participants, the current results would not predict disproportionate benefit for persons with SCZ. Instead, methods that may allow one to decipher signals in an otherwise noisy system may be more efficient. For example, sequential sampling models of decision making show that information leading to perceptual or cognitive decisions are quantitatively dependent on the accumulation of information over time via a random-walk process (Ratcliff and McGoan, 2008). In such models, greater noise necessitates greater time to make correct decisions—i.e., the time needed to accumulate adequate information (i.e., drift rate) is longer. Therefore, SCZ-related deficits in face processing may benefit from the simple intervention of encouraging patients to process the information for longer time periods. Similarly, pharmacologic manipulations known to

increase neural signal relative to noise may also be a potential avenue for augmenting face processing in this population (Rolls and Deco, 2010).

This study is limited by a modest sample size, following the exclusion of participants necessary for the calculation of internal noise. In this context, replication of the study, in addition to a larger sample size, is essential to confirm these results. Regarding sample characteristics, although participants in the current study were not intentionally matched for education and estimated FSIQ, both healthy controls and people with SCZ demonstrated equivalent results in these domains. This may raise generalizability concerns, as equivalence across these dimensions is not typically observed, and so this patient sample may arguably represent higher functioning participants in the SCZ group. Furthermore, it is unknown whether these findings are specific to SCZ or whether similar results would be observed in other types of psychopathology. It would be useful, therefore, for future studies to explore such potential deficits among persons with a range of psychiatric diagnoses.

Additionally, the current study included the use of only two levels of external noise to determine calculation efficiency and internal noise. The noise masking function, however, could be better represented using multiple levels of external noise in order to obtain more accurate estimations of these measures. Finally, all participants with SCZ who took part in the experiment were medicated and we are unable to comment whether the results seen in the study were confounded by medication status. In this regard, future research would be well advised to include samples of unmedicated SCZ patients.

## AUTHOR NOTE

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