Deficits in early visual processing are well documented in schizophrenia, using methods such as contrast sensitivity. Higher, integrative stages of functioning, such as susceptibility to visual illusions, have been evaluated less extensively. For example, patients show increased susceptibility to (ie, are more easily affected by) the Muller-Lyer illusion but decreased susceptibility (ie, are less easily affected by) to stereopsis based upon binocular disparity. The basis for pattern of illusion response and interaction between sensory and integrative stages of processing, however, is unclear. We tested a group of 38 patients and 28 control subjects in contrast sensitivity, the Muller-Lyer and Poggendorff illusions, as well as a subgroup in stereopsis and the Ponzo illusion, Sander parallelogram, and Hermann grid illusions. We predicted that patients would be more susceptible to tests that become more apparent with increased contrast (Muller-Lyer illusion), less susceptible to tests that become less apparent with increased contrast (stereopsis, Ponzo illusion, Hermann grid), and equally susceptible to contrast-insensitive tests (Poggendorff illusion). Additionally, the Hermann grid was tested at varying levels of contrast. Patients demonstrated significant deficits in contrast sensitivity, especially to brief, low spatial frequency stimuli, and the predicted differential response to the tested illusions. Additionally, poor performance on stereopsis and the Hermann grid significantly correlated with decreased contrast sensitivity (all \( P < .01 \)). Muller-Lyer illusion and stereopsis performance were also inversely related (\( P < .01 \)). This study replicates and expands upon previous findings with visual illusions. Our results offer a unifying explanation for disparate studies and suggest that deficits in early sensory gain affect subsequent integrative processes.

Key words: visual illusions/contrast sensitivity/schizophrenia/magnocellular/stereopsis/Muller-Lyer

Introduction

Schizophrenia is associated with deficits in early visual processing that represent a core feature of the disorder. The early visual system consists of 2 main components: a magnocellular system that conducts low-resolution, low spatial frequency (SF) input rapidly from retina to visual cortex and that functions primarily in a high, nonlinear gain mode and a parvocellular system that conducts higher SF information more slowly and shows more linear response to increasing stimulus contrast. Deficits in early visual processing have been demonstrated consistently over recent years using methods such as contrast sensitivity and steady state and transient event-related potentials and functional brain imaging. The process of nonlinear gain appears especially impaired, leading to preferential impairment of magnocellular function.

In schizophrenia, deficits have also been documented on tests that require integration of information within and across visual regions, such as contour integration, perceptual closure, the hollow face illusion, center surround inhibition and Yoon et al, (in this issue), coherent motion, face, face emotion recognition (in this issue), and closure flexibility (P.D.B., I.S., N. Revheim, PhD, G.S., D.C.J., unpublished data, 2009). To date, the relationship between deficits in gain and integration are poorly understood, as is the question of whether integration deficits in schizophrenia represent a distinct domain or an upward manifestation of the more basic disturbances in sensitivity to contrast.

An issue in assessing outcomes in schizophrenia, especially cognitive dysfunction, is that most tasks depend upon general factors such as cooperation and motivation. Therefore, it can be difficult to parse specific vs generalized aspects of cognitive dysfunction. In the case of the visual system, this has been partially addressed by studies such as those reported by Place and Gilmore that showed that patients perform paradoxically better than control subjects under certain conditions where intrinsic visual integration processes actually interfere with task performance in healthy control subjects. In the Place...
and Gilmore study,\textsuperscript{12} subjects viewed dot arrays that suggested shapes to greater or lesser degrees. For control subjects, automatic recognition of the shape interfered with the ability to count the dots. Patients, however, were less affected by configural information, leading to less of an interference effect. This paradoxically superior performance could not be attributed to impaired cooperation or motivation and thus presumably reflects differential physiological processing within the early visual system.

An additional approach to probing integrity of the early visual system is through the use of visual illusions. Illusions come about because the sensory gain and integration mechanisms that are useful for determining interrelationships among objects in 3-dimensional space can provide erroneous information when applied to 2-dimensional drawings. In such cases, the “normal” response is to report erroneous relationships, whereas dysfunctional early visual processes may lead patients to show paradoxically “better” performance than control subjects.

For example, we have recently investigated the phenomenon of stereopsis in schizophrenia.\textsuperscript{14} Stereopsis, which gives rise to the illusion of 3-dimensionality, is tested by introducing a small binocular disparity between 2-dimensional images presented separately to the 2 eyes by means of polarized lenses or a glass plate. Patients showed significantly decreased susceptibility to the stereopsis illusion, suggesting impaired integrative processes within regions of the brain, such as visual areas V1, V3A, and MT\textsuperscript{15,16} that are sensitive to spatial disparity.

Patients have also been characterized on an alternate visual illusion, the Muller-Lyer. The Muller-Lyer (figure 1, top left) is an illusion in which angled lines at the end of a line segment can give the illusion of either increased or decreased line length, depending upon whether an acute (“a”) or obtuse (“b”) angle is used. As opposed to their decreased susceptibility to stereopsis, patients may show increased susceptibility to the Muller-Lyer illusion,\textsuperscript{17–19} as recently reviewed.\textsuperscript{20} This differential susceptibility cannot be accounted for by nonspecific task demands and thus presumably reflects differential integration within the early visual system between patients and control subjects.

One potential explanation to account for decreased susceptibility to stereopsis but increased susceptibility to the Muller-Lyer illusion effect in schizophrenia may be the inverse dependence of the 2 tasks on stimulus contrast. Parkinson\textsuperscript{21} and Alzheimer disease\textsuperscript{22} are also associated with reductions in contrast sensitivity, and increased attention has been paid over recent years in delineating the relationship between such deficits and impairments in higher order cognitive processing, such as the Wechsler Adult Intelligence Scales Revised picture arrangement\textsuperscript{23} in Alzheimer disease and reading speed\textsuperscript{21} in Parkinson disease. Moreover, manipulations of contrast in Alzheimer disease patients may improve overall functioning.\textsuperscript{24}

The differential effects of contrast manipulations have also been evaluated across several different illusion types in normal volunteers,\textsuperscript{25,26} with susceptibility to the illusion of 3-dimensionality (stereopsis) increasing in parallel with increases in contrast. Reduced sensitivity to contrast should weaken the illusion and therefore produce a decreased susceptibility to the illusion of stereopsis. The Muller-Lyer illusion, however, is reportedly weaker (ie, less prominent) with increasing stimulus contrast (ie, the difference in luminance between the arrowhead and shaft)\textsuperscript{27–29} although alternative results have also been reported.\textsuperscript{30} Thus, decreased sensitivity to contrast should increase susceptibility to the illusion. For both paradigms, therefore, alterations in contrast sensitivity could underlie the integration deficits that form the basis of the illusion and could explain previous findings in schizophrenia.

For the present study, patients were again evaluated in stereopsis and the Muller-Lyer illusion. Stereoptic evaluation was repeated with 2 additional batteries that make use of different methods to induce binocular disparity, providing additional information regarding the basis of the deficit in schizophrenia. Additionally, 3 additional visual illusions were evaluated: the Sander parallelogram, Ponzo, and Poggendorff (figure 1). Both the Sander parallelogram and the Ponzo illusion, like the Muller-Lyer illusion, reflect illusory alterations in length of stimuli due to surrounding picture elements. However, unlike the Muller-Lyer illusion, but like stereopsis, the Ponzo illusion becomes more powerful with increased contrast between the converging and horizontal lines.\textsuperscript{31} Thus, impairments in strategy would be expected to produce similar impairments across all 3 illusions, whereas contrast sensitivity–based deficits would predict
opposite impairments to the Muller-Lyer vs the Ponzo illusion. The susceptibility of the Sander’s parallelogram illusion to contrast, at present, is unknown.

The Poggendorff is an illusion in which a solid rectangle is intersected by a line drawn at a 45° angle. The tendency in this illusion is to view the line as if it is displaced vertically, even when it is not. This test is reported to be relatively insensitive to alteration in contrast\(^2\) and so should not be differentially affected if the sensitivity to illusions in schizophrenia reflects underlying impairments in contrast sensitivity and thus serves as a control.

While neither the Ponzo illusion nor the Sander parallelogram has been studied in schizophrenia, we are aware of one prior evaluation of the Poggendorff illusion, in which patients were reported to show increased susceptibility to the Poggendorff illusion.\(^3\) In that study, however, patients were also of borderline intellectual function, which might of itself affect performance on the illusion.\(^3\)

Finally, patients were tested on the Hermann grid illusion. In the Hermann grid, illusory dots are seen at the junctures between regularly spaced rectangles of solid color (figure 2). The illusory presence of these dots is based upon lateral inhibition processes within the concentric receptive fields of retinal and/or geniculate ganglion cells, with contributions by the binocular orientation-specific cortical cells, and is strongly influenced by contrast.\(^3\)

Table 1. Effect of Increased Contrast and Susceptibility to Illusions in Healthy Volunteers

<table>
<thead>
<tr>
<th>Test</th>
<th>Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muller-Lyer(^2\text{-}^4)</td>
<td>Decreased(^a)</td>
</tr>
<tr>
<td>Poggendorff(^5)</td>
<td>No change</td>
</tr>
<tr>
<td>Hermann grid(^6)</td>
<td>Increased(^b)</td>
</tr>
<tr>
<td>Ponzo(^7)</td>
<td>Increased</td>
</tr>
<tr>
<td>Stereopsis(^8)</td>
<td>Increased</td>
</tr>
<tr>
<td>Sander parallelogram</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

\(^a\)Decreased—decreased susceptibility to illusion-supported response with increased contrast.

\(^b\)Increased—increased susceptibility to illusion-supported response with increased contrast.

The strength of this effect increases with increasing contrast between the boxes and the background.\(^9\) In order to operationalize this illusion, subjects were queried as to whether they saw dots either at the junction between squares (true illusion effect) or at additional locations within blocks or outside the grid (eccentric locations). Furthermore, for this illusion, performance was tested across a series of contrast levels (10%, 30%, 50%, and 100% between the background and boxes—figure 2) in order to characterize relative performance of patients and control subjects across contrast levels. We are unaware of any previous evaluations of the Hermann grid in schizophrenia.

Hypotheses for this study were 3-fold. First, that patients would show inverse susceptibility to the stereopsis and Ponzo and Hermann grid illusions, which increase (ie, become more apparent) with increasing contrast vs the Muller-Lyer illusion, which decreases (ie, become less apparent) (table 1). Second, that patients and control subjects would show differential susceptibility to the Muller-Lyer illusion, which is contrast sensitive, and not the Poggendorff illusion, which is relatively contrast insensitive. Finally, we predicted that altered susceptibility to illusions would correlate with impaired sensitivity to detection of contrast, particularly to low SF, magnocellularly biased stimuli.

**Methods**

**Subjects**

Subjects consisted of 38 patients recruited from inpatient and outpatient sites associated with the Nathan Kline Institute and 28 control subjects recruited from the healthy volunteer pool at the Nathan Kline Institute, who had completed the contrast sensitivity, Muller-Lyer illusion, and Poggendorff illusion tasks. We also report on subsamples who completed the Hermann grid, Ponzo illusion, Sander parallelogram, and stereopsis tasks. All subjects signed informed consent.
All patients met Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition, Text Revision) criteria for either schizophrenia or schizoaffective disorder, and all were receiving antipsychotic medications at the time of testing. We excluded control subjects with a history of an Axis I psychiatric disorder, as defined by the Structured Clinical Interview for Diagnostic and Statistical Manual of Mental Disorders (Fourth Edition). Patients and control subjects were excluded if they had any neurological or ophthalmologic disorders (including strabismus and color blindness) that might affect performance or if they met criteria for alcohol or substance dependence within the last 6 months and/or abuse within the last month. All participants had 20/30 corrected visual acuity or better on the logarithmic visual acuity chart (Precision Vision, LaSalle, IL). All patients were interviewed using semistructured clinical interviews (Brief Psychiatric Rating Scale [BPRS]) and Schedule for the Assessment of Negative Symptoms [SANS]). Chlorpromazine equivalents (CPZ eq) were calculated. All data in text are mean ± standard error of the mean.

Patients were ill for a mean 17.3 ± 1.4 years and were receiving a mean antipsychotic dose equivalent to 1163.9 ± 87.4 mg CPZ per day. BPRS scores of 40.9 ± 2.0 and SANS scores of 31.9 ± 1.9 were in the moderately ill range. The patient and control groups did not differ significantly in age (patients: 37.3 ± 1.5 y; control subjects: 36.5 ± 1.9 y) or parental socioeconomic status (SES), as measured by the 4-factor Hollingshead Scale (patients, 40.4 ± 3.5; control subjects, 46.2 ± 2.3), although there were significant differences in the percentage of males (patients, 86.8%; control subjects, 57.1%; Fisher exact test; P < .05). Parental SES could not be computed for 10 patients because of lack of information. As expected, patients had significantly lower individual SES (patients: 25.0 ± 1.6; control subjects: 48.0 ± 2.3), IQ (patients: 100.8 ± 1.8; control subjects: 110.0 ± 1.6), and education (patients: 11.8 ± 0.37 y; control subjects: 16.5 ± 0.45 y). Individual SES and IQ data were unavailable for 2 patients. Despite being significantly lower than control subjects, the patient group’s IQ was in the normal range, and 59% had graduated high school. Illness duration, CPZ eq, or total BPRS/SANS did not correlate with any of the tasks, other than a significant negative correlation (−0.40, P < .05) between the percentage of responses supported by the illusion for the Poggendorff and CPZ eq. When patients and control subjects were examined separately, significant negative correlations with IQ were found for the Ponzo illusion (−0.59, P = .013) and Muller-Lyer illusion (−0.39, P < .05) for patients and control subjects, respectively.

Contrast Sensitivity

Contrast sensitivity levels to sine-wave gratings were obtained using a 2-alternative forced choice procedure, as described previously, for all subjects. Separate thresh-
Table 2. Impaired Contrast Sensitivity in Schizophrenia

<table>
<thead>
<tr>
<th>Duration (ms)</th>
<th>Spatial Frequency (Cycles Per Degree)</th>
<th>Contrast Sensitivitya</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Patient (n = 38)</td>
<td>Control Subjects (n = 28)</td>
</tr>
<tr>
<td>32</td>
<td>0.5</td>
<td>62.0 ± 4.7</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>82.9 ± 3.2</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>3.2 ± 0.2</td>
</tr>
<tr>
<td>500</td>
<td>0.5</td>
<td>62.8 ± 4.2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>109.4 ± 8.0</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>4.3 ± 0.5</td>
</tr>
</tbody>
</table>

aContrast sensitivity is reciprocal of contrast threshold percentage. Larger numbers equate to better performance.

**P < .01, ***p < .001.

effective methods for assessment. The Graded Circles Stereo Test (Graded Circles; Stereo Optical Co, Inc, Chicago, IL) was used from study onset, while other tests were added after the first 10 subjects had already been studied.

The Graded Circles Stereo Test. In this test, the 3-dimensional illusion is produced by polarized glasses that present the image separately to each eye, and presentation followed standard administration consistent with test instructions. The test contains 9 arrays of 4 circles. For each array, participants choose which of the 4 circles appears to be 3 dimensional. The target circle in each array has 2 slightly displaced images. The displacement ranges from large to small (800–40 arc seconds), making the task progressively more difficult. Achieved sample consisted of 35 patients and 28 control subjects.

The Frisby Stereo Test. In the Frisby Stereo Test (Frisby; Clement-Clarke Ltd, Harlow, UK), the 3-dimensional illusion is produced by stimuli drawn on either side of 3 glass test plates (6, 3, and 1.5 mm thick), which permit stereoacuity measurements in a range of 15–600 arc seconds. Presentation followed standard administration and scoring consistent with test instructions. Participants were asked to point to (or verbalize) the square on the plate that contained the circle. The lowest disparity for which this task could accurately be performed at least 2 out of 3 times was deemed to be the stereoacuity threshold. Achieved sample consisted of 26 patients and 21 control subjects.

Random Dot Stereo Vision Tests. In the Random Dot Stereo Vision Test (Richmond Products, Boca Raton, FL), the 3-dimensional illusion is produced by stimuli that are delivered to the eyes individually through use of red/green glasses and was performed using the standard procedure. After a screening examination, the subject was asked to point to or verbally identify the number at each level that appeared to be floating in front of or jumping out of the page. The last level for which the individual answered correctly was considered to be the level of stereoacuity. Once the individual’s level of stereoacuity was determined, the examiner went back 3 levels and repeated the test. The final stereoacuity threshold was derived as the mean of these 2 results. If the individual was unable to comprehend the task, the Random Dot Stereo Vision Test—Animals was used following the same procedure. Achieved sample consisted of 27 patients and 23 control subjects.

Statistical Analyses

Demographics for the 2 groups were compared by Fisher exact test for categorical values and by Student t tests for continuous values. Stereоасuity threshold values were log transformed for normality prior to analysis. Between-group performance on the specific tests in each category, eg, (1) contrast sensitivity, (2) stereopsis, (3) illusions, and (4) Hermann grid, was compared with repeated-measures multivariate analysis of variance, with follow-up t tests as required. Relationship among measures was determined by Pearson correlations and linear regressions. Two-tailed statistics are used throughout.

Results

Between-Group Comparisons

Contrast Sensitivity. At brief duration, there was a significant main effect of group ($F_{1,64} = 18.2, P < .001$) and a significant group × SF interaction ($F_{2,63} = 9.5, P < .001$), reflecting significantly greater deficits of patients to low (0.5 CPD) than mid-high (7 and 21 CPD) SF stimuli (table 2). Deficits to long-duration stimuli were also seen across SF for patients (main effect of group, $F_{1,64} = 21.8, P < .001$), with significant group × SF interaction ($F_{2,63} = 9.0, P's < .001$), reflecting significantly greater deficits of patients to mid-high (7 and 21 CPD) than low (0.5 CPD) SF stimuli.

For both patients and control subjects, sensitivity to briefly presented low SF (0.5 CPD) stimuli strongly predicted sensitivity to both low and high SF stimuli (all r’s > 0.528, P’s < .001) presented for longer duration, suggesting significant contribution of magnocellular processing across SF bands at longer stimulus duration.

Stereopsis. Patients showed highly a significant reduction in sensitivity to the stereopsis effect across all tests ($F_{1,42} = 10.2, P = .003$), with greatest deficit in stereopsis as measured by the Graded Circles ($t_{61} = 3.8, P < .001$) (figure 3). Significant deficits were also seen on the Random Dot Stereo Vision Test ($t_{48} = 2.6, P < .013$) and the Frisby Stereo Test ($t_{45} = 2.2, P < .034$). There was no significant group × test interaction ($F_{2,41} = 2.5, P = .098$). Furthermore, intraclass correlation showed significant
consistency across tasks, suggesting a shared underlying metric ($r = 0.39, P < .001$).

**Illusions.** Statistics were conducted across the 3 line length illusions (Muller-Lyer, Ponzo, and Sander parallelogram) as well as the Poggendorff (figures 1 and 4). Across tests, there was a highly significant group × test interaction ($F_{3,26} = 8.22, P < .001$), with no significant main effect of group ($F_{1,28} = 0.01, P = .9$), suggesting a differential response to the illusions. Paired $t$ tests demonstrated that patients showed significantly increased susceptibility to the Muller-Lyer illusion relative to control subjects ($F_{1,64} = 10.9, P = .002$) but not the Poggendorff illusion ($F_{1,64} = 0.21, P = .9$) or Sander parallelogram ($F_{1,28} = 0.35, P = .6$) illusions. On the Ponzo illusion, however, patients showed significantly less susceptibility than control subjects ($F_{1,28} = 5.2, P = .03$).

**Hermann Grid.** At 100% contrast, patients showed a significantly decreased sensitivity to the Hermann grid illusion (figure 5), as reflected in percentage of illusion-supported responses ($t_{27} = -2.22, P < .05$). When tested at reduced contrast levels, the main effect of contrast was significant, with strength of the illusion decreasing in parallel with decreasing contrast ($F_{2,25} = 24.6, P < .001$). The group × contrast effect was also significant ($F_{2,25} = 3.96, P = .032$), with patients showing significantly reduced susceptibility to the illusion at 50% contrast ($t_{27} = 2.22, P = .035$) but not at 30% or 10%.

On the contrary, patients did not show significant differences from control subjects at eccentric locations, as reflected in absence of both main effect ($F_{1,26} = 1.2, P = .277$) and group × contrast interaction ($F_{1,26} = 0.86, P = .478$) on a repeated-measure analysis of variance. On separate paired $t$ tests, for contrast levels >10%, both patients and control subjects reported significantly more dots at junctures than eccentric locations (all $P's < .05$). Neither patients ($t_{15} = 0.284, P = .78$) nor control subjects had significant differences at 10% contrast ($t_{11} = 1.9, P = .085$).

**Relationship Among Measures**

Correlations for the full sample are presented in table 3. For the full sample, the increase in susceptibility to the Muller-Lyer effect correlated significantly and inversely with susceptibility to stereoacuity as measured by the Graded Circles ($r = 0.34, P = .006$). Subjects who were most susceptible to the Muller-Lyer illusion were least susceptible to stereopsis. Stereopsis threshold on the Graded Circles also significantly correlated with contrast sensitivity at both brief and long-duration stimulus levels.

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**Fig. 3.** Stereopsis Impairment in Schizophrenia. Bar chart of stereoacuity threshold for patients (white bars) and control subjects (black bars).

**Fig. 4.** Differential Susceptibility to Illusions in Schizophrenia Vs Control Subjects. Bar chart of illusion-supported responses for patients (white bars) and control subjects (black bars).

**Fig. 5.** Effect of Contrast Manipulation on Hermann Grid in Patients and Control Subjects. Line plot of illusion-supported responses as a function of contrast for patients (white) and control subjects (black) on the Hermann grid.
Table 3. Relationship Between Contrast Sensitivity and Illusions

<table>
<thead>
<tr>
<th>Duration (ms)</th>
<th>Spatial Frequency (Cycles Per Degree)</th>
<th>Contrast Sensitivity</th>
<th>Stereopsis</th>
<th>Hermann Grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>0.5</td>
<td>0.38*</td>
<td>-0.27</td>
<td>-0.27</td>
</tr>
<tr>
<td>7</td>
<td></td>
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<td>0.29</td>
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<td>500</td>
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<td>0.27</td>
<td>0.31</td>
<td>0.50*</td>
</tr>
<tr>
<td>7</td>
<td></td>
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<td>21</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Spatial Frequency (Cycles Per Degree)</th>
<th>100%</th>
<th>50%</th>
<th>30%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
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<td>21</td>
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</tbody>
</table>

*Note: Pearson correlation coefficients for the whole sample. Regular font, P < .1; bold, P < .05, bold values with asterisk; P < .01. Values with P > .1 are not listed. Graded Circles, Graded Circles Stereo Test.

presentations, such that subjects with increased contrast sensitivity showed worse stereopsis.

After controlling for group in a linear regression, the relationship between stereopsis (Graded Circles) and both the Muller-Lyer effect ($\beta = .2, P = .1$) and reduced contrast sensitivity at low SF ($0.5, \beta = -0.22, P = .1$) remained significant at trend level. Increased sensitivity to brief duration (SF $= 21, \beta = .34, P < .05$) stimulus presentations, however, continued to correlate with higher (ie, less sensitive) stereoaucity thresholds.

For the full sample (table 3), sensitivity to the Hermann grid illusion also correlated significantly with sensitivity to contrast. After controlling for group, when performance on the Hermann grid was entered into linear regression vs sensitivity to contrast, sensitivity to 500-millisecond, 7-CPD stimuli continued to predict increased susceptibility to the illusion across a range of contrasts ($100\%, \beta = .41, P < .05; 50\%, \beta = .60, P < .01; 30\%, \beta = .65, P < .01$) as did sensitivity to 500-millisecond, 21-CPD stimuli ($50\%, \beta = .39, P < .05$).

**Gender Effects**

Because there were significant differences between control subjects and patients in gender, post hoc independent t tests were done. Women had significantly greater sensitivity to 32-millisecond, 7-CPD stimuli and less susceptibility to the Sander parallelogram (both P’s < .05) across groups. All other between gender comparisons were not significant. Between-group differences in contrast sensitivity and illusion sensitivity remained significant with gender included as a factor.

**Discussion**

Illusions provide insight into integrative mechanisms within the early visual system. In general, illusions are based upon the fact that integrative mechanisms that are useful in decoding 3-dimensional information may lead to misinterpretation of 2-dimensional stimuli (ie, illusions). We have previously observed that patients with schizophrenia have decreased sensitivity to 3-dimensional percepts induced by coarse disparity of visual elements (eg, stereopsis), whereas others have reported that patients are paradoxically more sensitive to the Muller-Lyer illusion. The basis for these individual results, however, was not well explained. The present study evaluates the role of reduced gain within the early visual system, as manifested by reduction in contrast sensitivity, as predicting the pattern of altered susceptibility to visual illusions in schizophrenia.

Visual illusions, in general, are apparent percepts generated within the early visual system based upon stimulus configuration. Because the visual system gives priority to detection of certain stimulus elements, such as edges and shapes, other aspects of processing can be distorted, in particular the relationship between stimuli, creating the illusions used in this experiment. Previous studies in healthy volunteers demonstrated that visual illusions have varying sensitivity to manipulations of luminance contrast. The major finding of the present study is that patients with schizophrenia show increased susceptibility to some, but not all, visual illusions and that the relative susceptibility may be related to impaired sensitivity to stimulus contrast.

Specifically, we demonstrate a significantly increased susceptibility of patients to the highly contrast-sensitive Muller-Lyer illusion for patients, while no differences in susceptibility were found for the contrast-insensitive Poggendorff illusion. Moreover, patients appear to be less sensitive to tests of stereopsis and the Ponzo illusion and Hermann grid, consistent with findings of these illusions becoming more prominent with increased contrast. As predicted, while susceptibility to the Hermann grid increased with increasing contrast, patients showed less of an increase than control subjects with increasing contrast levels (figure 5). Also as predicted, for the full sample, sensitivity to the Muller-Lyer and stereopsis illusions were inversely correlated and decreased susceptibility to both stereopsis, and the Hermann grid illusions correlated with reduced contrast sensitivity, reflecting...
a significant relationship to early visual processing. The relationship between Hermann grid and contrast sensitivity remained significant after controlling for group.  

While we are unaware of any previous reports of the Hermann grid, Ponzo illusion, or Sander's parallelogram in schizophrenia, we replicate previous findings for the Muller-Lyer illusion.\textsuperscript{17-19} The Muller-Lyer illusion is a subject of a growing literature in schizophrenia,\textsuperscript{21} which suggests that it may be useful in animal models of the disorder. We are aware of one prior study of the Poggen- dorff illusion in schizophrenia,\textsuperscript{32} in which patients with borderline intellectual functioning were more susceptible than control subjects. The Poggen-dorff illusion has been shown to be affected by IQ,\textsuperscript{33} and in our study, although patients showed lower IQ than control subjects, they nevertheless showed IQs in the normal range (mean = 100.8).

In the present study, we evaluated contrast sensitivity across a range of stimulus durations and SFs. As noted previously by ourselves\textsuperscript{2,3} and others,\textsuperscript{42} the magn- and parvocellular systems show differential but overlapping sensitivities to most stimulus characteristics, so no one stimulus can be viewed as entirely selective for magnocellular vs parvocellular processing. In general, however, the feature that distinguishes most clearly between systems is contrast, with magnocellular neurons responding even to relatively low stimulus contrast, but saturating once contrast reaches approximately 16%, and parvocellular neurons showing low response at low contrasts (eg,  <10%) but graded response thereafter. In the present study, contrast sensitivity thresholds to low-SF (0.5 CPD) stimuli were close to 1%, suggesting that these were mainly processed by the magnocellular system. Contrast thresholds were much higher to high SF (21 CPD) than to lower SFs across both groups, consistent with reduced sensitivity of the magnocellular system to these stimuli. However, the absolute threshold at which detection took place (calculated as reciprocal of the sensitivity value) remained below 10% for all conditions other than the 32-millisecond, 21-CPD condition, in which both groups showed contrast sensitivity values corresponding to absolute contrast levels of approximately 30%, supporting our use of SF to bias activity toward the magnocellular vs parvocellular system.

In the 32-millisecond, 21-CPD condition, which most emphasizes the parvocellular contribution, no between-group difference in contrast sensitivity was observed in the patient group participating in this study, supporting relative preservation of parvocellular function. Across groups, subjects with the lowest contrast sensitivity for low-SF stimuli had the highest (ie, least sensitive) stereopsis thresholds, supporting a role for preserved magnocellular function in contributing to the depth perception percept. In patients, higher contrast sensitivity to high-SF stimuli also correlated with increased thresholds, suggesting that intact parvocellular function may interfere with the percept.  

On a neurophysiological level, processes underlying the illusions used in the present study are not fully understood but are thought to depend, in general, upon local lateral inhibitory processes within the early visual system. Several of the stereoptic tests can be used in children as young as age 2,\textsuperscript{43} making it unlikely that deficits were due to difficulty with comprehension. Nevertheless, patients required markedly greater stimulus disparity to detect apparent 3-dimensionality, functioning at a level normally surpassed by age 10 years, and with correlating deficits seen in all 3 commonly employed tests. Of note is a case report\textsuperscript{44} of a person, who after extensive lesions to his ventral system in childhood illness essentially developed an isolated parvocellular deficit. While the person exhibited intact stereopsis, little to no susceptibility to the Muller-Lyer illusion was demonstrated. This was an opposite response to our patients, whom we hypothesize have a preferential magnocellular deficit, and showed decreased stereopsis but increased susceptibility to the Muller-Lyer illusion. Other evidence, however, supports a significant role of the parvocellular system in also mediating the Muller-Lyer illusion.\textsuperscript{45} Finally, previous studies also suggest that coarse stereopsis is primarily a dorsal stream function related to visual areas V1, V3A, and MT,\textsuperscript{15,16} with input arising primarily through the magnocellular pathway.\textsuperscript{46} Our results, therefore, appear to support a relative magnocellular deficit in schizophrenia.

A limitation to this study is that contrast was not directly manipulated for tasks other than the Hermann grid, making it possible that factors other than contrast sensitivity mediated the differential responses to the various tasks. This limitation is minimized by previous demonstrations of the differential effect of increased contrast and susceptibility to illusions in healthy volunteers (table 1). It is also possible that control subjects and patients had a differential familiarity with both the illusions and the test instructions, which may have affected the results. Because we did not debrief subjects on their baseline familiarity to the different tasks, we cannot eliminate this possibility, but given our findings of increased susceptibility to some illusions, this seems unlikely. Furthermore, in the Herman grid, patients showed a parallel pattern of response to control subjects with increasing performance as contrast increased, albeit with a lower absolute score, which suggests that they were trying to perform the task. Patients also showed no increase in extraneous responses, suggesting that they were not responding either randomly to the stimuli or failing to follow directions. We also note that patients participating in this study showed relatively persistent symptoms and were receiving relatively high doses of medication. Further research is needed with patients in earlier stages of the illness.

Prior studies have demonstrated failures in integrative processing in schizophrenia using tasks such as contour...
integration, perceptual closure, the hollow face illusion, center surround inhibition and Yoon et al. (in this issue), coherent motion, face, face emotion recognition (in this issue), and closure flexibility. In all such tasks, however, reduced integrity of early visual processing is associated with reduced performance in patients. The present tasks provide a complementary approach in that early deficits may produce paradoxically superior response. For example, in the Hermann grid illusion, dots do not in reality exist at the intersections of the dark blocks, although lateral inhibitory processes within the early visual system attempt to place them there. Similarly, in the stereopsis tests, objects are not really 3-dimensional even though the introduction of binocular disparity “tricks” the visual system into believing that they are. In some ways, therefore, patients showed superior response to control subjects on these tests. Nevertheless, the ability to be fooled is an integral process of the mechanisms by which visual information is decoded. Standard visual communication, such as reading or decoding of facial information, depends critically on the sensitivity of the brain to some aspects of visual illusion.

In conclusion, patients with schizophrenia show significant deficits in early visual processing that both may explain subjective disturbances that patients experience and may also lead to downstream impairments in real-world abilities. These deficits, in general, are associated with reduced sensitivity of the early visual system to differences in luminance between different stimulus elements. These deficits create a “dimmer” world for patients with schizophrenia and lead to increased susceptibility to some forms of visual illusions and decreased sensitivity to others. Overall, however, these results suggest that these early visual deficits may lead to impaired ability to extract information needed for complex task performance.

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