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Impaired saccadic eye movements on stationary targets in patients with schizophrenia spectrum disorder

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Abstract This study examined tracking eye movements on predetermined stationary targets in patients with schizophrenia spectrum disorder. The targets were 8 black points or 8 arabic-numbered points placed on the circumference of a circle. Self-paced eye movements during clockwise tracking of these points by 23 patients and 23 normal controls were recorded using an infrared eye-mark recorder. Eye movements were analyzed at two settings: firstly, when "fixation point" was defined as a point at which a gaze was held for at least 200-ms; and secondly, when held for at least 100-ms. The results indicated that at the 200-ms setting schizophrenic patients track with significantly fewer correct scores and more deviant scores than controls under black-point conditions. At the 100-ms setting, however, the correct scores of patients were not significantly different from those of controls, although patients displayed more aberrant paths than controls. The superfluous fixations in the patients improved significantly under numbered-point conditions, but patients still achieved lower correct scores than controls. Four of the 23 patients exhibited centering (aberrant path directed toward the center point), suggesting immature control of eye movements under black-point conditions, but not numbered-point conditions. These results suggest that some schizophrenic patients viewed the targets too quickly, and that they have impaired directed attention, which can be improved by cues, and may have impaired preprogramming of eye movements, which is not improved by external cues.

Key words Schizophrenia · Eye movements · Tracking test · Fixation time · Attention

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Introduction

Eye movements consist mainly of two types of movements, smooth-pursuit eye movements and saccadic eye movements. Whereas smooth pursuit eye movements act to adjust eyeball velocity to target velocity, saccadic eye movements act to bring a visual target in the periphery of the visual field onto the fovea. Dysfunctions in smooth pursuit eye movements that track a moving object have been extensively studied in schizophrenic patients (Diefendorf and Dogde 1908; Holzman et al. 1973), and more recently, impairment of saccadic movements in a step-tracking task with a stationary target has also been reported (Schmid-Burgk et al. 1982, 1983). In addition, several studies have examined exploratory eye movements in schizophrenic patients while they are viewing figures or pictures. When a static figure is being viewed, eye movements take the form of discrete periods of relative immobility (eye fixation) separated by quick jumps of the eye from place to place (saccades).

Schizophrenic patients often exhibit fewer eye fixations, longer duration of eye fixation, shorter eye scanning length, or limited ranges of eye fixation on figures. In these studies various figures have been used such as a horizontal S-shaped figure (Moriya et al. 1972; Kojima et al. 1990), a Binet-Bobertag's picture (Gaebel et al. 1987), figures from the Benton Visual Retention Test (Tsunoda et al. 1992), and the WAIS Picture Completion Test (Matsui et al. 1993; Kurachi et al. 1994). Some of the characteristics seen in the patients seem to depend on the task used. For instance, basic eye-movement parameters (e.g., number of fixations, mean duration of fixation) were not impaired, but the scanning styles of the patients were different from those of normal controls when situational pictures were used (Gaebel et al. 1987; Matsui et al. 1993). These tasks may involve many different factors, such as elementary afferent information processing, perception of visuospatial relations, attention and cognitive strategy (top-down vs bottom-up process), as well as the elementary motor aspects of saccades. Although these findings in exploratory eye movements seem to mainly represent the cognitive characteristics of the patients, elementary motor aspects should also be taken into account. Regarding this Reischies et al. (1988, 1989) reported disturbed eye movements guided by visuospatial cues in schizophrenic patients. In addition to direction perception, their task required other visuospatial elements including peripheral target identification and distance determination.

The focus of the present study was to examine elementary motor aspects of eye movement in a simple saccadic tracking task using stationary targets. In most previous studies a fixation point has been defined as a point at which gaze is held for more than 200-ms (Gaebel et al. 1987; Reischies et al. 1988; Kojima et al. 1990; Matsui et al. 1993; Kurachi et al. 1994).

In the present study, however, we have also included the results for 100-ms, because some subjects gazed at targets very quickly, but correctly. The second aim of this study was to investigate the factor of attention in the saccadic tracking task. Shagass et al. (1976) provided evidence that defective eye-tracking performance (smooth-pursuit eye movements) can be improved by a simple procedure that requires the subject to read numbers on an oscillating pendulum. Therefore, we also used stationary targets on which numbers were placed.

Subjects and methods

A total of 23 patients with schizophrenia spectrum disorder recruited from the inpatient and outpatient clinics of Toyama Medical and Pharmaceutical University Hospital participated in this study. A total of 19 patients fulfilled DSM-III-R criteria for schizophrenia, one for delusional disorder, and three for schizotypal personality disorder (12 males and 11 females). Their mean age was 27.6 ± 9.2 (SD) years (range 15–43 years), and their mean duration of illness was 6.4 ± 7.0 years. The mean daily chlorpromazine-equivalent dosage was 503.1 ± 805.0 mg. The control subjects consisted of 23 healthy volunteers (13 males and 10 females) with a mean age of 26.7 ± 5.6 years (range 23–42 years). The purpose and procedures of the study were explained to the subjects, and their informed consent was obtained. Symptoms were assessed using the Scale for the Assessment of Negative Symptoms (SANS; Andreasen 1983) and selected items (delusion, conceptual disorganization, and hallucinatory behaviour) from the Positive and Negative Syndrome Scale (PANSS; Kay et al. 1986). Referring to Liddle's three-syndrome hypothesis (1987), clinical symptoms were grouped under three subsyndromes: the total SANS score, the PANSS conceptual disorganization score, and the PANSS delusion plus hallucinatory behaviour score.

The subject sat on a chair equipped with a Nac V-type eye-mark recorder, a device that detects corneal reflections of infrared light. The subject's head was held in place by a chin rest and lateral supports. As shown in Fig. 1, two saccadic tracking figures were projected individually onto a translucent screen located 1.2 m directly in front of the subject's eyes. Eight points of 1 angular degree large were placed on the circumference of a circle having a diameter of 20 angular degrees (Fig. 1). One figure contained 8 black points, whereas the other had 8 points with arabic numbers (1–8). The subject was first instructed to look at the center (+) of each figure. Then he/she was asked to scan each of the 8 points once in clockwise order by moving the eyes. The order of the two figures was counterbalanced across subjects. Each task was self-paced. Eye movements during two tracking tasks were recorded on videotape using the eye-mark recorder as described in the previous report (Kurachi et al. 1994). The eye-mark recorder consists of a helmet equipped with very small video cameras attached to the left and right sides and to the top of the helmet. The side cameras record the infrared lights reflected on the eyeballs. The camera on top of the helmet records figures on the screen. These recordings are stored in a videotape recording system. This technique enables us to see the eye-fixation points and eye movements on the figures simultaneously. Data for two figures recorded with the eye-mark recorder were analyzed by computer.

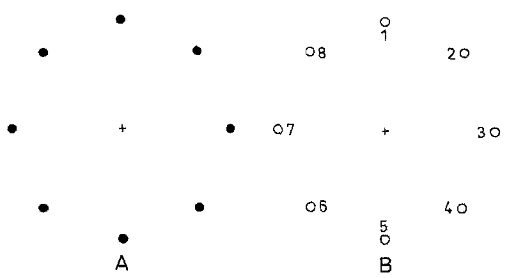

Fig. 1 A, B A saccadic tracking task on 8 **A** black-point and **B** numbered-point targets. Actually, the number was put in the open circle. The subject was instructed to look at the center (+) of the figure first. He/she was then asked to scan the 8 points clockwise, in order

Measurement

The analysis of eye-movement behaviour was based on the following measures. We analyzed the data at two settings, firstly, when fixation point was defined as point at which a gaze is held for at least 200-ms, and secondly when held for at least 100-ms. Eye movements were assessed using the following parameters:

1. *Correct score*, composed of the number of target hits plus normal paths. The maximum possible score is 15 points. *Target hitting:* When a fixation hits a target, one point is scored. The maximum possible score is 8 points. *Normal path:* Normal saccade lines (straight lines from one point to the next point) are scored one point each. The maximum possible score is 7 points.

2. *Deviant score*, composed of the number of superfluous fixations plus aberrant paths. *Superfluous fixation:* Some fixations occur elsewhere and do not hit a target. The total number of such events is the score. *Aberrant path:* A path deviating from the normal paths. The total number of such paths is the score. Paths directed toward the center point in aberrant paths are referred to as "Centering" and the number of centerings was included in the aberrant path score.

The cue effect was defined as attainment of a significantly higher correct score or lower deviant score under numbered-point conditions than black-point conditions.

Statistical analysis. Differences between eye-movement parameters in controls and patients were examined using the Mann-Whitney U test. The Sign Test was performed for the effect of conditions within the same group of subjects. Fisher's exact test was performed for differences in frequency between groups on the correct score. Spearman's rank correlation test was used for correlations between eye-movement parameters and clinical syndromes or drug dosage.

Results

Figure 2 shows the plots from three subjects that were selected as representative examples.

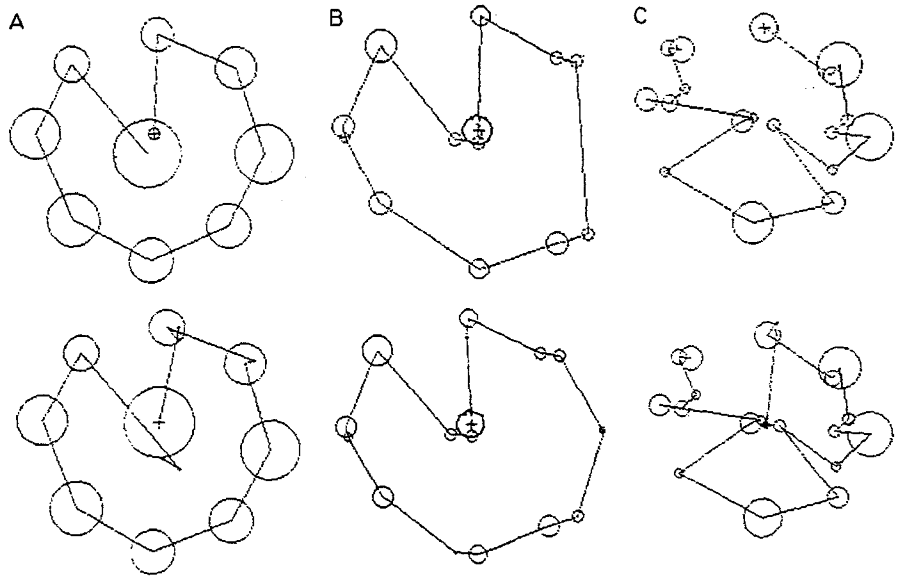

Fig. 2 A–C Sequence of eye movements in a saccadic tracking task. A circle indicates a single fixation, and the size of the circle indicates duration of fixation. The lines represent succesive eye movements performed from the first to the last point of fixation. Upper figures are at 200-ms setting, and lower figures are at 100-ms setting. **A** A normal control. This subject directed his gaze directly onto the targets, and the target hitting score was 8 points. His eye fixation also moved from one target to the next by normal saccade lines, and the normal path score was 7 points. Correct score: 15 (target hitting: 8 plus normal path: 7); deviant score: 0 (superfluous fixation: 0 plus aberrant path: 0) in both settings. **B** A schizophrenic patient who omitted one target. Correct score: 13 (target hitting: 7 plus normal path: 6) in the 200-ms setting and correct score: 15 (target hitting: 8 plus normal path: 7) in the 100-ms setting; deviant score: 2 (superfluous fixation: 2 plus aberrant path: 0) in the 200-ms setting and deviant score: 3 (superfluous fixation: 3 plus aberrant path: 0) in the 100-ms setting. **C** Another schizophrenic patient who had a high deviant score. This patient's eye fixation moved toward the center twice. Correct score: 12 (target hitting: 8 plus normal path: 4); deviant score: 18 (superfluous fixation: 8 plus aberrant path: 10, including centering) in both settings

Table 1 Eye movements during a saccadic tracking task in controls and patients (mean ± SD)

Conditions	Eye-movement parameters						
	Correct score	Target hitting	Normal path	*Deviant score*	Superfluous fixation	Aberrant path	Centering
200-ms setting							
Black point							
Normal controls	13.9 ± 2.5	7.6 ± 1.0	6.2 ± 1.5	1.3 ± 1.6	1.1 ± 1.5	0.2 ± 0.6	0
Schizophrenic patients	$13.6 \pm 1.6^{*a}$	7.6 ± 0.7	6.0 ± 1.1	$4.4 \pm 6.0^{**a}$	$3.1 \pm 3.5^{**a}$	1.3 ± 2.9	(0.1 ± 0.5)
Numbered point							
Normal controls	14.7 ± 0.9	7.9 ± 0.3	6.8 ± 0.6	0.7 ± 1.1	0.7 ± 1.1	0	0
Schizophrenic patients	$13.4 \pm 2.3^{**a}$	$7.3 \pm 1.0^{*a}$	$6.0 \pm 1.4^{**a}$	$2.1 \pm 3.3^{*b}$	$1.5 \pm 2.5^{**b}$	$0.6 \pm 1.1^{*a}$	0
100-ms setting							
Black point							
Normal controls	14.5 ± 1.0	$8.0 \pm 0^{*c}$	6.5 ± 1.0	$4.8 \pm 4.1^{**c}$	$3.7 \pm 2.8^{**c}$	$1.1 \pm 2.0^{**c}$	0
Schizophrenic patients	13.9 ± 1.3	$8.0 \pm 0^{**c}$	6.0 ± 1.3	$9.1 \pm 6.8^{*a; **c}$	$6.7 \pm 4.0^{*a; **c}$	$2.5 \pm 3.7^{**c}$	(0.2 ± 0.5)
Numbered point							
Normal controls	$14.8 \pm 0.6^{*b}$	8.0 ± 0	$6.8 \pm 0.6^{*b}$	$3.3 \pm 2.7^{*b; **c}$	$2.8 \pm 2.2^{**c}$	$0.4 \pm 1.5^{*b}$	0
Schizophrenic patients	$14.6 \pm 0.7^{*b; **c}$	$7.9 \pm 0.3^{**c}$	$6.7 \pm 0.6^{**b; **c}$	$6.3 \pm 7.0^{*b; **c}$	$5.1 \pm 5.1^{**c}$	$1.2 \pm 2.1^{*a; *c}$	0

NOTE: A perfect correct score is 15 points (number of target hits plus normal paths). Deviant score equals the number of abberant paths plus superfluous fixations.

[a] Mann-Whitney U test, controls vs patients
[b] Sign test, black-point condition vs numbered-point conditions in same group
[c] Sign test, 200-ms setting vs 100-ms setting in same group

$^{*}P < 0.05$
$^{**}P < 0.01$

Table 2 Numbers of subjects who attained a perfect correct score and less than a perfect correct score

Score	Condition			
	Black points		Numbered points	
	Perfect (15)	Less than perfect (< 15)	Perfect (15)	Less than perfect (< 15)
200-ms setting				
Controls	17	6	20	3
Patients	9*	14	10**	13
100-ms setting				
Controls	17	6	21	2
Patients	11	12	16	7

*$P < 0.05$ (Fisher's exact test on scores for controls and patients)
**$P < 0.01$

Analysis of eye movements at the 200-ms setting

Table 1 shows the group means and standard deviations for eye-movement parameters under both conditions (black points/numbered points) in the saccadic tracking task. At the 200-ms setting, schizophrenic patients showed fewer correct scores ($P < 0.05$), more deviant scores ($P < 0.01$), and more superfluous fixations ($P < 0.01$) than normal controls under black-point conditions. The schizophrenic patients, but not the normal controls, exhibited a significant cue effect, i.e. only the patients had fewer deviant scores ($P < 0.05$) and fewer superfluous fixations ($P < 0.01$) under numbered-point conditions than under black-point conditions. The patients, however, still had fewer correct scores ($P < 0.01$), fewer target hittings ($P < 0.05$), fewer normal paths ($P < 0.01$), and more aberrant paths ($P < 0.05$) than normal controls under numbered-point conditions.

Table 2 shows the number of subjects who achieved a perfect correct score (15 points), and those who did not attain a perfect correct score. At the 200-ms setting, 17 of the 23 normal controls attained a perfect correct score, whereas only 9 of the 23 patients attained a perfect correct score under black-point conditions ($P = 0.0361$). Under numbered-point conditions, 20 of the 23 normals attained a perfect correct score, whereas only 10 of the 23 patients attained a perfect correct score ($P = 0.0045$).

Four patients at the 200-ms setting exhibited centering under black-point conditions, but not under numbered-point conditions. None of the normals showed centering under either condition.

Analysis of eye movements at the 100-ms setting

There were no significant differences between the correct scores, target hittings, or normal paths of patients and controls at the 100-ms setting, but patients had more deviant scores ($P < 0.05$) and superfluous fixations ($P < 0.05$) than controls under black-point conditions. A significant cue effect was seen in both patients and normal controls, because they had more correct scores (patients $P < 0.05$; controls $P < 0.05$), more normal paths ($P < 0.01$; $P < 0.05$), and fewer deviant scores ($P < 0.05$; $P < 0.05$) under numbered-point conditions than under black-point conditions. Controls also had fewer aberrant paths ($P < 0.05$) under numbered-point conditions. Patients had more aberrant paths ($P < 0.05$) than controls under numbered-point conditions.

As shown in Table 2, at the 100-ms setting, 21 of the 23 normal controls, and 16 of the 23 patients, achieved a perfect score under numbered-point conditions, and there was no significant difference between the controls and the patients.

Five patients at the 100-ms setting exhibited centering under black-point conditions, but not under numbered-point conditions. None of the normals showed centering under either condition.

Comparison between eye movements at the 200-ms and 100-ms setting

Under black-point conditions both normal controls and patients had more target hittings ($P < 0.05$; $P < 0.01$) at the 100-ms setting than at the 200-ms setting. However, both groups also had more deviant scores ($P < 0.01$), more superfluous fixations ($P < 0.01$), and more aberrant paths ($P < 0.01$) at the 100-ms setting. Under numbered-point conditions the patients had more correct scores ($P < 0.01$), more target hittings ($P < 0.01$), more normal paths ($P < 0.01$), and more aberrant paths ($P < 0.05$) at the 100-ms setting than at the 200-ms setting. Both normal controls and patients had more deviant scores ($P < 0.01$ each) and more superfluous fixations ($P < 0.01$ each) at the 100-ms setting than at the 200-ms setting.

Relationship of eye-movement parameters with clinical syndromes and neuroleptic dosage

There was no significant correlation between eye-movement parameters and the three clinical syndromes scores. Assessment of the effect of neuroleptics on eye-movement parameters showed no significant correlation between eye-movement parameters and chlorpromazine-equivalent dosage.

Discussion

In this study eye fixation was analyzed at both 200-ms and 100-ms settings. It has been estimated that the duration of a complete eye-movement cycle is approximately 230 ms, with 200 ms being the duration of fixation and 30 ms required for the movement itself (Russo 1978). During eye fixation information from the stimulus being fixated is presumably acquired for only the first 100-ms, while the rest of each fixation is probably spent computing where the next fixation will be made (Loftus 1976). Consolidation of information may also take time (Inui and Miyamoto 1981).

The results of this study revealed that patients with schizophrenia spectrum disorder track with slightly, but significantly fewer, correct scores than normal controls under black-point conditions at the 200-ms setting, and that perfect correct scores were obtained less frequently in patients (9 of 23) than in normal controls (17 of 23). Patients showed more superfluous fixations and deviant scores than normal controls under black-point conditions. Reischies et al. (1988) also demonstrated an increased number of fixations and multiple sequence repetitions at the 200-ms setting in schizophrenic patients in a saccadic tracking task on stationary targets. Thus, an increased number of fixations or superfluous fixations was observed in these stationary eye-tracking tasks in schizophrenic patients. In contrast, previous studies using situational pictures showed that schizophrenic patients had a normal number of fixations (Gaebel et al. 1987; Matsui et al. 1993). Furthermore, schizophrenic patients had been reported to exhibit fewer fixations in relatively simple figures tasks (Moriya et al. 1972; Kojima et al. 1990; Tsunoda et al. 1992). These differences among tasks should be assessed in the same subjects in the future.

At the 100-ms setting the differences in correct scores between controls and patients were not statistically significant, and the number of patients who achieved a perfect correct score was not significantly different from the number in the control group.

Differences between patients and controls at the 100-ms setting were only seen in the deviant score item, however, these scores were higher at the 100-ms setting than at the 200-ms setting in both groups. These results indicate that some schizophrenic patients viewed the targets too quickly, i.e., their fixation time was more than 100-ms but less than 200-ms. Many normal controls, however, took more than 200-ms. If the latter part of the fixation time is spent computing the position of the next fixation, this may be one reason why some patients track with aberrant paths.

Several patients exhibited centering. Centering has been reported in normal children less than 7 years old, but it decreases as they grow up (Nomura and Noguchi 1973). Thus, the centering in these patients may reflect immature control of their eye movements. Eye movements in schizophrenic patients may be easily triggered by peripheral events, most probably due to their poor ability to direct attention, as in children.

There was no evidence to suggest that medication was the cause of poor eye movements. Clinical syndromes were not significantly correlated with eye movements, but this study was performed in a relatively small sample, and this should be reexamined with larger numbers of subjects, and comparisons should be made between the psychotic state and the remitted state.

Regarding the second aim of this study, the results provided evidence that defective saccadic eye-tracking performance, especially deviant scores, can be improved by using stationary targets on which numbers have been placed. Shagass et al. (1976) reported that eye-tracking performance (smooth-pursuit eye movement) is markedly improved in both patients and normals by replacing the fixation dot on the pendulum by numbers in order to maintain attention and aid focusing. Thus, additional stimuli, such as numbers, to direct attention had the same effect in smooth pursuit and saccadic eye-tracking tasks. Shagass et al. (1976), however, showed that although eye tracking in schizophrenic patients improved to some degree, differences between schizophrenic patients and normals persisted under number-reading conditions. This residual impairment was called "involuntary inattention" by Shagass et al. (1976; Holzman et al. 1976). In the present study saccadic movements were also improved with a cue, but not completely. Under numbered-point conditions at the 200-ms setting, the number of patients who achieved a perfect correct score (10 of 23) was significantly less than in controls (20 of 23), and patients had lower correct scores and more aberrant paths than controls. These results suggest that there are at least two components of impairment in the eye-tracking task. The first component improved with cues to direct attention, but the second did not.

Schmid-Burgk et al. (1983) reported that schizophrenic patients exhibited more saccadic hypometria (undershooting of the target) than controls. Mather and Puchat (1983) also found that schizophrenic patients displayed an increased numbers of both hypometric and hypermetric (overshooting of the target) saccades than controls. Some of the impairments in the saccadic tracking task in the present study may be related to dysmetric saccades.

In saccadic tracking tasks, subjects should first identify target points. Their brains compute the distance to move the eyeball and then the signal to start movement is transmitted to the neurons. The programs for such eye movements are made before movement starts, and because the movements are based on these programs, they are termed "preprogrammed movements." This operates on the basis of a feed-forward regulatory mechanism. Once the movement starts it cannot be voluntarily modified, so it is also called a ballistic movement (Russo 1978; Komatsuzaki et al. 1985). In normals there is little problem in identifiying targets and making programs, leading to efficient performance. In patients, however, poor identification or maintenance of target points is likely to be the main cause of superfluous fixations and aberrant paths, because these features were improved by cues (numbers). The impairment that persists after the presentation of a cue may be accounted for by poor programming of eye movements. Further studies will be needed to clarify the neural mechanism of saccadic eye movements in schizophrenic patients.

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