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# Reduced top-down influences in contour detection in schizophrenia

Steven M. Silverstein, Michi Hatashita-Wong, Lindsay S. Schenkel and Sandra Wilkniss

*Weill Medical College of Cornell University, White Plains, NY, USA*

Ilona Kovács and Akos Fehér

*Laboratory of Vision Research, Rutgers University, NJ, USA*

Thomas Smith, Claudia Goicochea, Peter Uhlhaas, Kelly Carpiniello, and Adam Savitz

*Weill Medical College of Cornell University, White Plains, NY, USA*

*Introduction*. Chronic schizophrenia patients have previously demonstrated performance deficits in contour integration tasks. The purpose of this study was to investigate whether schizophrenia patients, spanning a range of illness severity, would demonstrate responsiveness to manipulations that recruit top-down processing strategies involving learning and sequencing effects in a contour integration task.

*Methods*. We administered a contour integration test over four consecutive days and in two different presentation conditions each day. In one condition, the stimuli were administered in order of increasing difficulty, and in the other they were presented in random order. The order in which these two conditions were presented was counterbalanced across days and participants. In addition, a nonschizophrenia psychotic disorders control group was included to determine if past findings of a contour integration deficit in schizophrenia could be replicated in the presence of a symptomatically similar control group.

*Results*. All groups demonstrated similar learning curves across the four days and generally similar overall levels of performance, with the exception of the group of the most chronic schizophrenia patients. In addition, the order in which the stimuli were presented to subjects affected their performance, with higher scores achieved

Correspondence should be addressed to Steven Silverstein, who is now at The Center for Cognitive Medicine, Department of Psychiatry, University of Illinois at Chicago, 912 South Wood Street, Chicago, IL, 60612, USA; e-mail: Steven.Silverstein@att.net

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for all groups in the condition where the stimuli were presented in increasing order of difficulty. Interaction effects revealed that the effects of order presentation were greater for nonpatient than for psychotic patients.
*Conclusions*. These data are further evidence that perceptual organization impairments in schizophrenia are illness severity-related, and that schizophrenia patients as a whole are less sensitive to top-down manipulations in this type of task.

Perceptual organisation has been studied extensively in the area of form perception, where it has been related to long-range excitatory interactions between orientation-tuned spatial channels in layer 2/3 in primary visual cortex (Grossberg & Raizada, 2000). The dynamic grouping that occurs between orientation filters whose outputs are correlated is thought to occur via synchronisation of firing rates within the gamma band (Phillips & Singer, 1997; Singer & Gray, 1995; Watt & Phillips, 2000; Yen & Finkel, 1998). This leads to the bound group of elements being processed as a single group at higher stages of processing.

We and others have studied the integration of orientation information using a contour integration paradigm (e.g., Braun, 1999; Field, Hayes, & Hess, 1993; Kovács, 1996; Kovács & Julesz, 1993; Kozma-Wiebe et al., in press; Pennefather, Chandna, Kovács, Polaf, & Norcia, 1999; Silverstein, Kovács, Corry, & Valone, 2000; Kovács, Kozma, Fehér, & Benedek, 1999). The local rules of neural interactions governing our ability to link contour segments together have been determined by employing stimuli with a continuous path of Gabor signals embedded in noise (see Figure 1). Gabor signals roughly model the receptive field properties of orientation selective simple cells in V1. They are thus appropriate stimuli for the examination of these small spatial filters and their interactions. The embedded contours cannot be detected purely by local filters, or by the known types of orientation tuned neurons with large receptive fields. The long-range orientation correlations along the path of the contour can only be detected by the integration of local elements. Thus, with these stimuli, long-range interactions subserving spatial integration can be studied in isolation.

Several past studies have demonstrated a perceptual organisation deficit in patients with schizophrenia (Cox & Leventhal, 1978; Izawa & Yamamoto, 2002; Knight, 1992; Place & Gilmore, 1980; Rabinowicz et al., 1996; Silverstein et al., 1996a; Silverstein, Bakshi, Chapman, & Nowlis, 1998a), including studies employing the contour integration paradigm (Kozma-Wiebe et al., in press; Silverstein et al., 2000). The potential relevance of this deficit is that it may be a low level manifestation of a general disturbance in organising cognitive representations. There is now both neurobiological and computational evidence for a cortical processing algorithm that binds information (e.g., visual features, ideas) that is predictably related to the context in which it occurs (e.g., correlated visual features, conceptually related ideas) (reviewed in Phillips & Singer, 1997). This algorithm is thought to operate across cognitive domains and to normally

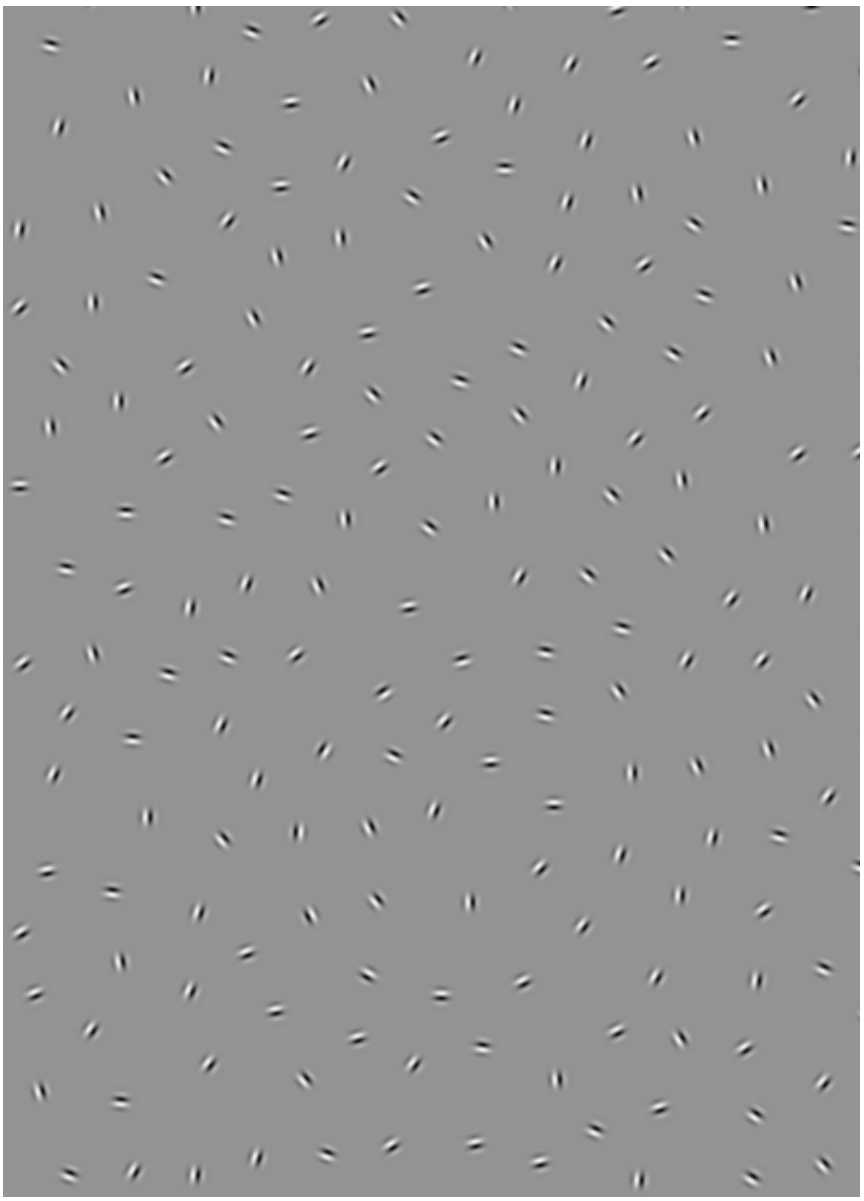

**Figure 1.** Example of a test card. A closed path of Gabor signals is embedded in noise. The observer is asked to locate the position of the contour. The ratio of element spacing in the noise background to spacing along the contour ($D$) is 1.0 in this example.

support diverse forms of context processing including perceptual organisation, lexical disambiguation (and coherent thought), and selective attention. Evidence that there is an impairment in this algorithm in schizophrenia comes from consistent demonstrations that perceptual organisation deficits are significantly correlated with thought disorganisation in this illness (reviewed in Knight & Silverstein, 1998 and Phillips & Silverstein, 2003).

An unanswered question in the perceptual organisation in schizophrenia literature is the extent to which these impairments reflect abnormalities in bottom-up (i.e., stimulus driven) versus top-down processes. Evidence for reduced top-down effects in perceptual organisation in schizophrenia comes from three studies. One, however, was an auditory perceptual organisation task (Silverstein, Matteson, & Knight, 1996b) where the effect could also have been due to a set-switching (i.e., executive) dysfunction. In the other two studies (Silverstein et al., 1998a; Silverstein, Bakshi, Nuernberger, Carpinello, & Wilkniss, 2005), the effect was in the form of reduced perceptual learning (i.e., reduced benefit from repeated exposure) for nonconfigural patterns. Schizophrenia patients' difficulties with verbal and nonverbal memory are well known (Silverstein, Osborn, & Palumbo, 1998b, Heinrichs, 2001), and so it is difficult in these studies to tease apart effects due to problems in developing, storing or recalling memory representations versus using memory representations to organise the stimuli. Therefore, more focused investigations of top-down effects in perceptual organisation in schizophrenia are needed. In this study, we used the contour integration paradigm, where bottom-up (stimulus-driven) factors are considered sufficient to process the stimuli, although the extent to which performance on the task can be affected by top-down factors is relatively unknown (see below). Three types of top-down effects were then investigated (see below, and Methods).

Evidence that activity within primary visual cortex is sufficient for integration of features in the contour integration paradigm comes from Giersch, Humphreys, Boucart, & Kovács (2000), who found normal contour integration performance in a visual agnosic patient with intact V1 but severely damaged occipital areas beyond V1. These data suggest that schizophrenia patients' contour integration difficulties reflect bottom-up stimulus assembly processes. On the other hand, the extent to which top-down influences can affect contour integration performance is relatively unknown. Attentional and perceptual learning effects have been found in studies of lateral interactions between targets and flankers (Gilbert, Ito, Kapadia, & Westheimer, 2000), raising the possibility that top-down factors could operate during contour integration as well, since both tasks are thought to involve long-range interactions between feature detectors.

To date, the only direct evidence of top-down effects on contour integration comes from a study of the effects of repeated exposure on contour integration performance. Pennefather et al. (1999) reported small amounts of change over

repeated testings. However, in that study, all testings were conducted on the same day. It is known that perceptual learning increases when periods of REM sleep occur between testing sessions (Karni, Tanne, Rubenstein, Askenasy, & Sagi, 1994). Therefore, estimates of learning within a single day may underestimate potential learning effects.

In this study, we explored the sensitivity of schizophrenia and control subjects to top-down effects in the contour integration paradigm by having subjects take the test on four consecutive days and examining learning effects. To further investigate top-down effects, the stimulus set was presented twice each day, once in order of increasing difficulty and once in a random order. Effects of presentation order are unlikely to be due to effects that operate solely within V1 as the stimuli in each condition are the same. Any such effects are therefore likely to involve feedback from higher cognitive processes. In addition, the order in which participants were administered the two conditions each day was counterbalanced across people and across days (see below, Methods). This allowed for a determination of the degree to which, within a single session, receiving the sequentially ordered deck prior to the random deck, or vice versa, would contribute to performance relative to any practice effects that might be observed across two administrations of the same stimuli. The counterbalancing also allowed for a determination of whether differences in condition presentation order affected performance across multiple days.

The main hypothesis guiding this study was that schizophrenia patients would demonstrate reduced top-down effects, as indicated by less of a learning effect and a relative insensitivity to the sequence and condition order manipulations, compared to the nonpatient control group. As noted below (next paragraph), we also included a group of schizoaffective disorder patients in this study. This was done to determine if effects observed in the schizophrenia group are specific to that group. While some previous studies of perceptual organisation in schizophrenia have included a control group of patients with other psychotic disorders (e.g., Knight, 1984; Silverstein et al., 1996a), these studies included a combination of diagnoses in that group, some of which (e.g., schizoaffective disorder) shared more similarities to schizophrenia than others (e.g., depression with psychotic features, bipolar disorder with psychotic features). The inclusion of a homogeneous group of schizoaffective disorder patients in this study will thus allow for the first test of whether patients with this diagnosis demonstrate difficulties in perceptual organisation similar to those found in schizophrenia.

## METHOD

### Participants

Three groups participated in the study: (1) 38 schizophrenia patients (31 male) recruited from either a specialised long-term unit for treatment-refractory patients (Silverstein, Wong, & Bloch, 2002) ($n$ = 16), a short-stay unit for

patients experiencing acute exacerbations of illness ($n$ = 12), or a continuing day treatment programme ($n$ = 10); (2) 32 schizoaffective disorder patients (24 male) taken from the same three programmes and included as a control for the presence of psychotic symptoms ($n$ = 10 treatment refractory, $n$ = 10 short-stay acute, and $n$ = 11 continuing day treatment); and (3) 17 nonpatient participants (9 male). All patients from the long-stay programme had been transferred from state hospitals due to treatment nonresponse, and had lengths of stay during the current admission (including state hospital stay) of at least three years. Patients on the short-term unit were tested after medication stabilisation. Day treatment patients who had been out of the hospital for at least six months were considered for inclusion. For all participants, a history of vision disorders, closed head injury, mental retardation, and neurologic syndromes (e.g., epilepsy, cerebral palsy) were exclusion criteria. All patient participants had had ophthalmologic examinations within the past year and were documented as having normal or corrected-to-normal vision.

Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) (American Psychiatric Association, 1994) diagnoses of schizophrenia or schizoaffective disorder for treatment-refractory patients were established using a four-step process. First, diagnoses were made by treating therapists on admission. Second, these diagnoses were reviewed and confirmed or modified by the Chief Psychiatrist, who is the seventh or eleventh author and a member of the research group. Third, members of the research group who did not work on the long-term unit reviewed each patient's chart to confirm or modify the research diagnosis. Finally, the first author, who was Program Director for the long-term unit, reviewed the diagnosis given to each patient at each step. Patients were considered eligible for the study only if the last three steps produced the same diagnosis. Diagnoses for patients from the short-term unit and continuing day treatment programmes were established using the first three of the four procedures described above. In addition, all of these patients had been treated at the hospital for at least three years (with the majority of the time spent in day treatment) and most had participated in prior research studies where Structured Clinical Interviews for DSM-IV Axis I Disorders (SCID-I/P Version 2.0) (First, Spitzer, Gibbon, & Williams, 1995) had been completed by this research group some time during the past 2–3 years. All of this information was used to determine study diagnoses for these patients.

All study patients were taking antipsychotic medication at doses considered stable and therapeutic by their treating physicians. Nearly all patients were taking either clozapine or olanzapine as their primary antipsychotic medication, and the majority were taking additional antipsychotic and other (e.g., mood stabiliser, anxiolytic, etc.) medications. Prior studies have demonstrated that antipsychotic medication has little effect on perceptual organisation in psychotic patients (e.g., Knight, 1992; Knight & Silverstein, 1998), including on tasks known to be mediated by activity in V1-V2 (Spencer et al., 2003). Moreover, it

is unlikely that the complex pattern of results observed in this study (see below) could be accounted for by medication effects. Nonpatient participants, who were hospital staff and/or acquaintances of members of the research team, were not screened for psychopathology.

## Stimuli

Each stimulus set consisted of 15 cards which contained varying numbers of Gabor elements against a uniform grey 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 (Field et al., 1993; Kovács, 2000). 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 Figures 1 and 2). The Gabor carrier spatial frequency was 5 cycles per degree and contrast was approximately 95%.

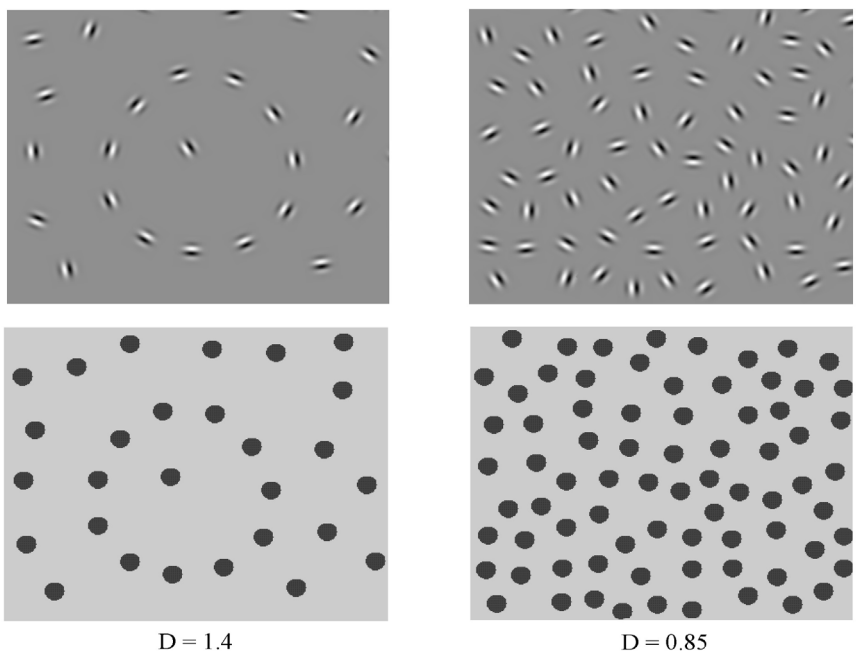


**Figure 2.** Examples of Gabor-defined contours with different $D$ values (left: $D = 1.4$, right: $D = 0.85$.). In the bottom panels, Gabor elements were replaced by discs. Without orientation cues, the contour remains invisible at $D < 1$, and this is the range where perceptual organisation depends on long-range, horizontal, excitatory interactions between feature detectors.

The Gabor arrays with the embedded contours were generated on a Silicon Graphics Iris Indigo R 4000 computer, and printed on a 1200 dpi printer. The position and orientation of the Gabor elements within the arrays were computed with a Monte Carlo technique adapted from molecular dynamics (Braun, 1999). This technique allows for precise control over the spacing parameters, creating the smallest permitted separations between background elements while avoiding spurious spacings. Since Pettet, McKee, and Grzywacz (1998) demonstrated that contour smoothness is an important constraint on contour visibility, we limited the orientation variation along the contour so that all contours had continuously positive curvature with no inflection points. All contours had the same general size and shape, and therefore all differences in detectability were related to changes in background noise density, rather than to changes in contour salience.

Spacing along the contour, and the spacing among the background elements were controlled independently. A graded series of 15 cards was produced by varying the average spacing between the background elements while holding the spacing between elements of the closed contour at eight 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 1.2 to 0.50 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 the basis of long-range correlations between elements (see Figures 1 and 2). 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 degrees. A 10 card series of contour stimuli has demonstrated good test-retest reliability in prior studies (Kovács, Polat, Pennefather, Chandna, & Norcia, 2000; Pennefather et al., 1999). The card set was developed, and has been used previously, to detect perceptual grouping impairments in amblyopia (Kovács et al., 2000; Pennefather et al., 1999), 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 presentations of the same stimuli (Kovács, unpublished data). The ten card series was used in the Silverstein et al. (2000) study that demonstrated a contour integration deficit in schizophrenia. The stimulus set used in the present study was an expanded set, and included two cards at easier *D* levels than in the prior study (1.2 and 1.15) and three cards at more difficult levels (0.60, 0.55, 0.50).

## Test administration

Cards were presented binocularly from a distance of one metre on a flat table-top. The participants were allowed to scan the cards for up to 30 seconds, until they were able to make a decision about the location of the contour. The contour was either positioned in the centre, shifted to the left, or shifted to the right within the rectangular arrays. The participants' task was to identify the contour by pointing to its location on the card and then tracing the outline with an index finger. Each correct localisation and tracing was considered one correct response, leading to a maximum score of 15, or *D*-value of 0.50. Contour detection threshold was defined as the *D*-value corresponding to the number of correct contour identifications. In almost all cases, this value was equal to the *D*-value of the most difficult stimulus where a correct response was given. That is, it was rare for a participant to correctly detect a contour at a *D*-value lower than on another stimulus card where they were not able to correctly perceive the contour.

Half of the subjects in each group were administered the sequentially ordered deck first on Days 1 and 3 and the randomly ordered deck first on Days 2 and 4 (order SR RS SR RS), and the other half received the randomly ordered deck first on Days 1 and 3 and the sequentially ordered deck first on Days 2 and 4 (order RS SR RS SR). Condition presentation order was alternated between participants in each group as they were entered into the study.

## Data analyses

All between-condition analyses (e.g., examining participant groups, days, card sets, presentation order, etc.) were conducted using BMDP 5V (Dixon & Merdian, 1992). This program uses a maximum-likelihood approach to analyses of variance, and results are reported in terms of Wald-type chi-square statistics. An advantage of using this program for repeated measures analyses is that Akaike's Information Criterion (AIC; Akaike, 1973) can be calculated for each type of covariance structure, and the best fitting model can be used in the final analyses. For the repeated measures analyses in this study, the AICs indicated that a banded, or general autoregressive covariance structure best fit the data, and therefore this was specified for all these analyses. For single-degree of freedom contrasts (Rosenthal & Rosnow, 1985) and most post hoc analyses of interaction effects, BMDP 2V (Dixon, 1992) was used.

In the following discussion of the data analyses, the following names will be used for each factor: *diagnosis* (nonpatient vs. schizophrenia vs. schizoaffective disorder), *unit* (chronic vs. short-term acute vs. outpatient), *day* (1-4), *deck* (sequentially presented stimuli vs. randomly presented stimuli), and *order* (SR RS SR RS vs. RS SR RS SR).

## RESULTS

*Demographic data*. The three diagnostic groups did not differ in age: schizophrenia = 36.53 (8.44), schizoaffective = 37.47 (8.58), nonpatient = 40.29 (9.30), $F(2, 84) = 1.18$, $p > .31$. The groups differed in education level, $F(2, 84) = 13.74$, $p < .0001$. Post hoc analyses indicated that the nonpatient group had more years of education (14.06) than either the schizophrenia (11.58) or schizoaffective disorder (12.00) groups, who did not differ from each other. Because main and interaction effects involving the factor of ''diagnosis'' were generally not significant (see below), however, education was not used as a covariate in the analyses of the contour integration data. In addition, because reduced years of education is often a direct result of the early onset of illness in psychotic disorders, matching groups on education, or controlling for it statistically, leads to nonrepresentative samples of psychotic patients (Meehl, 1971). To determine if education was related to performance, however, correlations were computed between education level and several performance indices. Since most of the significant top-down effects reported below occurred across Days 1 and 2, correlations with overall performance (collapsed across all other conditions) were calculated for these days only. Nonsignificant effects were observed on both Day 1 ($r = -.04$, $p = .69$) and Day 2 ($r = -.03$, $p = .79$). Also, as the largest effect of condition presentation order (i.e., which deck was given first) was observed on Day 1 (see below), correlations were calculated between education level and the difference between performance on the random and sequential decks on Day 1. Because the magnitude of the condition presentation order effect was a function of which deck was experienced first, correlations were calculated separately for the two condition orders. For subjects who received the random deck first on Day 1, the correlation was nonsignificant ($r = .01$, $p = .93$). For subjects who received the sequential deck first on Day 1, the correlation was also nonsignificant ($r = .04$, $p = .81$). Taken together, these data indicate that education level was not a significant determinant of either overall performance or the primary top-down effect investigated in this study.

Patients in this study could be characterised in terms of two factors, diagnosis, and treatment unit (or severity of illness). Whereas each patient could be assigned to one of six cells based on this distinction (2 diagnoses $\times$ 3 units), nonpatient subjects formed a single group. Therefore, it was not possible to conduct a full analysis of unit $\times$ diagnosis $\times$ day $\times$ card set for the full sample. Instead, one set of analyses, using all participants, was conducted using the diagnosis variable, and then subsequent analyses, also using all participants, were done using the unit variable. A preliminary analysis, including patients only, indicated that the diagnosis by treatment unit interaction term was not significant: $\chi^2(2) = 1.15$, $p = .56$, and no three-way interaction term involving both diagnosis and unit was significant.

*Interaction, main, and simple effects involving condition presentation order*. The four-way interactions involving order (RS SR RS SR vs. SR RS SR RS) × diagnosis × day × deck (sequential vs. random), and order × unit × day × deck were not significant: $\chi^2(6) = 2.49$, $p = .87$, and $\chi^2(9) = 2.94$, $p = .96$, respectively. In addition, the main effect of order on overall performance (collapsed across days and decks) was not significant: $\chi^2(1) = 0.17$, $p = .68$. There were three three-way interactions with the order factor that were significant, however. First, there was a significant order × day × deck interaction: $\chi^2(3) = 14.73$, $p < .005$. Post hoc analyses indicated that the two-way order by deck interaction effect was significant for Days 1, $F(1, 91) = 4.22$, $p < .05$, and 2, $F(1, 89) = 6.57$, $p < .05$, but not for Days 3, $F(1, 85) = 1.28$, $p = .26$, and 4, $F(1, 83) = 2.04$, $p = .16$.

*Overall effects of condition presentation order*. Simple effects tests of the two significant two-way interactions revealed that on Day 1, the group that received the random deck first and the sequential deck second (i.e., RS SR RS SR) performed much better in the sequential condition compared to the random condition, $t(40) = -3.13$, $p < .005$. In contrast, the group that received the sequential deck first and the random deck second (i.e., SR RS SR RS) performed similarly in the two conditions $t(43) = -0.32$, $p = .75$. On Day 2, the group that received the random deck first (and who had received the sequential deck first on Day 1, i.e., SR RS SR RS) performed significantly better on the sequential deck, $t(43) = -2.04$, $p < .05$. In contrast, the group that received the sequential deck first on Day 2 (and who had received the random deck first on Day 1, i.e., RS SR RS SR) performed similarly on both decks, similar to the group that received the sequential deck first on Day 1, $t(40) = -1.75$, $p < .09$. The differences in the patterns across the two days cannot be accounted for by differences in overall levels of performance, as the two order groups did not differ in their performance, collapsed across decks, on either Days 1 and 2 ($p$ values for these post hoc comparisons were .73 and .43, respectively). Examination of the above effects suggests the following explanation: On Day 1, participants who received the random deck first demonstrated below-potential contour integration performance, but then performed better when they subsequently received the next set of stimuli in sequential order. However, patients who first received the sequential deck suffered no performance change when they next received the random deck. On Day 2, the same effects obtained, even though both groups had demonstrated the reverse effect on the prior day (i.e., participants who received the order RS on Day 2 performed better on the sequential deck even though they had not demonstrated a difference between the two decks the day before when receiving them in the opposite order, and participants who received the order SR on Day 2 performed similarly on both decks even though they had performed better on the sequential deck when receiving that after the random deck the day before). This pattern suggests a strong effect

of condition ordering, and one that overrode any potential within-session practice effects. By Days 3 and 4, it appears as if there had been enough exposure to the stimuli to eliminate any ordering effects.

*Group differences in the condition order effect*. The three way interactions of order × diagnosis × day, and order × unit × day were both significant: $\chi^2(6) = 22.80$, $p < .001$, and $\chi^2(9) = 21.50$, $p < .05$, respectively. Post hoc analyses of the order × diagnosis × day effect examined the order × day effect separately for each diagnostic group (see Figure 3). For both the schizophrenia group, $F(3, 105) = 1.46$, $p < .23$, and the schizoaffective group, $F(3, 87) = 2.26$, $p < .09$, the two-way interaction was not significant. In contrast, for the nonpatient group, the two-way interaction was significant, $F(3, 45) = 5.95$, $p < .005$. Post hoc analyses of the nonpatient group data indicated that the interaction of order with the Day 1 versus Day 2 contrast was significant, $F(1, 15) = 6.14$, $p < .05$. The interaction of order with the Day 2 versus Day 3 contrast was not significant, $F(1, 15) = 0.35$, $p = .56$. The interaction of day order with the Day 3 versus Day 4 contrast was not significant, $F(1, 15) = 3.68$, $p < .08$. This suggests that the three-way interaction of order × diagnosis × day was mainly a function of the sensitivity of the nonpatient group to the changing of the condition presentation order, and the difference in this effect, among nonpatients, between Days 1 and 2. The two patient groups were relatively insensitive to the relative ordering of the presentation conditions, confirming one of this study's hypotheses.

A similar set of findings was observed with the three way interaction of order × treatment unit × day. Post hoc analyses examined the order × day effect separately for each treatment unit (all collapsing across schizophrenia and schizoaffective disorder). For the chronic psychotic patients, $F(3, 72) = 0.18$, $p = .91$, the acutely psychotic patients, $F(3, 60) = 2.15$, $p = .10$, and the outpatients, $F(3, 54) = 0.65$, $p = .59$, the two-way interaction was not significant. The nonpatient group results are described in the paragraph above. The three-way interactions of order × diagnosis × deck, and order × unit × deck were not significant: $\chi^2(2) = 0.49$, $p = .78$, and $\chi^2(3) = 1.49$, $p = .68$, respectively, and no other interactions involving the day order variable were significant. Thus, the patient groups were insensitive to the order presentation manipulation, whether divided by diagnosis (and collapsed across acuity level) or by acuity level (collapsed across psychotic diagnoses).

*Effects involving change over time (i.e., effect of Day)*. A diagnosis × day × deck ANOVA revealed significant effects of day: $\chi^2(3) = 34.94$, $p < .0001$, and deck: $\chi^2(1) = 5.19$, $p < .05$, indicating that performance changed over the four-day period, and differed between the sequential and random presentation conditions (i.e., between decks). As can be seen in Figure 4, performance generally improved over the four-day period, and was superior in the sequential

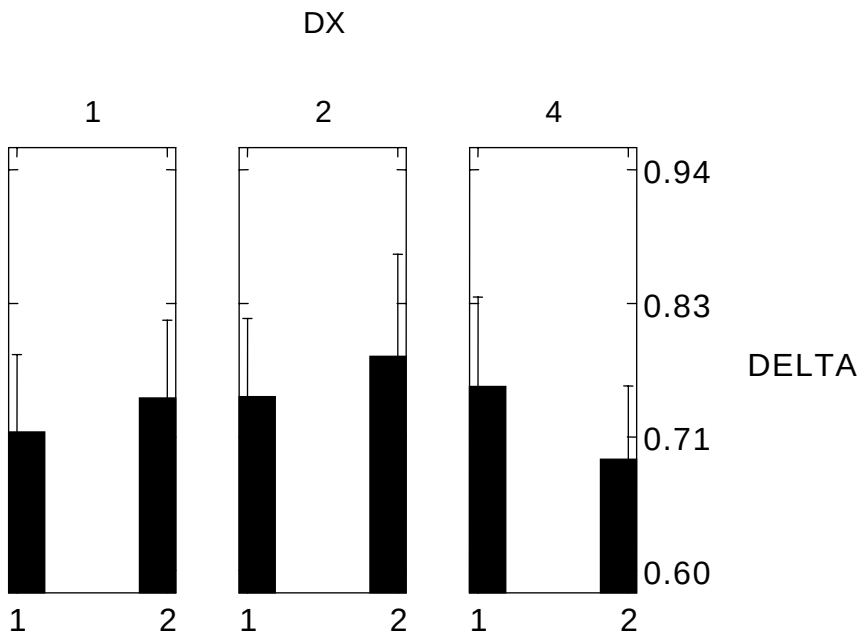


**Figure 3.** The order × group interaction on Day 1. This graph demonstrates that for nonpatient controls, but not for patient groups, subjects who received the stimuli in a random order first (and the sequential order second) performed better than subjects who received the sequential order first (and the random order second). Specifically, among nonpatients (*D*x = 4), the random-sequential group (Condition 2 on *x*-axis) had a lower detection threshold (indicating superior performance) than the sequential-random group (Condition 1 on the *x*-axis). Note that this same effect was observed on Day 2 (graph not shown), even though the group that received the random-sequential order on that day had received the opposite order on Day 1 (and showed no performance difference between conditions), and that the group that received the sequential-random order on Day 2 (and showed no performance difference) was the group that had shown the performance difference when they received the random-sequential order on Day 1. Thus, the order effect overrode a practice effect. Among the schizophrenia (*D*x = 1) and schizoaffective (*D*x = 2) groups, there was no difference between condition orders on the first two days, indicating a lack of benefit from beginning with an unstructured stimulus sequence and moving to a predictable sequence (thresholds for these two groups were actually nonsignificantly lower in the sequential-random order condition). On Days 3–4, there were no longer condition order effects for any group. Error bars reflect standard deviations.

presentation condition compared to the random condition. The effect of diagnosis was not significant: $\chi^2(2) = 3.50$, $p > .17$, indicating that the two patient groups and the nonpatient group performed similarly. The two-way interaction effects of diagnosis by day: $\chi^2(6) = 10.24$, $p>.11$, diagnosis by deck $\chi^2(2) = 5.50$, $p < .07$, and day by deck, $\chi^2(3) = 5.95$, $p > .11$, were not significant. The trend indicated in the diagnosis by deck interaction term was due to the schizoaffective disorder group having a larger difference between decks than the

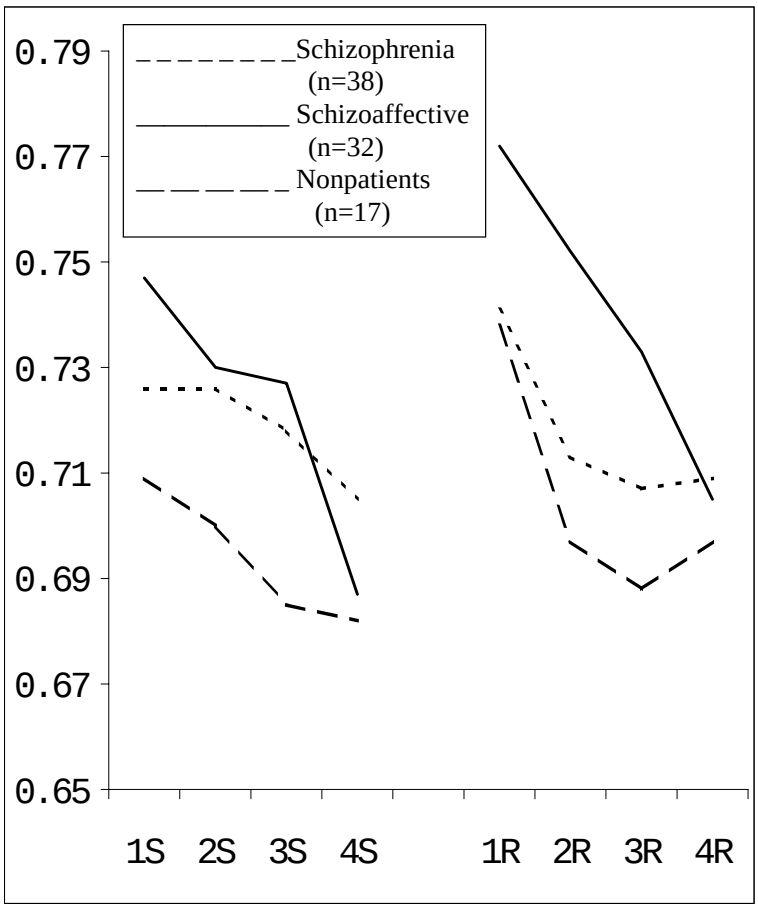


**Figure 4.** Performance across the four days (1–4) in the Sequential (S) and Random (R) presentation conditions for each group.

other two groups. The three-way interaction of group × day × deck was also not significant: $\chi^2(6) = 2.66$, $p > .85$. Because the groups did not differ overall and none of the interaction terms involving group were statistically significant, the groups were combined for further analyses probing the day and deck effects. The only exceptions to this are where a priori reasons led to the nonpatient and patient groups being examined separately (e.g., to examine replication of a previously demonstrated effect among nonpatients, see below).

The unit × day × deck analysis revealed a trend towards a significant effect of unit: $\chi^2(3) = 7.47$, $p < .06$. Estimates of the regression parameters indicated

that only Unit 1 (chronic, long-hospital-stay patients) performed significantly worse than the overall mean ($z = -2.18$, $p < .05$).

Exploration of the significant day effect was explored with contrasts that compared each day with the following day. The Day 1 versus Day 2 contrast was significant, $F(1, 84) = 8.41$, $p < .005$. The Day 2 versus Day 3 contrast approached significance, $F(1, 84) = 3.13$, $p < .08$, and the Day 3 versus Day 4 was significant, $F(1, 84) = 7.05$, $p < .01$. These data indicated that performance continued to improve throughout the four testing days. In order to compare these learning effects against our prior data with nonpatients, the effects were examined separately for the nonpatient and combined patient groups. For the patient group, the Day 1 versus Day 2 and Day 3 versus Day 4 contrasts were significant ($p$s $< .5$ and .005, respectively), whereas the Day 2 versus Day 3 contrast was not ($p > .15$). For the nonpatients, only the Day 1 versus Day 2 contrast was significant ($p < .05$), whereas the Day 2 versus Day 3 and Day 3 versus Day 4 contrasts were not ($p$s of .30 and .80, respectively).

*Effects of deck (sequential vs. random presentation).* As noted above, the diagnosis × day × deck ANOVA revealed a significant effect of deck. Exploration of the deck effect indicated that, overall, the sequentially ordered deck was associated with superior performance compared to the random deck. While the day by deck interaction term was not significant, it is interesting to note that the only day on which the two decks differed significantly from each other was Day 1, $F(1, 84) = 6.72$, $p < .05$. Days 2–4 results were $F(1, 84) = 0.23$, $p > .60$, $F(1, 84) = 0.01$, $p > .90$, and $F(1, 84) = 2.86$, $p > .09$, respectively.

## CONCLUSIONS

There were four main findings from this study. First, contour integration, a basic function of the visual system and one that is thought to be carried out in primary visual cortex, improved with practice over a four-day period. Second, the order in which the stimuli were presented to subjects affected their performance, with higher scores achieved in the condition where the stimuli were presented in increasing order of difficulty compared to when they were presented in a random order. Third, further top-down effects were observed in that performance, during the first two days, was a function of the order that the two conditions were presented to the participants. These effects were most pronounced for non-patients, whereas patients, whether classified by treatment unit or diagnosis, were relatively insensitive to the condition ordering manipulation. Fourth, a schizophrenia-related deficit in overall contour integration performance that was observed in two prior studies was not replicated. Each of these findings will be briefly considered below, beginning with the top-down effects in nonpatients, which set the context from within which the patient data must be understood. By ''top-down'' effects, we are referring to effects of practice/learning, stimulus

sequencing, and condition ordering. These are unlikely to be stimulus driven, and were therefore considered top-down effects within the framework of this study.

Our data on performance improvement over four days is consistent with the findings of Pennefather et al. (1999), who found improvement of $D = .053$ across four testings. We observed changes in $D$ of .027 and .041 in the nonpatient group, and of .039 and .048 in the combined patient group in the sequential and random presentation conditions respectively. These levels of improvement are slightly lower than that found by Pennefather et al. (1999), and are lower than might have been expected given that subjects in the present study had one night of sleep between each testing (unlike in the Pennefather et al. study). It is possible, however, that exposure to two testings on the initial day (one from each of the sequential and random conditions), using 30 stimuli in all, led to a smaller practice or learning effect across presentation episodes than is found when fewer stimuli are used at each testing (as in Pennefather et al., 1999).

Top-down effects were also observed in the performance superiority in the sequential presentation condition compared to the random condition. At the most self-evident level, this indicates that viewing the stimuli in increasing order of difficulty leads to superior performance compared to when they are viewed in random order. This effect has not been reported before in studies of contour integration and is further evidence of factors from outside area V1 influencing performance. An open question is whether it is the sequencing per se that leads to improvement, as opposed to having more prior experience with contour perception in the sequential deck (by virtue of the number of contours that would be perceived prior to any failure) compared to the random deck. Data indicating that prior experience reduced recognition threshold for disoriented pictures of familiar objects (Lawson & Jolicoeur, 1999) suggests that prior exposure to (perceived) contours could have an equal or greater effect than the sequencing per se. Our finding that the difference between the two conditions was significant only on Day 1 is also consistent with this, suggesting that after Day 1, participants already had enough exposure to eliminate the between condition difference, even in the presence of continually improving performance across the four days overall (in both conditions).

It is also possible that a motivational effect could account for the initial superiority in the sequential condition. Subjects may have exerted more effort in the sequential condition due to their early success in the task and the perception that they were competent at it. In contrast, in the random condition, a proportion of subjects would have experienced several failures early in the task, possibly leading to a reduced sense of perceived competence and motivation, and lowered task performance. This issue could be investigated further by evaluating subjects' subjective evaluation of their competence in the task prior to each trial in both conditions, as well as assessing confidence in their judgements after each trial. It is important to note that since psychotic disorder patients demonstrated

the same overall superiority in the sequential compared to the random condition as controls, expectancy, and motivational factors can be assumed to have been equivalent across the three groups.

The effects of the variable ''order'' revealed a complex pattern. On Days 1 and 2, receiving the sequentially ordered deck after the randomly ordered deck led to significant performance increases. In contrast, receiving the random condition second did not lead to performance changes. It appears as if receiving the random deck first within a session led to suboptimal performance which could be enhanced by increased exposure to the stimuli in increasing order of difficulty, whereas initial experience with the stimuli in sequential order ''inoculated'' participants from any negative effects of a random order. By the third and fourth days, however, it appears that participants had had enough experience with the stimuli that condition ordering effects did not affect performance. It is notable that this ordering effect was only significant for the nonpatient group. The absence of an effect of condition ordering in the patient groups is, however, consistent with a growing literature on task context processing impairments in people with psychotic disorders (reviewed in Phillips & Silverstein, 2003).

A surprising finding from this study was the nonreplication of the schizophrenia-related overall performance deficit that was observed in two of our prior studies of contour integration (Kozma-Wiebe et al., in press; Silverstein et al., 2000). Methodological differences between the three studies could account for this discrepancy. In the Silverstein et al. (2000) study, a 10-card stimulus set was used and there was only a single testing session. This raises the possibility that the use of two larger stimulus sets during each day is responsible for the reduced group effect in the present study. That is, it may be that the impairment among schizophrenia patients is only evident during the initial trials. It is also possible that in the Kozma-Wiebe et al. (in press) study, the use of a two second exposure and forced-choice procedure placed greater processing demands on subjects, producing a more sensitive test, and revealing a group difference that was not apparent in this study, which used a 30 second exposure duration without a forced-choice procedure.

Another possibility is that the results of the prior two studies were due more to the chronic nature of the patient population than to schizophrenia per se (i.e., to having a chronic form of schizophrenia rather than simply having schizophrenia). The schizophrenia subjects in the Silverstein et al. (2000) and Kozma-Wiebe (in press) studies, where group effects were found, were all chronic schizophrenia inpatients who had spent years in the hospital. In this study, in contrast, most of the patients did not have chronic courses, and many were living outside of a hospital. Within our sample, however, there was a trend for the effect of treatment unit ($p < .06$) on overall performance level, and inspection of the regression parameters indicated that only the chronic inpatient group (collapsed across schizophrenia and schizoaffective diagnoses) differed significantly

from the sample mean. Further support for the idea that perceptual organisation deficits develop over time comes from recent evidence indicating that they may not be apparent early in the course of the illness, but become more pronounced during chronic courses associated with severe disability (Parnas et al., 2001), and other studies from our group found that a perceptual organisation deficit is associated with a more severe form of schizophrenia (Knight & Silverstein, 1998; Phillips & Silverstein, 2003; Silverstein et al., 1996a, 1998a, 2000). It should be noted here that the association of perceptual organisation impairments with chronic schizophrenia is not due to a generalised performance deficit, because in a number of those studies, chronic or more severely ill patients actually performed better than other groups in conditions where intact grouping would hinder task performance (Knight & Silverstein, 2001; Silverstein et al., 1996a; Uhlhaas, 2003). It is possible, however, that the chronicity effect is mediated by level of disorganised symptoms. This is because several prior studies have indicated relationships between disorganisation and reduced perceptual organisation and top-down processing (reviewed in Knight & Silverstein, 1998, and Phillips & Silverstein, 2003), and disorganisation levels are associated with greater functional impairment and poorer community functioning (Norman et al., 1999), poorer response to medication (Rodriguez, Catalina, Garcia-Noblejas, & Cuesta, 1998), early illness onset and longer duration of illness (Salokangas, Honkonen, Stengard, & Koivisto, 2002), and long-term inpatient status (Silverstein, Wallace, & Schenkel, in press). In short, our nonreplication of the overall performance effect may have been due to including a more heterogeneous group of schizophrenia patients than in past studies, including a larger group of higher functioning patients. Future studies that examine subgroups specifically can determine whether there is a subgroup of schizophrenia patient that is impaired in single trial performance or perceptual learning with contour integration or related paradigms.

A final issue involves the similar performance between the schizophrenia and schizoaffective disorder groups. While prior studies have identified reduced top-down influences to perceptual organisation in schizophrenia (Silverstein et al., 1996b), the data from this study suggest that the observed reduction in sequencing effects may be a characteristic of schizophrenia spectrum disorders in general. Other evidence in support of this is a recent study which found abnormal perceptual organisation in schizotypal subjects with thought disorder (Uhlhaas, Silverstein, Phillips, & Lovell, 2004). Additional studies with psychotic and nonpsychotic psychiatric patients can help clarify the specificity of impairments in top-down feedback to perceptual processes to schizophrenia spectrum disorders. Understanding the specificity and prevalence of these problems in different disorders can have treatment implications. Spaulding et al. (1999) suggested that a fundamental problem in schizophrenia is the inability to benefit from context and to recruit the appropriate cognitive operations and strategies for the task at hand, as opposed to having impairments in basic

processes. To the extent that this hypothesis (which is supported by the data from this study) is correct, it suggests that psychological interventions to restore cognitive functioning need to focus increasingly on improving patients' meta-cognitive abilities, as opposed to only their basic cognitive-perceptual skills (Silverstein & Wilkniss, in press).

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