

# Motion Perception in Schizophrenia

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**Background:** Eye-tracking dysfunction has been found in many patients with schizophrenia and in about 40% of their first-degree biological relatives. We hypothesized that a deficit in motion processing is associated with eye-tracking dysfunction because both motion signals and the brain regions responsible for processing motion signals are implicated in the generation of smooth pursuit. We examined several aspects of visual perception, including motion perception, in patients with schizophrenia.

**Methods:** To evaluate motion perception, contrast sensitivity for velocity discrimination was measured in patients with schizophrenia (n=15) and normal control subjects (n=18). Contrast sensitivities for orientation

discrimination and contrast detection were measured as control tasks.

**Results:** Patients with schizophrenia showed significantly lower contrast sensitivity (ie, higher thresholds) than normal controls for the discrimination of small velocity differences (eg, 11 vs 9 degrees/s). This reduction in contrast sensitivity was severe (up to 10-fold) in about 40% of the patients. No group differences were found on the other tasks.

**Conclusion:** The discrimination of small velocity differences is impaired in a subgroup of patients with schizophrenia.

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**W**E REPORT a study of visual motion perception in patients with schizophrenia. Following the finding that smooth-pursuit eye movements (SPEM) are abnormal in many patients with schizophrenia and in about 40% of their first-degree relatives,<sup>1,2</sup> the present study represents a functional probe into the nature of these abnormalities. Specifically, we examined whether patients with schizophrenia have a diminished capability for discriminating the velocity signals of moving targets.

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Of the more than 20 distinct areas in the extrastriatal cortex of macaque and owl monkeys that have been identified, the middle temporal (MT) and the medial superior temporal areas play important roles in the processing of motion information and in the control of SPEM.<sup>3,4</sup> Extensive physiological studies indicate that the MT area, lying at the junction of the temporal, occipital, and parietal lobes, is activated mainly by visual motion signals and is therefore considered the visual motion center of the brain.<sup>3,5</sup> Cells in this area re-

spond selectively to the direction of motion, to the velocity of a moving target, and to apparent motion.<sup>6-8</sup> Both the MT and the medial superior temporal areas contain cells that respond vigorously during the execution of SPEM. Furthermore, lesion studies show that the neural systems that process visual motion information are also directly involved in the control of SPEM.<sup>9-12</sup>

A pilot study has been done of behavioral responses to motion signals in patients with schizophrenia.<sup>13,14</sup> In that study, the dependent variable was contrast sensitivity. One way to assess motion perception is to examine how much contrast is needed to perform a specific motion discrimination task. From physiological, psychophysical, and computational studies,<sup>15-17</sup> we know that contrast processing is a precursor of motion perception and other visual perceptual acts. When the mechanisms for analyzing motion signals are impaired, perceiving motion requires greater stimulus contrast.<sup>12,18</sup> Consequently, the measurement of contrast sensitivity provides a metric assessment of the functional integrity of motion processing. Because cognitive or other unforeseen sensory dysfunctions might also influence performance on motion tasks, we designed a set of control tasks (contrast

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## PATIENTS AND METHODS

The patients ( $n=15$ ), a random selection of patients with schizophrenia discharged during the past year from McLean Hospital, Belmont, Mass, met *DSM-III-R* criteria<sup>20</sup> for schizophrenia or schizoaffective disorder. Diagnoses were assigned by experienced clinicians based on a review of a standardized interview (Structured Clinical Interview for the *DSM-III-R*) conducted by trained interviewers and a review of all hospital records. Patients had been ill for an average of 15.8 years ( $\sigma = 7.6$  years), and their average Brief Psychiatric Rating Scale score was 39.5 ( $\sigma = 7.2$ ), indicating moderate severity of psychotic symptoms even though all were outpatients. Twelve of them were receiving antipsychotic medication (mean chlorpromazine hydrochloride dose equivalent, 328.2 mg [ $\sigma = 198.6$  mg]). Two patients were receiving an antidepressant medication only, and 1 patient was receiving no psychotropic medication. Two patients were receiving lithium carbonate in addition to an antipsychotic drug. The normal control subjects ( $n=18$ ), who were selected from a medical outpatient clinic, were matched to the patients for age, socioeconomic status, and education; none had ever had an Axis I psychotic condition. The median social class<sup>21</sup> for both groups was III. The proportion of men to women in the 2 groups differed. All participants were equally inexperienced in making psychophysical judgments. Written informed consent was obtained from all participants.

The targets were vertical gratings ( $90^\circ$ ), sinusoidal gratings with a spatial frequency of 0.5 cycles per degree, except in the orientation discrimination task, where orientation varied between  $80^\circ$  and  $100^\circ$  (Figure 1). The spatial luminance distribution of the gratings was a sinusoidal waveform. For all motion tasks, temporal frequency ranged from 2.5 to 7.5 Hz (temporal frequency = spatial frequency  $\times$  velocity). Under certain conditions, the contrast sensitivity can be affected by temporal frequency such that perceived contrast differences could be possible cues for discriminating velocity. This effect, however, is minimal when the motion stimulus is generated within a spatiotemporal window that has low spatial frequency (eg, 0.5 cycles per degree) and an intermediate temporal frequency, as was used in this study.<sup>22</sup> Within this range, contrast sensitivity changes little with temporal frequency. At higher temporal frequencies, however, contrast could become a cue for the presence of motion. Therefore, contrast sensitivity can be used as a measure of velocity discrimination only for comparing moving targets whose contrast sensitivities are similar, especially at near detection threshold levels.

The stimuli (Figure 1) were presented on a computer monitor (Macintosh, Apple Computer, Inc, Cupertino, Calif) adapted with a luminance attenuator,<sup>23</sup> which allowed fine gradations in contrast. The gratings were shown through a circular window subtending  $19^\circ$  of visual angle with a space average luminance of 45 cd/m<sup>2</sup>. The duration of each stimulus was 300 milliseconds, and the interval between 2 comparison stimuli was 500 milliseconds.

We compared the contrast sensitivity of patients with schizophrenia with that of normal participants on the 3

visual tasks (Figure 1); we used a 2-alternatives, forced-choice method of determining contrast thresholds for all tasks.<sup>24</sup>

- Velocity discrimination ("Which of 2 gratings is moving faster?"). We used 2 comparisons, 1 an easy one, and the other a more difficult one, around a base velocity of 10 degrees/s (5 Hz). The easy comparison (15 vs 5 degrees/s) involved a difference of 100% ( $[(15-5)+10] = 1 \times 100\%$ ); and the more difficult comparison (11 vs 9 degrees/s) involved a difference of 20% ( $[(11-9)+10] = 0.2 \times 100\%$ ). Normal observers easily distinguish both of these velocity differences.<sup>25</sup>

- Contrast detection ("Which stimulus contains the grating?"). A stationary condition (0 degrees/s) and a moving condition (10 degrees/s) were chosen. In the moving condition, the velocity was identical to that for the velocity and the orientation discrimination tasks.

- Orientation discrimination ("Which of the 2 gratings is tilted to the right?"). The orientation pairs for comparison were  $80^\circ$  vs  $100^\circ$  (an easy comparison) and  $88^\circ$  vs  $92^\circ$  (a more difficult comparison).

Two control conditions are embedded in these procedures. First, all of the tasks, which are 2-alternatives, forced-choice tasks, have identical nonsensory demands in that an accurate response requires attending to 2 events separated by a short interval (0.5 seconds) and remembering the first event to compare it with the second. Such a task design imposes comparable attentional demands and memory requirements. Thus, contrast detection and orientation discrimination provide a baseline for sensitivity changes in velocity discrimination with similar levels of task difficulty. Second, orientation discrimination thresholds also provide an index of performance on a visual perception task unrelated to the processing of motion signals.

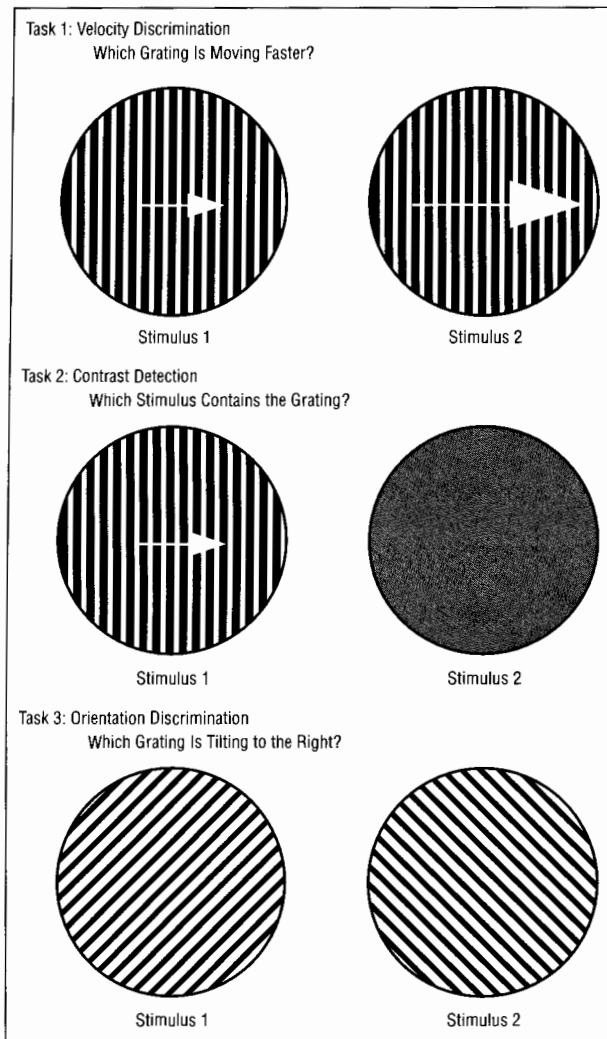
We set the initial contrast at 1.5%, an adequate level for performing these tasks, and used the psychophysical "staircase" method for determining contrast thresholds. In this method, the contrast was reduced by 30% after 3 consecutive correct responses or increased by 30% whenever a single error occurred. This standard 3-down, 1-up procedure identifies the 79.4% correct threshold point on a psychometric function.<sup>24</sup> The staircase stopped after 12 reversals. The staircase design ensures that all subjects, patients and volunteers alike, perform at 79.4% accuracy. Viewing was binocular.

A repeated-measures analysis of variance, adjusted for baseline contrasts sensitivity, was used to test (1) the magnitude of the difference in minimal contrast needed to discriminate stimulus velocities, (2) group differences (schizophrenic patients vs normal controls) on this variable, and (3) the interaction between 1 and 2. The reciprocal of the contrast threshold in each condition was taken as the dependent variable, following standard practice in psychophysics. The effect of the magnitude of the difference in velocities was also tested separately for each subject group by a Wilcoxon signed rank test, and the effect of group membership was tested for each task difficulty by a Student *t* test. Contrast thresholds for stimulus detection and orientation discrimination were similarly tested by analysis of variance.

detection, orientation discrimination, and direction discrimination) that tap different visual functions yet also require similar mental (especially attentional) demands.<sup>13</sup> The procedures used in the pilot study are al-

most identical to those described in the "Patients and Methods" section of this article.

The most severe impairment of performance in patients with schizophrenia occurred when they were re-



**Figure 1.** A schematic representation of the stimuli used for velocity discrimination, contrast detection, and orientation discrimination.

quired to detect small velocity differences between moving stimuli. As the velocities of 2 moving gratings became increasingly similar, schizophrenic patients showed much lower contrast sensitivity than control subjects to detect the velocity differences. This preliminary study suggested possible motion discrimination impairments in patients with schizophrenia. This view is supported by another study<sup>19</sup> that showed impaired motion perception in patients with schizophrenia; this study used a different method of measuring motion sensitivity: coherence of random dots.

## RESULTS

The **Table** presents the contrast sensitivity means (and SEs) for both subject groups on all tasks. As is the convention in psychophysics, the values in the Table represent the reciprocal of the contrast thresholds in each condition (eg, 484 denotes a threshold of 0.21% contrast for the schizophrenic group). Larger reciprocals thus represent greater contrast sensitivity (ie, lower thresholds).

As expected, there was a significant reduction in contrast sensitivity when discriminating small velocity dif-

**Means (SEs) of Contrast Sensitivity\*  
for Schizophrenic Patients and Normal Controls**

Task	Normal Controls (n = 18)	Schizophrenic Patients (n = 15)	P
Contrast detection, 10 degrees/s 15 degrees/s vs 5 degrees/s difference	502 (48)	484 (47)	.85
Velocity discrimination, 11 degrees/s vs 9 degrees/s difference	430 (45)	417 (45)	.87
Velocity discrimination, 11 degrees/s vs 9 degrees/s difference	173 (25)	71 (10)	<.002†
Contrast detection, 0 degrees/s difference	291 (36)	219 (21)	.14
Orientation discrimination, 20° difference	200 (17)	189 (23)	.72
Orientation discrimination, 4° difference	183 (35)	138 (14)	.30

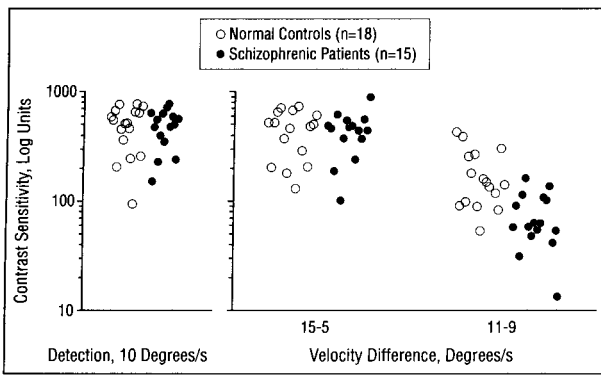
\* Contrast sensitivity was presented as the reciprocals of contrast threshold.

† Effect size = 1.34.

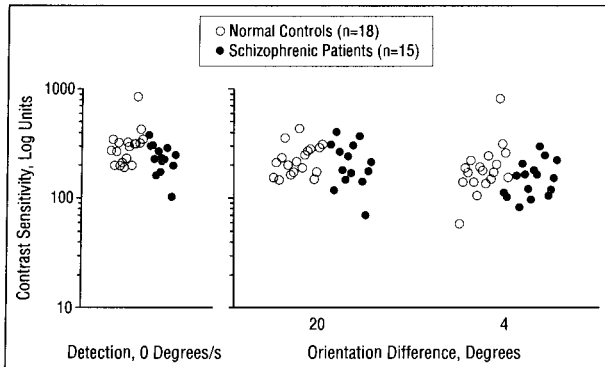
ferences compared with discriminating large velocity differences ( $F_{1,29}=11.20$ ;  $P<.003$ ). The Wilcoxon signed rank test showed that both groups showed lower sensitivity when judging the more difficult pair of stimuli (schizophrenic patients, Wilcoxon T test=60,  $P<.001$ ; normal controls, T=65,  $P<.001$ ). Patients with schizophrenia had significantly lower sensitivity (ie, higher thresholds) than did normal controls on the more difficult velocity discrimination (Table). Thus, the difference in velocity sensitivity between patients with schizophrenia and normal controls is greatly amplified when the velocity discrimination becomes more difficult (repeated-measures analysis of variance, adjusted for baseline contrast sensitivity at 10 degrees/s, yielded a significant interaction between subject groups and velocity condition [ $F_{1,29}=7.17$ ;  $P=.01$ ]). This effect was confirmed by a test of simple effects that showed no significant differences between the groups for the easy comparison, but was statistically significant for the difficult comparison (Student  $t$  test=3.70;  $P<.002$ ). The effect size is large: 1.34. For the other tasks—contrast detection at 2 velocities (0 and 10 degrees/s) and orientation discrimination at 2 levels of difficulty—there were no significant differences between the 2 groups. The removal of outliers by a Moses test did not change the pattern of results.

We plotted the results of individual subjects in each group. The contrast sensitivities for contrast detection are almost identically distributed in both groups (**Figure 2**, left panel). These values are similar to those obtained under comparable experimental conditions in other studies.<sup>22</sup>

For the normal controls, mean contrast sensitivity decreases moderately as the velocity discrimination becomes more difficult to discriminate (eg, from 15 vs 5 degrees/s to 11 vs 9 degrees/s), as expected<sup>18</sup> (Figure 2, right panel). Among the patients with schizophrenia, however, although there is also a decrease in contrast sensitivity, there is marked heterogeneity of performance. At the large velocity difference (15 vs 5 degrees/s), most patients cluster at the same level as do the normal controls. At the smaller



**Figure 2.** Contrast sensitivity for contrast detection (left panel) and for velocity discrimination (right panel). The groups differed significantly only on velocity discriminations of 11 vs 9 degrees/s.

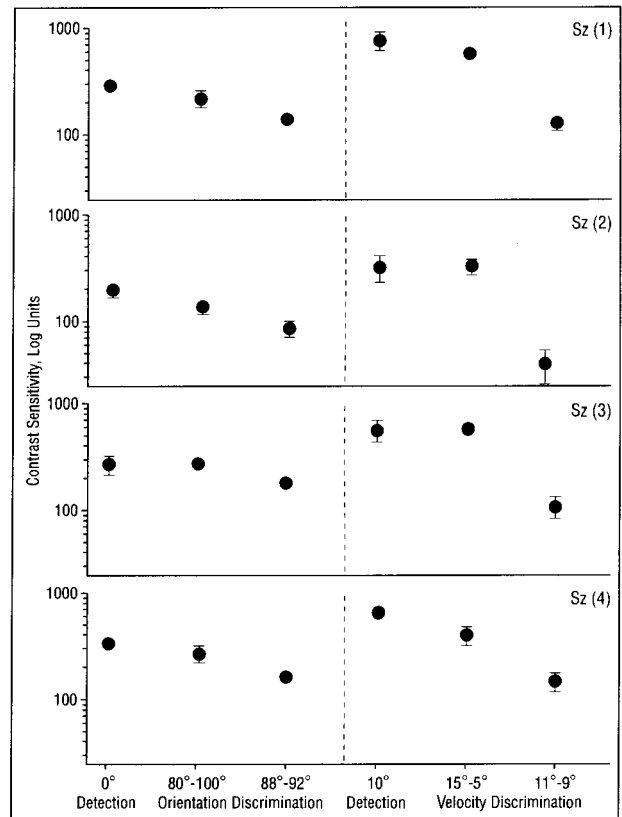


**Figure 3.** Contrast sensitivity for detection (left panel) and for orientation discrimination (right panel). Patients and normal controls performed similarly.

velocity differences (11 vs 9 degrees/s), the schizophrenic patients as a group show a significantly greater decline in contrast sensitivity than do the normal subjects, some patients as much as 10-fold greater. It is striking, moreover, that all patients, even those with the most precipitous declines in contrast sensitivity for the difficult motion discrimination targets, showed normal contrast detection thresholds. We tested this assertion by computing the ratio of velocity discrimination to contrast detection for each subject. This procedure normalizes the velocity discrimination values with respect to each subject's contrast detection threshold. When the contrast detection level of each subject is thus taken into account, the pattern of results shown in the Table and in Figure 2, right panel, is essentially unchanged.

Contrast sensitivity for detection and orientation discrimination for both groups are similar (**Figure 3**); an analysis of variance shows no significant group differences.

To determine the stability over time of contrast sensitivity measurements, we retested 4 patients with schizophrenia and 4 normal controls 4 times for 2 months. The results show highly reliable thresholds on all of the tasks: contrast detection, orientation discrimination, and velocity discrimination. All patients with schizophrenia maintained their sensitivity levels, with little variation from one testing time to another, and no detectable practice effect (**Figure 4**). Results for 4 normal controls show the same stability of thresholds over time.



**Figure 4.** Repeated measurements of contrast sensitivity for contrast detection, velocity discrimination, and orientation discrimination. The data were collected from 4 subjects with schizophrenia (Sz 1, Sz 2, Sz 3, and Sz 4). There are 2 subpanels for each subject. Left, Contrast detection at 0 degrees/s, and orientation discriminations for differences of 20° and 4°. Right, Contrast detection at 10 degrees/s, and velocity discrimination for 15 vs 5 degrees/s and 11 vs 9 degrees/s. The plotted data points for each condition represent an average for the 4 different sessions. The bars represent SEs for the 4 measurements. Where no bars are visible, the SEs were too small to be represented on the graph. The relatively small SEs indicate the stability of the thresholds over time.

We repeated the velocity discrimination experiment using a base velocity of 20 degrees/s (10 Hz) and obtained qualitatively similar results. These faster-moving targets resulted in significantly higher thresholds for both groups of subjects; however, the differences between the groups when judging speeds separated by 20% (22 vs 18 degrees/s), the difficult discrimination comparisons, remained statistically significant.

#### COMMENT

We report degraded velocity discrimination performance in a group of patients with schizophrenia when the velocities of the 2 stimuli are relatively difficult to discriminate. The difficult velocity discrimination task, which requires a comparison between 9 and 11 degrees/s, is at least twice as large as the velocity discrimination thresholds of normal observers with no motion perception deficits.<sup>11,12,25</sup> The same degradation in velocity discrimination is evident when a basal level of contrast sensitivity is used to normalize the threshold levels. The patients' thresholds in tasks of contrast detection and orientation discrimination, however, are comparable to those of the normal controls.

Several considerations support the interpretation that patients with schizophrenia show a specific impairment in the processing of motion signals but not in other aspects of visual perception, such as orientation and contrast detection. First, because the same 2-alternatives, forced-choice procedure was used for detecting contrast and discriminating velocity, normal performance on the contrast and orientation tasks indicates that schizophrenic patients understood the task response requirements. Second, the patients performed the velocity discrimination tasks at normal levels except when small velocity differences were being judged. The same pattern of selective impairment for differentiating small velocity differences was observed independent of temporal frequency. The normal control participants also showed a modest but significant rise in discrimination threshold for these more difficult judgments, but not to the extent shown by the schizophrenic patients, suggesting that the deficit in schizophrenia appears only when fine processing of a motion signal is required. Third, the specificity of this impairment for velocity discrimination is underscored by the finding that orientation judgments showed no group effects even when a discrimination of small differences was required. These findings are consistent with those reported by Stuve et al.,<sup>19</sup> who showed no relation between a motion perception decrement and a test of sustained visual attention in schizophrenic patients. The decrement in motion discrimination is therefore not adequately explained by a "generalized deficit" performance.<sup>26</sup> Finally, our method kept the performance of all subjects consistently at 79.4% correct on all tasks, which minimized experiences of failure on the task.

The processing of motion signals requires coordination of both spatial and temporal information. We suggest that the perceptual deficit of motion discrimination in schizophrenic patients is primarily due to an impairment in some part of the motion pathways, although the exact brain areas responsible for the impairment are yet to be determined. Motion signals occur in an intermediate stage of visual processing; they may be influenced by early visual processing (ie, by receiving spatial and temporal inputs) and by later visual processing (ie, by the cognitive interpretation of moving targets). It is possible that the motion deficits in schizophrenia reflect secondary effects from those brain areas that provide earlier or later visual processing. Our contrast detection results, however, suggest that sufficient spatial and temporal information from the early stage of visual processing is available for motion processing, based on the intact capacity of schizophrenic patients to detect moving and nonmoving targets. We infer that the influence of later visual processing is limited as well. We base this inference on the fact that the poor performance of patients occurs only on the difficult, but not on the easy, velocity discrimination tasks. The cognitive requirements, including the memory and attentional but not the sensory demands, are presumably matched for the easy and difficult velocity comparisons. If the cognitive influence from the later stages played a major role in the patients' velocity discrimination performance, such information should have helped

them to perform normally on both the easy and the difficult velocity discrimination tasks. Yet, this was not the case. We can conclude that our tasks tapped brain areas that are specialized for analyzing motion signals, such as the MT and medial superior temporal areas, although the possibility that the brain areas responsible for other aspects of information processing may also have some influence on the velocity discrimination deficit cannot be ruled out.

There is an obvious difference between the motion perception deficits of our schizophrenic subjects and those of both monkeys and patients with lesions in motion-sensitive brain areas (MT and medial superior temporal areas): in schizophrenic patients, the deficit performance is stable rather than temporary. A lesion in the MT area in monkeys produces an immediate and dramatic loss of motion perception,<sup>27</sup> but a substantial improvement from that deficit performance is also observed within a few weeks. Such a recovery is generally attributed to either neural plasticity of the affected region or a functional takeover by other unaffected brain regions. In contrast, the deficient performance shown in many of our schizophrenic patients does not vary over time. Similar stability has been seen for patients with unilateral parietal lesions.<sup>11</sup> Furthermore, the high intrasubject reliability of the motion perception impairment suggests that the deficit in motion processing, like eye-tracking dysfunction, represents a traitlike characteristic in schizophrenia.

These studies in motion perception were undertaken as an exploration of the processes involved in the finding of eye-tracking dysfunction in schizophrenia.<sup>1,2,28-30</sup> Now that it has been determined in 2 independent samples that patients with schizophrenia show a substantial impairment in velocity discrimination, we are ready to turn to an exploration of the relation of this impairment to the deficits in SPEMs. In a companion article, we report that the motion perception deficit in schizophrenia patients—reduced contrast sensitivity for the discrimination of small differences in velocity—is related to both the initiation and the maintenance of SPEM.

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