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Perceptual organization, the disorganization syndrome, and context processing in chronic schizophrenia

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Abstract

Schizophrenia patients' perceptual organization abilities were assessed with a psychophysically well-controlled measure of contour integration. Compared with psychiatric and staff controls, schizophrenia patients were less able to detect contours comprising Gabor elements as the detection of these contours relied increasingly on long-range spatial interactions. Impaired task performance was also found to correlate significantly with higher levels of disorganized symptomatology. These data provide further evidence for impaired perceptual grouping in schizophrenia. In addition, the findings support the hypothesis that a common cortical processing algorithm involving contextual coordination is impaired in schizophrenia, leading to reduced binding of object features in vision, and reduced contextual disambiguation of linguistic information during thought and speech. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Context processing; Contour integration; Disorganization syndrome; Perceptual organization; Visual information processing

1. Introduction

One model of visual-information processing impairment in schizophrenia postulates a dysfunction in perceptual organization processes, or a reduced ability to combine stimulus components into object representations during the first 200 ms of processing (Place and Gilmore, 1980; Silverstein et al., 1996a, 1998a). Since perceptual organization is necessary for the delineation of objects in the visual field, and stimulus representations with object

properties are stronger competitors for attention than stimulus components (Kahneman and Triesman, 1984) or weakly organized stimuli (Ward and Goodrich, 1996), an impairment at this early stage of processing is thought to result in less focused attention and reduced processing of the meaning and/or significance of visual stimuli.

In general, the literature on visual perceptual organization in schizophrenia can be summarized in three statements: (1) stimuli with continuous contour that have symmetrical properties are processed normally (Knight, 1992; Chey and Holzman, 1997); (2) stimuli comprising noncontiguous elements that are nonconfigural are not processed as perceptual wholes to the same degree as they are among other individuals (Silverstein et al., 1996a, 1998a); and (3) there are mixed findings

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regarding the ability of schizophrenia patients to process configural stimuli made up of noncontiguous elements (Cox and Leventhal, 1978; Rabinowicz et al., 1996; Silverstein et al., 1998b). While some studies of the latter issue suggest that patients are impaired in this function, there has been no strong test of this hypothesis, as all past studies have had a number of methodological and conceptual weaknesses. For example, in Cox and Leventhal's (1978) visual suffix study, ease of grouping was manipulated across several conditions, but only overall, between-group accuracy rates (collapsed across condition), and not diagnostic group by condition interactions, were reported. Thus, no conclusions could be drawn about differential responsivity of the diagnostic groups to the perceptual organization manipulations. Moreover, Silverstein et al. (1998b) found a normal between-condition performance pattern among schizophrenia patients using the visual suffix task. In Cox and Leventhal's (1978) two other studies, perceptual grouping was required within the context of texture discrimination and numerosity tasks. These visual search tasks made heavy demands on processes other than perceptual organization, so although schizophrenia patients performed more poorly than controls, these data are not straightforward evidence of perceptual organization impairment. Similarly, Rabinowicz et al. (1996) reported that when the task was to determine the shape implied by sparse dot patterns, schizophrenia patients performed more poorly than other groups. This finding, however, may simply reflect a generalized performance deficit. Moreover, because schizophrenia patients improved at the same rate as controls as more elements were added to displays, the authors noted that they were able to process stimulus form. In short, while studies of schizophrenia patients' ability to perceptually organize configural arrangements of noncontiguous elements suggest that they are impaired in this function, strong evidence for this is minimal. Therefore, one goal of this study was to test this issue using a straightforward but psychophysically well-controlled procedure wherein degree of perceptual grouping could be formally specified, and where task performance was not confounded by other cognitive factors.

A second goal of the study was to examine the relationship between perceptual organization ability and the disorganization syndrome. In two previous studies, abnormalities in perceptual organization in schizophrenia were associated with greater disorganized (but not positive, negative, or general) symptoms (Knight and Silverstein, 1998; Silverstein et al., 1998a). In a third study (Knight and Silverstein, 1998), abnormal perceptual organization was related to increased disorganized and associative thought disturbance, but not combinatorial or idiosyncratic thought disturbance in schizophrenia. These data support the hypothesis that abnormal perceptual organization in schizophrenia is one manifestation of a larger disturbance in the combining of context-related stimuli (Carr and Wale, 1986; Silverstein and Schenkel, 1997). In this view, perceptual organization in vision is seen as a form of 'object thinking' (Glezer, 1995) involving the binding of image elements into a context-appropriate coherent whole, where the context can be seen as the other elements that combine to make up the line, curve, or object (Lamme, 1995; Kovács, 1996; Phillips and Singer, 1997). This is seen as analogous to the binding of words or concepts into coherent thought and linguistic structures, except that in these cases, the binding is based on context-appropriate meaning (Logan and Zbrodoff, 1999). Indeed, several investigators have hypothesized that the formation of propositional visual representations (i.e., those that represent the spatial relationships between object components) is necessary to process visual images, and that these are structurally similar to the propositional representations underlying thought and language (Chechile et al., 1996; Glezer, 1995; Logan and Zbrodoff, 1999). Further evidence for a common mechanism underlying linguistic and visual representations comes from studies of individuals with parietal lobe damage, where deficits in both the 'comprehension' of spatial relations (i.e., perceptual organization) and the comprehension of logical relations are commonly observed (Glezer, 1995). There is now growing support for the existence of common cortical processing algorithms (Grossberg, 1999; Phillips and Singer, 1997), as well as evidence that contextual coordination operates across domains to implement processes such as perceptual grouping in vision, lexical

disambiguation in language comprehension and speech production, and selective attention. All of these functions are impaired in schizophrenia (Carr and Wale, 1986; Silverstein et al., 1996a,b, 1998a; Cohen and Servan-Schreiber, 1992; Cohen et al., 1999; Patterson et al., 1986). If, indeed, visual perception and thinking share some common organizational principles, then a disruption in a common cortical processing algorithm might lead to impairments involving lack of organization in both visual and conceptual processing, and these deficits could be expected to covary.

2. Method

2.1. Subjects

Three groups of subjects participated in the study: (1) 23 chronic schizophrenia patients from inpatient programs at a state psychiatric center [17 men, 6 women; mean length of stay during the current admission of 97.52 months ($SD = 103.52$)]; (2) 19 nonschizophrenia psychiatric controls, who were also patients at the state hospital [12 men, 7 women; mean length of stay during the current admission of 37.53 months ($SD = 53.78$)]; and (3) 17 staff controls (3 men, 14 women). Demographic data are listed in Table 1. The groups did not differ in age. There was a significant difference in education level, $F(2,56) = 14.29$, $p < 0.0001$, with the staff control group having a higher level than either of the patient groups. Potential subjects with histories of vision disorders, closed head injury, mental retardation, or neurologic syndromes (e.g., epilepsy, cerebral palsy) were excluded from the schizophrenia group. The nonschizophrenia group

included individuals with different diagnoses, primarily schizoaffective disorder, bipolar disorder, and personality disorder due to a general medical condition.

DSM-IV (American Psychiatric Association, 1994) diagnoses of schizophrenia were confirmed at the time of the study by thorough chart reviews, consultations with the treating psychiatrist, and, where patient cooperation allowed, the Structured Clinical Interview for DSM-IV Diagnosis — Patient Edition (SCID-I/P, Version 2.0; First et al., 1995). SCID interviews were conducted by the first author, who had previously established reliability on SCID interviews with the Diagnostic and Psychopathology Unit of the UCLA Clinical Research Center for Schizophrenia and Psychiatric Rehabilitation (mean kappa = 0.82, mean sensitivity = 0.77, mean specificity = 0.88).

In order to test the hypothesis that abnormal perceptual organization would be related to the disorganization syndrome, individuals in the schizophrenia group were rated on two related symptom dimensions using the Positive and Negative Syndrome Scale (PANSS; Kay et al., 1987). One was the *Cognitive* component, which overlaps considerably with the concept of the disorganization syndrome (Liddle, 1987). This factor, part of the five-factor solution of Lindenmayer et al. (1994), consists of the symptoms poor attention, mannerisms and posturing, conceptual disorganization, difficulty in abstract thinking, and disorientation. In addition to this component, we rated participants with schizophrenia on the item inappropriate affect (Cuesta and Peralta, 1995) which allowed for a score on the *Disorganization* factor, which includes the items poor attention, conceptual disorganization, and

Table 1
Demographic and performance data

Group	Score on contour task (D)	Score on contour task (No. of correct responses)	Age	ED level	Left eye acuity (i.e. 20/X)	Right eye acuity (i.e., 20/X)
Schizophrenia ($n = 23$)	0.84 (0.12)	6.06 (2.69)	44.00 (7.95)	10.81 (2.79)	55.77 (34.87)	55.00 (33.91)
Psychiatric control ($n = 19$)	0.76 (0.07)	7.79 (1.32)	42.53 (17.16)	11.74 (1.88)	52.78 (23.40)	47.50 (22.57)
Staff control ($n = 17$)	0.74 (0.07)	8.24 (1.39)	40.89 (10.72)	14.59 (2.27)	34.71 (13.52)	31.76 (9.18)

inappropriate affect. PANSS items were rated by the first or third author or one of two trained research assistants. The first, third and fourth authors and these two interviewers had previously reached a high level of inter-rater reliability on PANSS interviews (mean ICC=0.90).

2.2. Stimuli

The stimulus set consisted of 10 cards which contained varying numbers of Gabor elements against a uniform gray background. Gabor elements are gaussian-modulated sinusoid luminance distributions which model the known receptive-field properties of neurons in the primary visual cortex (V1). Their oriented shape and small size ensures that each stimulus activates only a limited set of early cortical neurons that respond to small parts of the visual field. Each card contained a closed path of Gabor elements embedded in a random array of Gabor elements of the same spatial frequency and contrast (see Figs. 1 and 2). The Gabor carrier spatial frequency was 5 c/deg and contrast was approximately 95%. The cards were generated by an algorithm that allowed precise control over the important spacing parameters. Spacing along the contour and the spacing among the background elements were controlled independently. A graded series of 10 cards was produced by varying the average spacing between the background elements while holding the spacing between elements of the closed contour at 8 times the wavelength of the Gabor carrier. The ratio of the mean background spacing and spacing between neighboring contour elements (or delta, D) defines the contour signal to noise ratio, which ranged from 1.1 to 0.65 in 0.05 increments. Because the conspicuity of the contour and the strength of the noise both increase as their respective spacing decreases, the background-element to contour-element density ratio (D) expresses the actual signal to noise ratio within each card. At $D > 1$, the cards contain a first-order density cue, and therefore the contour can be identified by detecting the group of elements with the closest spacing. At $D < 1$, however, there is no density cue, and only second-order orientation cues are available for the location of the contour, which must be detected solely on

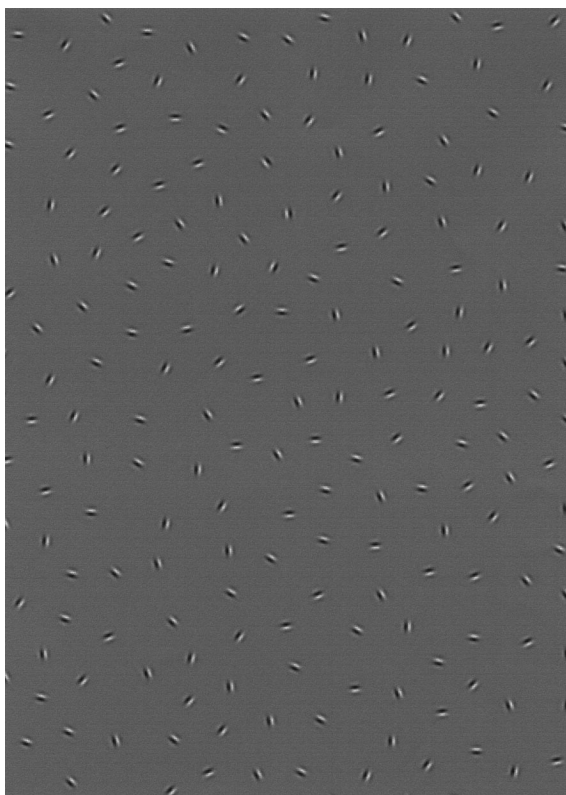


Fig. 1. Examples of the test cards. A closed path of Gabor signals is embedded in noise. The observer is asked to locate the position of the contour. The ratio of element spacing in the noise background to spacing along the contour (D) is 1.0.

the basis of long-range correlations between elements. With complete independence of the two spacing parameters, background elements can get into the spaces between contour elements at relatively small signal to noise values. The angular difference between adjacent Gabor elements on the contour was restricted to the range $\pm 30^\circ$. This 10-card series of contour cards has demonstrated good test–retest reliability and minimal practice effects in prior studies. The card set was developed, and has been used previously, to detect perceptual grouping impairments in amblyopia (Kovács et al., 1998; Peneffather et al., 1998), a disorder involving suspected deficits in long-range spatial interactions in cortical areas subserving one eye. In addition, this card set produced similar levels of performance compared to brief, computerized pre-

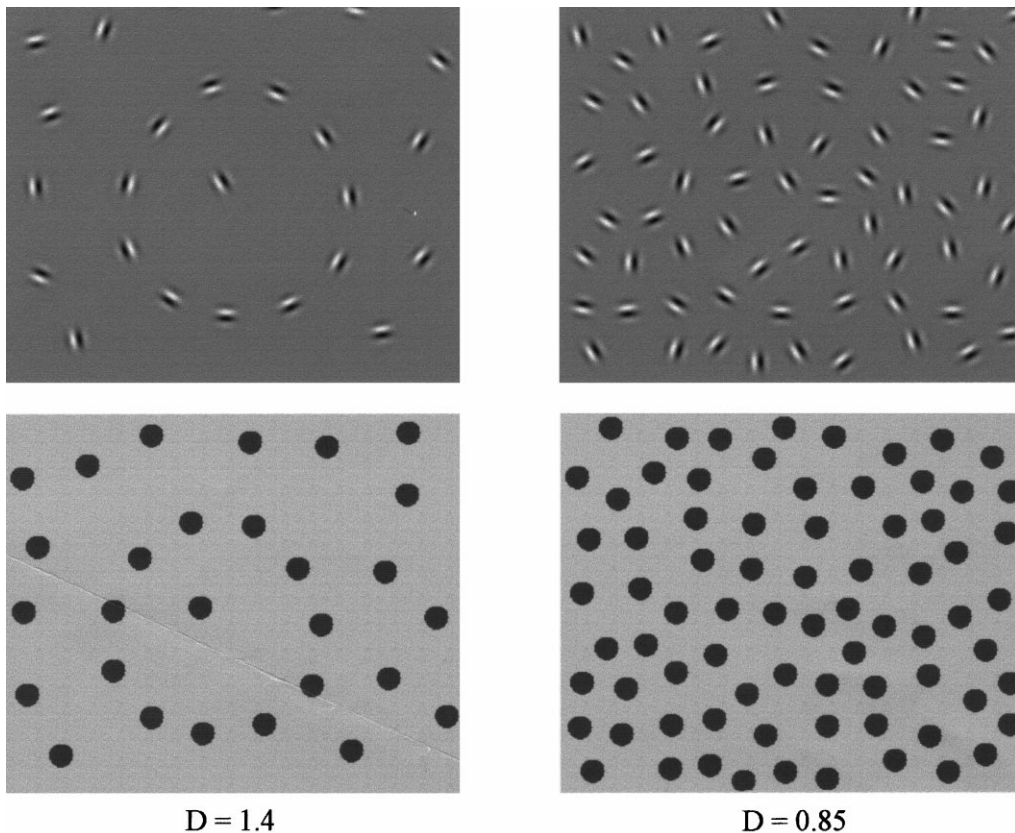


Fig. 2. Examples of Gabor-defined contours with different D values (left: $D=1.4$, right: $D=0.85$). In the bottom panels, Gabor elements were replaced by disks. Without orientation cues, the contour remains invisible at $D < 1$, and this is the range where perceptual organization depends on long-range spatial interactions.

sentations of the same stimuli, indicating the contour integration effect is perceptual and not due to higher level cognitive factors.

2.3. Acuity testing

After signing an informed consent form, subjects were administered a standard visual acuity examination (Snellen chart), which involved examining acuity monocularly in each eye, and then binocularly. Four out of 59 subjects refused to complete the acuity testing due to delusional ideation concerning bodily integrity changes that might occur if their eyes were covered. All of these subjects had had ophthalmologic examinations within the past 2 years, however, and were docu-

mented as having normal or corrected-to-normal vision.

2.4. Contour integration task

After the visual acuity check, subjects completed the contour integration task. Cards were presented binocularly from a distance of 1 m on a flat tabletop. The subjects were allowed to scan the cards for up to 30 s, until they were able to make a decision about the location of the contour. The contour was either positioned in the center, shifted to the left, or shifted to the right within the rectangular arrays. The subject's task was to identify the contour by pointing to its location on the card, and then tracing the outline with their index

finger. Each correct localization and tracing was considered one correct response, leading to a maximum score of 10, or D value of 0.65.

3. Results

There was a significant main effect of group in the contour integration task, $F(2,56)=7.84$, $p=0.001$. Post-hoc Scheffé tests indicated that the schizophrenia group scored significantly lower than both the psychiatric control and staff control groups, who did not differ from each other. Because there was a significant difference in variance between the groups, group means were also compared using the nonparametric Kruskal–Wallis test. This also revealed a significant group difference, $\chi^2(2)=10.18$, $p<0.01$.

There was also a significant main effect of group for visual acuity: left eye $F(2,52)=4.50$, $p<0.025$; right eye $F(2,52)=3.91$, $p<0.05$. Post-hoc Scheffé tests indicated that while the staff group had superior visual acuity compared with the two patient groups, the two patient groups did not differ. Due to differences in variance, these means were also compared using Kruskal–Wallis tests, which were also significant for both eyes: left $\chi^2(2)=13.02$, $p<0.01$; right $\chi^2(2)=9.55$, $p<0.01$.

Correlations between contour task score and left eye and right eye visual acuity revealed trends towards significant relationships [r values (53) left = -0.24 , $p<0.09$, right = -0.26 , $p<0.06$]. Contour task score correlated significantly with education level [$r(57)=0.38$, $p<0.005$], which reflected the typical lower educational level among chronic schizophrenia subjects, who also performed more abnormally on the contour task. Contour task performance was not significantly related to either age ($r(57)=-0.20$, $p>0.13$), or, among patients, length of hospital stay ($r(40)=-0.06$, $p>0.71$).

As expected, due to symptom overlap, the PANSS Cognitive and Disorganization factors were positively and significantly correlated in the sample of schizophrenia patients, $r(21)=0.84$, $p<0.001$. Score on the contour integration task correlated significantly with both the cognitive and

disorganization factors, [$r_s(21)=-0.47$ and -0.48 respectively, p values <0.025], indicating that schizophrenia patients who had poorer contour integration abilities also had higher levels of disorganized symptoms.

4. Discussion

These data are further evidence for a perceptual organization dysfunction in schizophrenia. More specifically, they suggest that schizophrenia patients are impaired in their ability to detect grouping among noncontiguous elements comprising a closed (i.e., circular) contour. The data are consistent with previous data in indicating that schizophrenia patients' perceptual organization abilities break down as the elements to be grouped become either less symmetrical or are spatially separated (Silverstein et al., 1998a,b). In general, these data have been interpreted as indicating reduced top-down influences to perceptual grouping in schizophrenia (Knight and Silverstein, 1998; Silverstein et al., 1996a,b, 1998b). In the present study, however, it is considered unlikely that top-down factors could have played a role in the type of contour integration under investigation. Previous studies of grouping of Gabor elements into contours hypothesized that the grouping process involved long-range spatial interactions between receptive fields (Field et al., 1993). Therefore, our data indicate that bottom-up mechanisms of perceptual grouping may also be impaired in schizophrenia, and that this may reflect an abnormality in the formation of long-range spatial interactions. It is also worth noting that the performance level of the chronic schizophrenia patients in this study is similar to that demonstrated by 5–6 year old children in past research (Kovács et al., 1999). In those cases, performance level was attributed to late maturation of neural connections at a very early level in the ventral stream of visual pathway. While this similarity may simply be a product of independent factors leading to reduced scores in both children and disabled adults (e.g., Chapman and Chapman, 1973), it is also possible that a neurodevelopmental abnormality exists in schizophrenia that is produc-

ing ‘immaturity’ in perceptual grouping abilities. Longitudinal studies examining perceptual organization in children who are at high-risk for schizophrenia would help to clarify this issue.

It is now thought that the formation of long-range spatial interactions involves excitatory, glutamatergic connections between pyramidal cells at NMDA receptors (Phillips and Singer, 1997; Singer, 1995). Since schizophrenia is thought to involve NMDA receptor hypofunction (Olney and Farber, 1995), it is possible that impaired perceptual grouping is one manifestation of this. We are currently testing this hypothesis by determining the effects of an NMDA co-agonist, glycine, on perceptual organization and symptoms in schizophrenia.

It is important to note that, since the evidence for a contour integration deficit in this study comes from the schizophrenia group achieving the lowest scores on the task, these data can also be interpreted as reflecting a generalized deficit (Chapman and Chapman, 1978). That is, it is possible that poor performance among schizophrenia patients reflects, at least in part, other illness-related disabling factors (e.g., negative symptoms such as apathy and poor motivation, sedation due to medication, poor nutrition, chronic understimulation, etc.), as opposed to the hypothesized perceptual organization impairment. It is not possible to distinguish between these competing hypotheses from the current data set. It is the case, however, that the pattern of group differences in task performance (e.g., schizophrenia < psychiatric controls = nonpsychiatric controls) was not demonstrated with the variables age, education level, or visual acuity, making it unlikely that poor performance was due to any of these factors. In addition, it is important to note that a number of demonstrations of perceptual organization dysfunction in schizophrenia have utilized process-oriented research strategies (Knight and Silverstein, 1998) where specific perceptual deficits were identified that could not be accounted for by a generalized deficit interpretation (e.g., Knight, 1992; Knight et al., 1985; Place and Gilmore, 1980; Silverstein et al., 1996a,b, 1998a). Therefore, data from the present study may be seen as consistent with a growing body of research indicating perceptual grouping

impairments in schizophrenia. Nevertheless, future studies of contour integration in schizophrenia could benefit from ruling out a generalized deficit interpretation.

One method of doing so would be to identify situations in which intact contour integration abilities would actually impair task performance among nonschizophrenia participants. Such tasks can lead to findings of ‘relative superiority’ (Knight and Silverstein, 1998) across task conditions among schizophrenia patients, and in some cases, to performance levels that are higher in some conditions, in absolute terms, than controls. This sort of finding was demonstrated by Place and Gilmore (1980) in conditions where schizophrenia patients’ lack of grouping processes allowed them to achieve more accurate numerosity determinations than controls in briefly presented displays of randomly oriented line segments. A number of paradigms have now been developed where contour integration abilities (Kovács and Julesz, 1993), or other perceptual abilities involving long-range interactions between spatial filters (Wolfson and Landy, 1999), are known to facilitate or hinder task performance. Modification of these paradigms for use with schizophrenia patients could prove useful in further testing the hypothesis of an abnormality in the formation of long-range, context-based, neural connections.

A related type of study would be to test whether schizophrenia patients with poor contour integration abilities are less susceptible to visual illusions. Geometric visual illusions are a class of stimuli where one can measure the strength of contextual effects in millimeters. A nice example is the Ebbinghaus size–contrast illusion, where two equivalent disks are surrounded by small versus large disks, and they are perceived to be very different in size by normal adults. A reduced susceptibility compared to normal adults has been found among children (Kovács, 1999; Weintraub, 1979), resulting in a more accurate perception of the stimulus. Presumably, this superior performance is due to poor spatial integration capacities, and therefore reduced contextual effects. The use of such paradigms in schizophrenia research could help provide convergent validity for the hypothesis

of reduced contextual coordination in this disorder.

Data from this study support previous evidence (Knight and Silverstein, 1998; Silverstein and Schenkel, 1997; Silverstein et al., 1998a) of relationships between abnormal perceptual organization and other aspects of disorganization in schizophrenia. This is now our fourth study to demonstrate this effect, with no negative findings obtained to date. Such data support models wherein: (1) perceptual organization impairment is seen as one manifestation of a broader deficit in the coordination of contextually related stimuli (Carr and Wale, 1986; Silverstein and Palumbo, 1995; Silverstein and Schenkel, 1997); (2) perceptual grouping is viewed as a concrete form of context processing (Grossberg et al., 1997; Phillips and Singer, 1997); and (3) sentence comprehension and the production of coherent verbal output are viewed as examples of context processing in the sense that early sentence components establish contextual constraints on the interpretation of later sentence components (in comprehension) or on the choice of words that are subsequently generated to be spoken (Patterson et al., 1986). Other data supporting this view come from studies demonstrating relationships between context processing deficits and disorganized (but not positive, negative, or general) symptoms (Cohen et al., 1999), and between context processing deficits and formal thought disorder (Kuperberg et al., 1997) in schizophrenia. In those studies, the nature of the contexts investigated was relatively abstract (e.g., in a lexical disambiguation task), whereas in the present study, it was concrete and visual. Taken together, these data suggest that there may be commonalities between the way that visual context structures object representations in vision, and the way that meaning serves as a context to structure linguistic and conceptual representations. In addition, these studies suggest that schizophrenia may be characterized by an impairment in the formation of propositional representations across a number of domains of cognitive functioning, and that this impairment may produce analogous impairments in the structuring of perception, memory, thought, and language.

To provide further evidence for this model, clearer a priori examples are needed, across multiple domains, of what is meant by disorganization. These domains can go beyond perception and thought, and include motor functioning as well (Carr and Wale, 1986). Studies that examine the relationships between hypothesized aspects of impaired contextual coordination across levels, and between these phenomena and presumed biological underpinnings (e.g., NMDA receptor hypofunction) have yet to be carried out. Also needed are experimental techniques that bridge multiple levels (e.g., behavioral, cognitive, biological). The use of, or natural observation of the effects of, chemical agents that should theoretically increase (e.g., glycine) or decrease (e.g., ketamine, PCP) contextual coordination in clinical and nonclinical populations, and observation of the covariance of sequelae at multiple levels would assist in testing the hypothesis of an impairment in a common cortical processing algorithm in schizophrenia.

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