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Perceptual organization by proximity and similarity in schizophrenia

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Abstract

Perceptual organization represents a basic and essential function that occurs at an intermediate level of visual processing. Much of the previous research on perceptual organization in schizophrenia employed indirect measurements, or included factors beyond sensory processing. The aims of the present study were to determine the integrity of perceptual organization in schizophrenia, as well as to determine the stimulus duration necessary to perform perceptual organization. Psychophysical measurements were compared between patients with schizophrenia and matched control subjects. Participants viewed dot patterns briefly presented on a computer monitor, and indicated whether stimuli appeared grouped as vertical or horizontal lines. Grouping was based upon either relative proximity or similarity in color. Across trials, relative proximity or color similarity was progressively reduced until stimuli became bistable (perceived as either of two patterns of grouping), establishing the grouping threshold. In separate conditions, stimuli were immediately followed by a mask to limit processing. Stimulus duration was progressively reduced until stimuli became bi-stable, establishing the critical stimulus duration (CSD). Schizophrenia patients demonstrated elevated grouping thresholds for grouping by proximity as well as color similarity. In addition, CSD was significantly extended for the schizophrenia group, with a nearly four-fold increase in duration of processing. These results provide direct evidence of impairment in schizophrenia for perceptual organization based upon spatial relationships and feature similarity, and suggest deficits in low-level perceptual organization processes. Although this study did not directly investigate the physiological correlates underlying perceptual impairments, these results are consistent with a theory of impaired lateral connections within visual cortical areas in schizophrenia.

Keywords

Perceptual grouping; Gestalt; Color similarity proximity; Critical stimulus duration

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1. Introduction

Perceptual organization describes the process of extracting perceptual objects from the initial retinal representation of stimuli. In this regard, perceptual organization enables observers to resolve elements of a complex scene into a series of unified forms. Perceptual organization occurs at an intermediate level of visual processing, preceded by the reception and encoding of basic stimulus features by the retina, and followed by interactions with more high-order processing (Finkel and Sajda, 1994). In this regard, perceptual organization is reliant upon the integrity of afferent signals and initial stimulus representations. In addition, higher-order processes, such as object recognition (Uttal, 1988) and memory (Humphrey and Kramer, 1999), may be degraded by impairment at the level of perceptual organization. Perceptual organization is a robust and dynamic process mediated by multiple interacting mechanisms. In this regard, perceptual organization is guided by both stimulus metrics as well as top-down factors (Beck and Palmer, 2002; Kimchi et al., 2002; Palmer et al., 2003).

When confronted with complex visual scenes, the brain automatically organizes them into a group of unified forms (“percepts”) that can be analyzed as discrete objects. Such perceptual organization operates in accordance with two general principles. First, regularities that exist among stimulus elements are identified, based upon a variety of spatial/temporal cues. Second, associated components are integrated into coherent forms. To accommodate novel stimuli with speed and accuracy, processes underlying these functions are thought to follow neural algorithms that specify grouping patterns best suited to identify forms. Visual perceptual organization is reliant upon neural connections that integrate information across striate and extrastriate cortex. Integration systems are composed of lateral connections within local circuits (Danzker and Callaway, 2000; McGuire et al., 1991; Stettler et al., 2002), as well as feedback connections that modify initial sensory representations (Angelucci et al., 2002; Bringuier et al., 1999; Kapadia et al., 1999).

Based upon tasks in which perceptual organization plays a role, it has been proposed that perceptual organization is abnormal in schizophrenia. For example, patients have been found to benefit less from perceptual grouping than control subjects in several tasks such as discrimination of disparate figures (Cox and Leventhal, 1978), numerosity judgments (Place and Gilmore, 1980; Wells and Leventhal, 1984), object sorting (Frith et al., 1983), and figure detection (Parnas et al., 2001). Furthermore, patients were impaired at identifying circles formed by collinear Gabor elements embedded in a field of randomly oriented elements (Silverstein et al., 2000). However, the number of studies examining basic levels of perceptual organization in schizophrenia remains limited, and there remains a need for further protocol development in this area. In order to understand the characteristics of perceptual organization capacities in schizophrenia, psychophysical measurements of visual function specific to organizational processes need to be made. Without such measurements, analysis of impairment at this stage of visual processing, and possible impact on higher levels of visual and cognitive function will remain incomplete.

The first aim of the present study was to determine the integrity of perceptual organization in schizophrenia. Two basic principles of grouping were explored that have not been examined previously in schizophrenia with these procedures: grouping by proximity and grouping by color similarity. Grouping by proximity refers to the tendency to perceptually group stimulus elements that are in close spatial proximity, which was engaged here by manipulating the relative proximity among elements. Grouping by similarity refers to the tendency to perceptually group elements that share stimulus features, which was engaged here by manipulating the degree of color similarity among elements. The integrity of perceptual grouping function was examined by progressively reducing the degree of intrinsic organization contained in the stimulus, by either reducing the difference in relative proximity, or the degree

of similarity among elements. Psychophysical thresholds were established by using an up–down transformed response method, thereby more precisely quantifying deficits. Measurements from the up–down staircase procedure reflect stimulus levels at which subjects accurately organize stimuli with a long-run probability of 71% correct. Stimuli consisted of simple patterns and discrimination did not require learning new configurations, thereby minimizing top–down influence. These procedures have previously been used to isolate basic grouping capacities in other populations, including Alzheimer’s disease (Kurylo et al., 1994, 2003; Kurylo, 2004), elderly individuals (Kurylo, 2006), and patients with acquired brain injury (Kurylo et al., 2006).

The second aim of this study was to determine the stimulus duration necessary for perceptual organization. These measurements differ from grouping thresholds in that at a fixed level of intrinsic stimulus organization the processing time necessary to perceptually organize patterns of elements was determined. Whereas schizophrenia patients are known to require longer exposure durations of stimuli in order to discriminate letters or patterns (Saccuzzo and Braff, 1981, 1986; Weiner et al., 1990; Slaghuys and Bakker, 1995; Butler et al., 1996, 2002; Schechter et al., 2003), stimulus durations necessary for perceptual grouping have not previously been determined. To accomplish this, stimuli were progressively decreased in duration until grouping patterns could no longer be discriminated. Test stimuli were immediately followed by the pattern mask, thereby maintaining experimental control over the test stimulus without introducing post-stimulus effects (Felsten and Wasserman, 1980). In this regard, the pattern mask served to disrupt iconic storage and associated attention factors that may otherwise play a role after the removal of the stimulus. As the stimulus duration is progressively reduced, perceptual organization is disrupted, whereas basic stimulus properties, such as element shape and color, remain apparent to observers (Kurylo, 1997). In this way, the critical stimulus duration for perceptual organization is indexed. Events that occur later in visual processing are thereby disrupted by the presence of the mask.

2. Methods

2.1. Subjects

Nineteen patients (17 men, 2 women) meeting DSM-IV criteria for schizophrenia ($n=16$) and schizoaffective disorders ($n=3$) from inpatient and outpatient facilities associated with the Nathan Kline Institute for Psychiatric Research participated in the study. Diagnoses were obtained with the Structured Clinical Interview for DSM-IV (SCID) (First et al., 1997) and all available clinical information. Twenty control participants (11 men, 9 women) volunteered for the study. Control volunteers with a history of SCID-defined Axis I psychiatric disorder were excluded. Patients and controls received a basic ophthalmologic examination, and were confirmed to be free from significant ophthalmologic disorders, including visual field restrictions and color abnormalities. Participants were excluded if they had any neurological disorders that might affect performance or if they met criteria for alcohol or substance dependence within the last 6 months or abuse within the last month. All participants provided written informed consent after procedures had been fully explained.

Patient and control groups did not differ significantly in age ($t(37)=0.25$, $p=0.81$; patient group mean=37.2 years, S.D.=10.8; control group mean=36.3 years, S.D.=12.2). However, there was a significant difference in gender ratio (Fisher exact test; $p=0.03$). Socioeconomic status (ses), as measured by the 4-factor Hollingshead Scale, was significantly lower for patients than for controls ($t(37)=8.9$, $p<0.001$; patient group mean=20.3, S.D.=9.4; control group mean=46.8, S.D.=9.4). Brief Psychiatric Rating Scale total score was (mean±S.D.) 39.5±10.9 and Scale for the Assessment of Negative Symptoms total score (including global scores) was 42.6±13.4. These ratings reflect the relatively chronic stabilized patients with prominent negative symptoms in our study. All patients were receiving antipsychotics with 16 patients receiving

atypical, 2 receiving both typical and atypical and 1 receiving typical antipsychotic medication. Chlorpromazine equivalents were 1278.7 ± 549.8 mg/day. Chlorpromazine equivalents were calculated using conversion factors described previously (Hyman et al., 1995; Peuskens and Link, 1997; Jibson and Tandon, 1998; Woods, 2003). Subject group characteristics are provided in Table 1.

Participants were tested binocularly. While all participants had at least 20/30 (0.67) corrected visual acuity or better (Snellen 143"), the patients had significantly lower visual acuity (vision ratio = 0.89 ± 0.11) than controls (0.97 ± 0.007) for their binocular vision ($t(37) = 2.7$, $p = 0.01$). Gender, sex, and visual acuity were used as covariates in between-group analyses.

2.2. Apparatus

Stimuli were presented on a computer (Sony PCG Z50JEK) with an XGA (1024×768) TFT display.

2.3. Stimuli

Stimuli were briefly presented on a computer monitor. Stimuli were composed of a grid of elements that subtended a 19.3° square field. Stimulus duration was linked to the display's vertical synchronization signal. Stimulus elements were organized either vertically or horizontally, which elicited the perception of a series of vertical or horizontal lines. The vertical or horizontal condition was selected randomly on each trial.

Two grouping conditions were examined, the first based upon relative proximity, the second based upon color similarity.

2.3.1. Proximity—For the proximity condition, stimulus elements were solid white squares, 0.35° on a side, positioned on a dark background. Elements were aligned and spaced at regular intervals, differing in separation between the vertical and horizontal orientation. Elements along the more distant separation (S_{dist}) were fixed at 1.16° . Elements along the more proximal separation (S_{prox}) ranged from 0.38° to 1.16° . Proximity thresholds are described in terms of relative proximity, calculated as $[1 - (S_{\text{prox}}/S_{\text{dist}})] \times 100$. At the beginning of each measurement series, the relative proximity was 67.2%. Across trials, relative proximity was progressively reduced in increments of approximately 10%. As the relative proximity approached equivalence, stimuli became ambiguous and bi-stable. Fig. 1 depicts stimuli with a relative proximity of 45.3, 34.7, 22.9, and 10.6%. For example, for the 45.3% stimuli, elements that are more closely spaced (proximal separation) are separated by 0.635° , whereas elements that are more distant (distal separation) are separated by 1.16° .

2.3.2. Color similarity—For the color condition, stimuli consisted of a 20×20 array of squares. Elements consisted of solid squares, 0.35° on a side and separated by 0.69° , that were either red (CIE-USC coordinates: $u' = 0.368$, $v' = 0.513$; luminance = 16.51 cd/m^2) or green (CIE-USC coordinates: $u' = 0.132$, $v' = 0.553$; luminance = 18.46 cd/m^2). Hue and saturation approximated isoluminance. For vertical grouping, each column contained elements of the same color, alternating between colors across columns. For horizontal grouping, rows contained the same color, alternating between colors down the rows.

Hue and saturation were based upon a matching procedure, administered to three laboratory personnel prior to experimental measurements, which estimated isoluminance. During experimental sessions, possible variability in isoluminance across subjects was controlled for by randomly varying luminance levels of each color element (Kurylo, 2006).

The organization of the stimuli was manipulated by randomly replacing colors of a percentage of elements. At the beginning of each trial series, percent similarity was set to 100%. Across trials, the percent similarity was changed in increments of 2%. Fig. 2 depicts stimulus arrays in which the percent similarity is set to 100, 95, 90, and 85%.

The contrast borders along the edges of stimuli depicted in Figs. 1 and 2 correspond to the edges of the computer monitor.

2.4. General procedure

Participants received four tests of perceptual organization that were based upon either spatial proximity or color similarity. For each stimulus condition, psychophysical measurements were made of grouping thresholds, which represent limits of perceptual organization, as well as masking thresholds, which represent processing time. To minimize confounding factors associated with slowed decision making or motor response, reaction time was not a factor, and participants were instructed to optimize accuracy. In addition, responses were based upon a two-alternative forced-choice procedure in order to preclude possible response bias that may distinguish subject groups.

Participants fixated a central target on the computer monitor at a viewing distance of 46 cm. Following a delay of 500 ms, a stimulus appeared. On each trial, the vertical or horizontal condition was randomly assigned. Following stimulus presentation, subjects indicated whether the stimulus was organized as a series of vertical or horizontal lines. Responses were made either verbally or by pointing to picture representations of the choices. Responses were then entered into the computer by the experimenter. For each test, subjects first received a demonstration, and then a series of practice trials in order to become familiar with the stimulus and procedure. Following the demonstration and practice, threshold measurements were made. Stimulus generation, data collection, and contingency algorithms were controlled by computer.

2.5. Grouping thresholds

Across trials, stimuli varied in the level of intrinsic organization. Highly organized stimuli provided strong cues for grouping, which facilitated grouping. For the proximity condition, intrinsic stimulus organization was established with large differences between the more proximal and the more distal elements. In this regard, elements that were highly proximal provided a strong cue for grouping, compared to elements that were more separated. For the color condition, intrinsic stimulus organization was established with a high percentage of color similarity along one orientation, whereas the alternate orientation contained elements that were highly varied in color. As trials progressed, the intrinsic organization of the stimuli was reduced, providing less of a cue for grouping. Subjects who were less capable of perceptually organizing stimuli require greater intrinsic organization of the stimuli. In contrast, individuals who possessed a greater capacity to perceptually organize visual system could derive organization from stimuli that contain less intrinsic organization.

For grouping thresholds, stimuli were presented for 500 ms and measurements were made of the lowest level of stimulus organization at which perceptual grouping could occur. Stimulus difficulty level was increased after two consecutive correct responses, and decreased after a single incorrect response, thereby converging on a level at which subjects responded correctly with a long-run probability of 71% (Levitt, 1971). Thresholds were based upon the mean of eight reversals from two descending series.

2.6. Masking thresholds

A backward mask was used to determine the duration of processing necessary to establish perceptual organization (Kurylo, 1997). The test stimulus was followed by a pattern mask,

which served to disrupt processing of the test stimulus. Test stimuli were immediately followed by the pattern mask, thereby maintaining experimental control over the test stimulus without introducing post-stimulus effects (Felsten and Wasserman, 1980). Across trials, stimulus duration was progressively reduced until the organization of the stimulus could no longer be determined. Under these conditions, other stimulus characteristics, such as element shape, were identifiable, but perceptual organization failed to be achieved. Masks were therefore not intended to eliminate detection of stimulus features, but to interfere with processes associated with perceptual organization.

2.6.1. Test stimulus—Test stimuli for the proximity and color similarity conditions were the same as those previously described. In both cases, relative proximity was fixed at 33% (proximity condition) or 100% similarity (color similarity condition), which provided strong grouping cues.

2.6.2. Masking stimulus—The masking stimulus was an 8×8 array of crosses (plus signs) that subtended a 19.3° field, thereby covering the area of test stimuli. The array of crosses contained robust horizontal and vertical co-linearity cues, and effectively disrupted perceptual organization of test stimuli.

2.6.3. Procedure—Participants fixated a central point, which was followed after 500 ms by the test stimulus. Immediately following the offset of the test stimulus, the mask appeared for 200 ms. After viewing both stimuli, participants indicated whether the test stimulus appeared to be organized as a series of vertical or horizontal lines. At the beginning of each trial series, the test stimulus duration was 600 ms. Across trials, stimulus duration was progressively reduced in increments of 14.3 ms (70 Hz temporal resolution). Psychophysical thresholds (discrimination accuracy of 71%) were again based upon the mean of eight reversals from two descending series, using a two-down, one-up procedure.

2.7. Control conditions

Each psychophysical measurement was accompanied by a control condition in which stimuli consisted of solid vertical or horizontal lines. These trials served to monitor subjects' ability to understand the requirements of the tasks, to perceive and discriminate solid figures, and to respond appropriately. In all cases, patients and control subjects performed with an accuracy of 90% or greater on the control condition, thus indicating that subjects understood task requirements.

3. Results

3.1. Grouping by proximity

Lower threshold values reflect a greater perceptual capacity, in that the proximal and distal separations are more similar. Thresholds for proximity differed significantly between subject groups ($F(1,34)=5.4$; $p=0.03$), in which the mean threshold for patients was 21.5% (SEM=3.1), compared to 11.3% (SEM=1.4) for control subjects (Fig. 3A). Effect size was calculated using Eta squared which measures the proportion of variance explained. Eta squared was 0.19 before covarying for gender, sex, and vision and 0.14 after covarying.

In addition to requiring a stronger proximity cue, schizophrenic patients had greatly extended processing times. For proximity masking thresholds, subject groups differed significantly ($F(1,34)=18.7$; $p<0.001$), in which the mean duration of the test stimulus was 458.3 ms (SEM=56.0) for patients, compared to 106.7 ms (SEM=16.0) for control subjects (Fig. 3B). Eta squared was 0.51 before and 0.36 after covarying for gender, sex, and vision.

For levels of relative proximity in which the grouping cue was strong (relative proximity of 67.2%), all patients performed with 100% accuracy. In this regard, when minimal demand was placed upon perceptual grouping processes, patients performed normally. Therefore, deficits found here are not attributable to a generalized decline in perceptual function by patients, but instead reflect processes that are engaged during perceptual grouping.

3.2. Grouping by color similarity

As with proximity, lower thresholds reflect a greater perceptual capacity, in that stimuli contain less intrinsic organization. Thresholds for color similarity differed significantly between subject groups ($F(1,34)=12.6$; $p=0.001$), in which the mean threshold was 88.9% (SEM=1.6) for patients, compared to 79.4% (SEM=1.0) for control subjects (Fig. 3C). Eta squared was 0.42 before and 0.27 after covarying for gender, ses, and vision.

For the color similarity condition, schizophrenia patients again had greatly extended processing times. For masking thresholds, subject groups differed significantly ($F(1,34)=10.0$; $p=0.003$), in which the mean duration for patients was 403.3 ms (SEM=75.0), compared to 77.2 ms (SEM=13.8) for control subjects (Fig. 3D). Eta squared was 0.34 before and 0.23 after covarying for gender, ses, and vision.

For the highest levels of color similarity (98 or 100% similarity), in which the grouping cue was strongest, 17 of the 19 patients performed with 100% accuracy. Similar to the proximity condition, patients performed normally when minimal demands were placed upon grouping processes, and deficits in grouping do not reflect a generalized decline in function.

While gender was included as a covariate in the above analyses, data from just the male patients and controls were analyzed to ensure that results were not driven by the inclusion of females in the control group. Between-group differences remained significant for all conditions [i.e., proximity threshold ($F=6.1$, $df=1/24$, $p=0.02$) and duration ($F=11.2$, $df=1/24$, $p=0.003$) and color threshold ($F=6.1$, $df=1/24$, $p=0.02$) and duration ($F=7.3$, $df=1/24$, $p=0.01$)].

3.3. Correlations

For schizophrenia patients, grouping and masking thresholds within each condition correlated significantly (proximity: $r=0.65$, $p=0.003$; color similarity: $r=0.59$; $p=0.01$). These results indicate that impaired function produces both the need for greater stimulus organization, as well as extended time to complete the process. There were no significant correlations between CPZ equivalents and grouping or masking thresholds in each condition.

4. Discussion

These results identify impaired visual processing in schizophrenia for two basic principles of grouping. Impairment was reflected by the need for greater intrinsic organization of the stimulus in order to perceptually group elements, as well as the need for increased stimulus processing time, extending by more than four times the mean duration of control subjects.

Elevated thresholds were accompanied by significantly slowed processing speed. Unlike reaction time measurements, critical stimulus duration used here was specific to stimulus processing. In this regard, factors including decision making, sensory–motor transformation, and motor programming and execution, are not reflected in measurements of critical stimulus duration used here. Schizophrenia patients display slowed information processing on other visual tasks, including longer critical stimulus duration (Saccuzzo and Braff, 1981, 1986; Weiner et al., 1990; Slaghuys and Bakker, 1995; Butler et al., 1996, 2002; Schechter et al., 2003), as well as longer interstimulus intervals for a backward masking task (Saccuzzo and Braff, 1981, 1986; Braff, 1981; Braff and Saccuzzo, 1985; Weiner et al., 1990; Rund, 1993;

Slaghuis and Bakker, 1995; Butler et al., 1996, 2002; Schechter et al., 2003). Elevated thresholds found here demonstrate a further source of reduced processing speed specific to basic perceptual grouping function. Reduced speed of perceptual grouping may result from dysfunction of grouping mechanisms, in which associations among stimulus elements are less efficiently established. In addition, reduced processing speed may reflect a reduction in automatic processing of stimuli, as evident with perceptual grouping as well as with increased critical stimulus duration. In this regard, impairment in perceptual organization mechanisms engaged in the discrimination of simple forms is evidenced by elevated grouping thresholds, as well as an increase in processing duration to complete these functions. Such deficits do not reflect sequential processes, but instead reflect impairment of the same mechanisms.

Psychophysical thresholds were derived from an up-down transformed response method, thereby specifying perceptual capacities. Measurements do not reflect signal-from-noise detection, but instead examine perceptual organization of visual patterns. In addition, the perceptual task consisted of discriminating simple patterns that did not require learning new configurations. In this regard, impairment appears to be associated with sensory processing and not the result of abnormal top-down factors or high-order visual processes that involve recognition or memory. These results confirm other studies reporting low-level perceptual grouping deficits in schizophrenia (Silverstein et al., 2000; Keri et al., 2005), and are consistent with an interpretation that disruption of bottom-up processing underlies these perceptual abnormalities (Silverstein et al., 2000). In addition to perceptual grouping studies, results from backward masking and critical stimulus duration studies further support lower level deficits in schizophrenia.

Low-level deficits found here may represent dysfunction that generalizes across processes, affecting basic grouping capacities across stimulus domains. Furthermore, abnormalities at basic levels of processing may be related to more complex aspects of perceptual organization. Deficits in basic grouping processes found here may underlie impairment reported for visual tasks in which perceptual grouping plays a role. Judgments of numerosity (Place and Gilmore, 1980; Wells and Leventhal, 1984) and the discrimination of disparate figures (Cox and Leventhal, 1978) were shown to be impaired in schizophrenia when performance could benefit from perceptually grouped stimulus elements. In this regard, complex stimuli that contain grouping cues of proximity or color similarity are less efficiently processed by schizophrenic patients, thereby interfering with more high-order visual functions.

A possible neural mechanism that may underlie impairments found here is reduced function of lateral connections within visual cortical areas. Perceptual organization of stimuli used here requires linking spatially isolated stimulus elements. At early levels of visual processing, stimulus elements are represented by increased neural activity at specific cortical sites. Neural representations of elements are encoded retinotopically, such that adjacent positions in space are represented at adjacent positions on the cortex. Spatially isolated stimulus elements are thereby represented by sites of activation that are separated by areas of less activity. In the process of grouping, activated sites are linked into functionally integrated units. Intrinsic connections within early cortical areas may provide a substrate for the selection and linking of primary representations (Ross et al., 2000). Such lateral connections may contribute to a system of enhancement and inhibition of signals based upon contextual effects from other cortical sites (Alonso, 2002; Angelucci et al., 2002).

Evidence of impaired lateral connections in schizophrenia has been reported for a perceptual task involving adjacent stimulus elements. Contrast sensitivity of targets is normally enhanced when placed adjacent to a second stimulus that is collinear and positioned along the same axis of orientation (Adini et al., 1997). Enhanced signal strength of these stimuli is thought to result from excitatory lateral connections that link neurons sharing common properties (Yao and Li,

2002). This effect did not occur in patients with schizophrenia, indicating impairment of lateral connections at early levels of visual processing (Keri et al., 2005). Similar impairment may contribute to perceptual deficits found here. With degraded lateral connections, the binding of adjacent elements within grouped patterns would be diminished, thereby requiring greater intrinsic organization of the stimuli to perceptually group elements.

A limitation of the study is that all patients were receiving medication at the time of testing. However, visual processing deficits have been found in both medicated and unmedicated patients (Braff and Saccuzzo, 1982; Butler et al., 1996; Cadenhead et al., 1997), as well as in (unmedicated) first-degree relatives of patients with schizophrenia (Chen et al., 1999; Green et al., 1997; Keri et al., 2004). In addition, no significant correlations were found between CPZ equivalents and grouping or masking thresholds for the proximity and color conditions. A further limitation is that there were more females in the control than patient group. To ensure that the differences between patients and controls were not a result of the greater number of females in the control group we covaried for gender. Between-group effects were still significant. In addition, when only males were included in the analysis, between-group differences remained significant.

The result provides evidence of impaired perceptual organization in schizophrenia for grouping by spatial relationships as well as grouping by feature similarity. Impairment was reflected by a reduced ability to perceptually organize patterns of elements, as well as extended processing time to accomplish grouping. Additional stimuli may be used to specify other spatial relationships and feature domains mediating grouping, including orientation, binocular disparity, motion coherence, and temporal contrast. These measurements may also be used to examine relationships between perceptual organization abilities and high-order visual capacities, such as discriminating complex scenes or dynamic images. These functions may be further explored when used in conjunction with electrophysiological measurements, identifying the location and characteristics of abnormalities associated with specific components of perceptual organization.

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Fig. 1.

Examples of stimuli for the proximity condition. Top and bottom rows correspond to the vertical and horizontal conditions, respectively. Relative proximity of 45.3, 34.7, 22.9, and 10.6% corresponds to a progressive decrease in grouping cue strength.

Fig. 2. Examples of stimuli for the color similarity condition. Similarity of 100, 95, 90, and 85% depicts the percentage of elements sharing color along the vertical (top row) or horizontal (bottom row) orientations.

Fig. 3. Performance for (A) proximity grouping thresholds, (B) proximity critical stimulus duration for perceptual grouping, (C) color similarity grouping thresholds, and (D) color similarity critical stimulus duration. Each circle represents an individual subject. Bars show the group mean.

Table 1

Subject group characteristics

Group	Age M (S.D.)	Gender ^a (M/F)	SES ^b M (S.D.)	BPRS M (S.D.)	SANS M (S.D.)	Illness duration(years) M (S.D.)
Patients	37.2 (10.8)	17/2	20.3 (9.4)	39.5 (10.9)	42.6 (13.4)	17.6 (8.5)
Control	36.3 (12.2)	11/9	46.8 (9.4)	—	—	—

Significant difference between patients and controls;

^a $p = 0.03$;

^b $p < 0.001$.

BPRS (Brief Psychiatric Rating Scale); SANS (Scale for the Assessment of Negative Symptoms).