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ORIGINAL PAPER

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Exploratory eye movements in schizophrenia

Effects of figure size and the instruction on visual search

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Abstract It has been reported that patients with schizophrenia show restricted eye-scanning in comparison with normal controls; however, the precise mechanism underlying the limited eye movement pattern remains unknown. The purpose of this study was to determine the factors affecting restricted eye-scanning in schizophrenic patients by examining exploratory eye movements during demonstration of two different sizes of the S-shaped figure. The second purpose was to determine the effect of the instruction for performance on the restricted viewing pattern in patients with schizophrenia. Eye movements during demonstration of the S-shaped figure of the original or half size were examined in 15 patients with schizophrenia and 15 normal controls using an infrared eye-mark recorder. The patients showed lower search scores than control subjects for both sizes of the figure. The subjects were then instructed to compare a slightly modified figure with the original one. Lower responsive search scores were found for the patients when "fixation point" was defined as a point at which a gaze was held for at least 200 ms, while the patients and control subjects performed equally at the 100-ms setting. Direct instruction to scrutinize the S-shape abolished the difference in the search scores between patients and control subjects at both the 100-ms and 200-ms settings. These findings suggest that the size of the S-figure is not a factor of restricted eye movements, and that the direct instruction improves the visual performance in patients with schizophrenia.

Key words exploratory eye movements · schizophrenia · eye-mark recorder · fixation point · scan paths

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Introduction

Visual searching behavior, or the visual scan path, that traces the direction, extent and duration of gaze is considered to be a physiological marker of information processing. Analysis of the visual scan path provides an important clue for understanding cognitive impairment in patients with schizophrenia (Phillips and David 1994). Although the studies of eye movements in schizophrenia have mainly focused on smooth pursuit eye movements, abnormalities in exploratory eye movements have also been suggested (Moriya et al. 1972, Nakajima et al. 1989, Xia et al. 1996). Moriya et al. (1972) reported, for the first time, that exploratory eye movements during demonstration of a stationary horizontal S-shaped figure are disturbed in patients with schizophrenia. Kojima et al. (1986, 1989, 1990,1992). subsequently developed the responsive search score whereby patients with schizophrenia perform worse than control subjects. Other authors investigated scanning behavior of subjects with schizophrenia using the Binet-Bobertag's picture (Gaebel et al. 1987), figures from the Benton's visual retention test (Tsunoda et al. 1992), and the WAIS picture completion test (Kurachi et al. 1994). These previous studies have found that patients with schizophrenia show restricted eye-scanning in comparison with normal controls. Furthermore, Matsushima et al. (1998) and Kojima et al. (2001) have reported that patients with schizophrenia are discriminated from non-schizophrenic subjects by the performance on exploratory eye movements with high sensitivity and specificity. These results indicate that exploratory eye movements are a useful discriminator for schizophrenia; however, the

EAPCN 390

precise mechanism underlying the limited eye movement in schizophrenia remains unknown. Two factors may play a role in the restricted eye-scanning behavior in subjects with schizophrenia: one is poor oculomotor activity; the other is a visual cognitive strategy unrelated to the size of the object. If the former were the main factor, then the extent of visual search of the patients would improve as the size of the object reduces. If the latter were the case, then patients might still show limited visual scanning even when the size of the figure object is reduced. Therefore, the first purpose of this study was to examine exploratory eye movements during demonstration of the conventional or a smaller size of the S-shaped figure in patients with schizophrenia.

The second purpose of the present study was to examine the effect of the instruction for performance on restricted viewing pattern in patients with schizophrenia. Several studies have demonstrated improvement in performance through instructional cues on the Wisconsin Card Sorting Test, a neuropsychological measure of executive function (Bellack et al. 1990, Goldman et al. 1992, Vollema et al. 1995). In the present study, a direct instruction, in addition to the confirmative question used by Kojima et al. (1990), was given to the subjects while viewing an S-shaped figure that is slightly different from the original one.

Exploratory eye movements consist of fixations and voluntary saccades. Therefore, the duration of fixation, as well as the spatial extent of visual scanning, is assumed to be responsible for visual cognitive processes. Russo (1978) reported 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 ocular movement itself. During eye fixation that takes 200 ms, information from the stimulus being fixated is presumably acquired within approximately 100 ms, while the rest of the period is for computing where the next fixation should be made. Moreover, it takes additional time to consolidate information or to process deeper information. In most previous studies on exploratory eye movement, a fixation point has been defined as a point at which a gaze is held for longer than 200 ms. However, Matsui et al. (1995, 1997). found that some schizophrenic patients viewed the targets in a shorter period during saccadic tracking task. Therefore, in this study, we examined the eye-scanning pattern characteristic of schizophrenia by setting two different levels of fixation, i. e., 100 ms and 200 ms.

Methods

Subjects

Fifteen patients (9 males, 6 females) who fulfilled DSM-III-R criteria for schizophrenia and 15 normal controls (9 males, 6 females) participated in this study. Two of 15 patients were diagnosed as schizophreniform disorder at the time of this research, but that diagnosis was later changed to schizophrenia. The mean (SD) age for schizophrenic patients and normal controls were 27.5 (5.2) years (range 21–38 years), and 25.0 (1.7) years (range 23–28 years), respectively. The patients, including 14 inpatients and 1 outpatients, were recruited from the Toyama Medical and Pharmaceutical University Hospital. The mean (SD) duration of illness was 5.0 (5.3) years (range 0.3–19.0 years). Neuroleptic medication dose was converted into chlorpromazine (CPZ) equivalent (Davis 1978). The mean (SD) daily CPZ dose was 319.6 (340.7) mg. Clinical symptoms were assessed using the Scale for the Assessment of Negative Symptoms (SANS) and the Scale for the Assessment of Positive Symptoms (SAPS; Andreasen 1984a, b). The control subjects were healthy volunteers recruited from colleges. Informed consent was obtained from all subjects. The mean (SD) duration of education for patients and normal controls were 13.9 (1.7) years (range 12–17 years) and 14.3 (1.1) years (range 13–17 years), respectively. There was no significant difference in the duration of education between patients and controls ($t = 0.65$; $df = 28$; $p = 0.52$).

Procedure

The subjects sat on a chair in front of a screen (1.2 m apart) and had an infrared eye-mark recorder (Nac, type-V) attached to the head. Recordings of eye movements were calibrated under the manipulations adjusting eye-marks in the monitor display to appropriate positions on the edges of the calibration grid during fixating each point. Two geometric figures of the same shape but differing in size, as shown in Fig.1 A and B, were individually projected from the rear on the screen: one was the original S-shaped target figure (Kojima et al. 1986) for which the angle of sight was 33° horizontally and 27.5° vertically; the other was a smaller figure with the angles that were half of those for the original figures. Each subject was shown a figure of the original size for 15 seconds, and was asked to draw the figure after viewing it. Next, the subject was shown the half-sized figure for 15 seconds, and was again asked to draw it. Eye movements during the subject's viewing each figure for 15 s were digitized in time and space on a computer (NEC, PC–9801), and were recorded every 33 ms. A fixation point was defined as a point at which a gaze is held within 1° of visual field for a duration of 200 ms or more. Eye-scanning tracks on a computer display were obtained using a computer software (Nac).

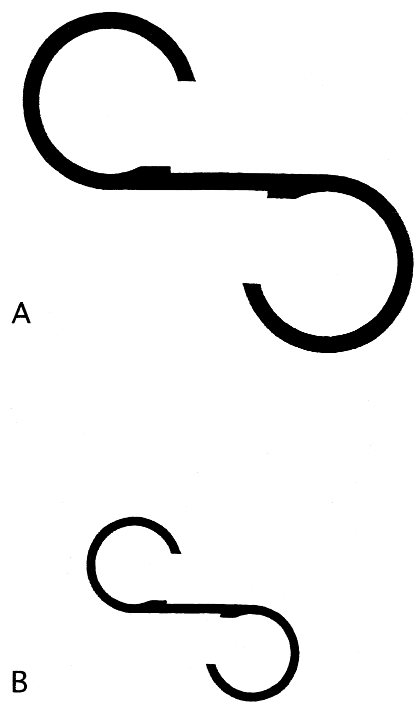


Fig. 1 S-shaped target figure. **A** the original-sized figure; **B** the half-sized figure obtained by reducing the sight angle for the original one to half both horizontally and vertically

Subsequently, the subject was shown a figure slightly different from the original one, in which one bump was in a different position (Fig. 2), for 15 s. The subject was then asked to compare the modified figure with the original one, and to answer how they differed each other. After the subject had finished replying and while still viewing the figure, the question, "Are there any other differences?" (Kojima et al. 1986), was asked. Then, the subject was instructed to draw the figure without seeing it. Next, the subject was again shown a figure that was slightly different from the original one, and was given the instruction, "Please look at all parts and check it up", and again asked to reproduce it.

Measurement

Search Score

To assess the extent of visual scanning, each figure was divided into seven sections according to Kojima et al. (1986) (see Fig. 6). The number of sections, on which the eye fixed more than once during the 15 s viewing period, was counted and scored for 1 to 7 points as the Search Score. The Search Score on seven sections for the first 5 s immediately after each question and instruction was analyzed using two setting levels for fixation point (in the present study, a search score after the instruction was designated as 'instructed search score'); in the 200- or 100-ms setting, a fixation point was defined as a point at which a gaze is held for at least 200 or 100 ms, respectively.

Score of picture reproduction

The subjects drew the target figure based on memory and the reproduced figures were evaluated according to the locations of each bump and the composition of the figure as a whole. The maximum score for the reproduced pictures was seven.

Statistical analyses

To examine the effect of figure size, the search score and the score of picture reproduction were analyzed using a two-way analyses of variance (ANOVAs) where group (patients or controls) and figure size (original or half-sized) were the main factors. To examine the effect of the instruction, the search score was analyzed using a three-way ANOVA where group (patients or controls), condition (question or instruction) and the setting level of fixation (100-ms or 200-ms) were the main factors. The Scheffe test was used in post hoc analyses. Spearman's rank correlation test was used to determine the relationship between search scores and scores of picture reproduction or clinical symptoms. The level of significance was set at $p < 0.05$.

Results

Fig. 3 shows the representative examples of the eye-scanning tracks of a normal control and a patient during demonstration of the original and half-sized figures for 15 s. The search scores for all subjects on each figure are presented in Fig. 4. The 2 (group) $\times$ 2 (size) repeated measure ANOVAs, employing search scores as the dependent variable, yielded a significant main effect of group ($F = 9.52$; $df = 1,28$; $p = 0.005$). There was neither significant main effect of figure size ($F = 0.83$; $df = 1,28$; $p = 0.37$) nor group-by-size interaction ($F = 0.03$; $df = 1,28$; $p = 0.86$).

The scores of picture reproduction for each figure are presented in Fig. 5. Repeated measure ANOVAs with scores of picture reproduction as the dependent variable yielded a significant main effect of group ($F = 30.92$; $df = 1,28$; $p < 0.0001$), but there was neither significant main effect of figure size ($F = 1.51$; $df = 1,28$; $p = 0.23$) nor group-by-figure size interaction ($F = 0.67$; $df = 1,28$; $p = 0.42$). There was no significant correlation between the search score and the score of picture reproduction.

No significant correlation was observed between the

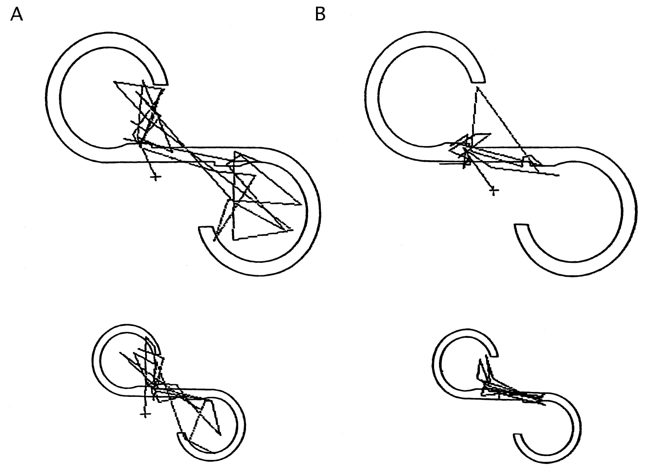


Fig. 3 The eye-scanning tracks on the original-sized figure (the top) and the half-sized figure (the bottom) during initial 15 s: **a** a normal control (24 year-old, female); **b** a schizophrenic patient (18 year-old, female)

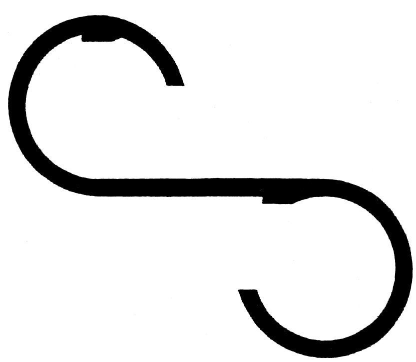


Fig. 2 A slightly modified S-shaped figure

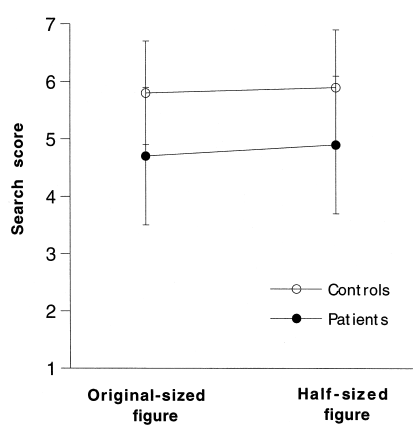


Fig. 4 The search scores for the original-sized figure and the half-sized figure. The number of sections on which the eye fixed once or more during the 15 s viewing period for each figure was counted and scored for 1 to 7 points as search score

search scores and the scores for any subscale of the SANS and SAPS. There was no significant correlation between the score of picture reproduction and the clinical symptoms. No significant correlation was found between the neuroleptic dose and the search score or the score of picture reproduction.

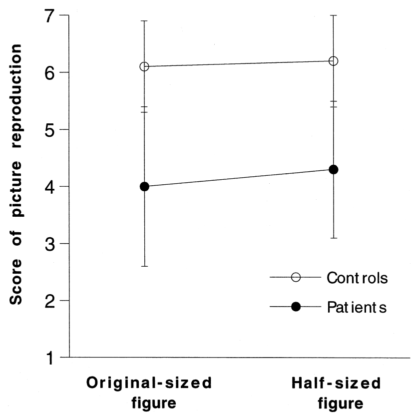


Fig. 5 The score of picture reproduction for the original-sized figure and the half-sized figure. Reproduced pictures were evaluated according to the composition of the figure and were scored for 0 to 7 points

Fig. 6 displays the representative example of the eye-scanning tracks and the search scores to show the effect of the instruction. All patients and normal controls provided the correct response in recognizing the different position of a bump in the modified figure during the first 15 s of demonstration.

Fig. 7 a and b shows the search score for the initial 5 s immediately after the question (responsive search score) or the instruction (instructed search score) was given, at the two setting levels of fixation. The 2 (group) $\times$ 2 (condition) $\times$ 2 (setting level) repeated measures ANOVA was conducted with search scores as the dependent variable. The main effect of group approached significance ($F = 4.05$; $df = 1,28$; $p = 0.054$). The main effect of setting level (100- vs. 200-ms) ($F = 32.16$; $df = 1,28$; $p < 0.0001$), but not that of condition (question vs instruction) ($F = 0.11$; $df = 1,28$; $p = 0.74$) or group $\times$ condition $\times$ setting level interaction ($F = 0.04$; $df = 1,28$; $p = 0.84$) was significant. At the 200-ms setting level, the responsive search score for the patients was signifi-

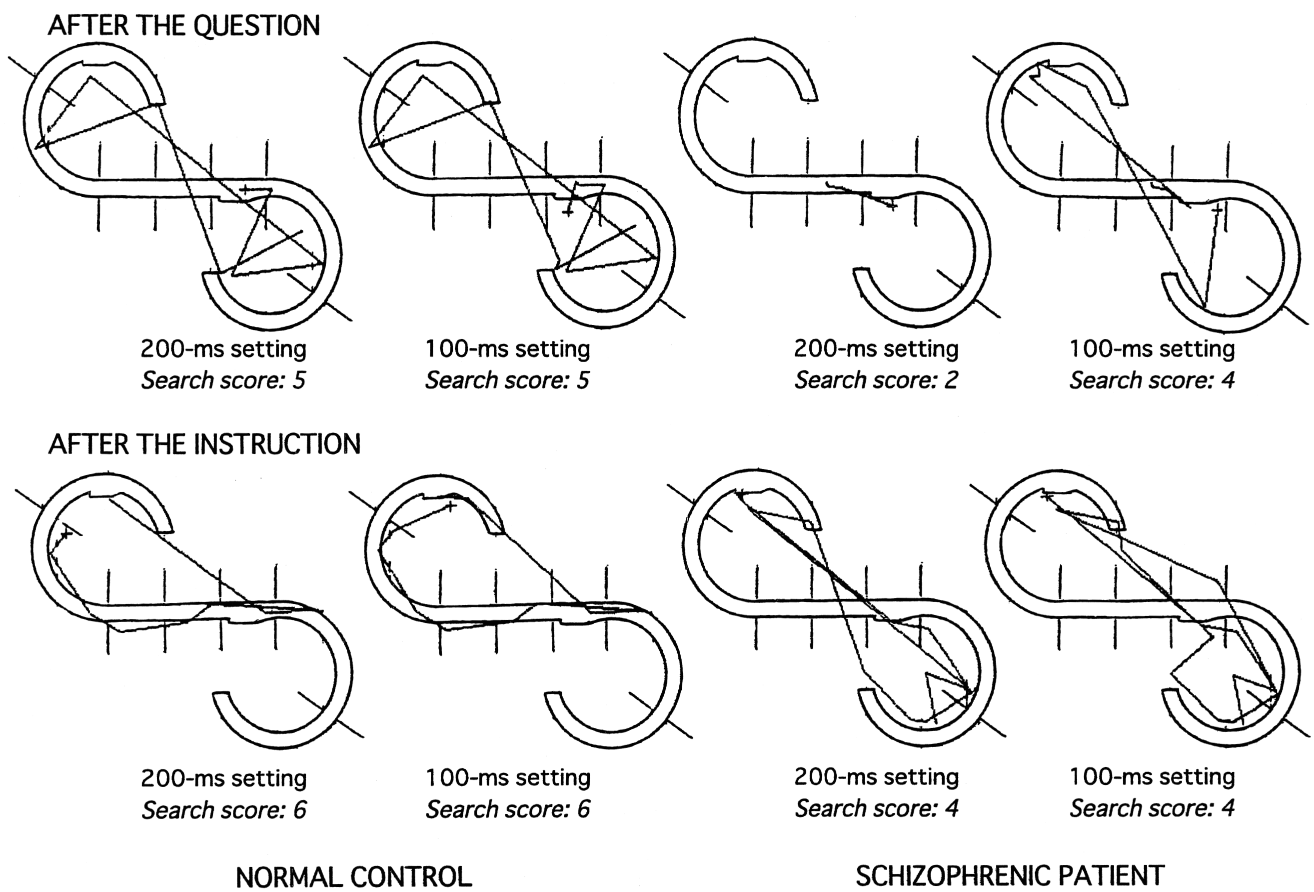
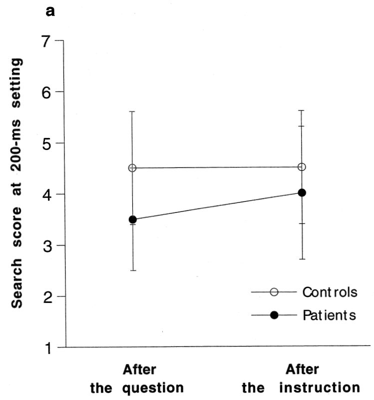


Fig. 6 The eye-scanning tracks and the scoring of search scores for 5 s in a normal control (23 year-old, male) and schizophrenic patient (33 year-old, male). Upper figures are sequences of eye movements at the 200-ms setting and 100-ms setting for 5 s after the question, and lower figures are after the instruction. A normal control showed a wide and similar extent of eye movements at two setting levels after the question, and the search score was 5 at both settings. After the instruction, the search score was 6 at both settings in the normal control. A schizophrenic patient had limited area of visual search at the 200-ms setting after the question, and the search score was 2. At the 100-ms setting, a patient showed a wider area of visual search after the question, and the search score was 4. After the instruction, a patient showed a similar extent of eye movement at both settings, and the search score was 4



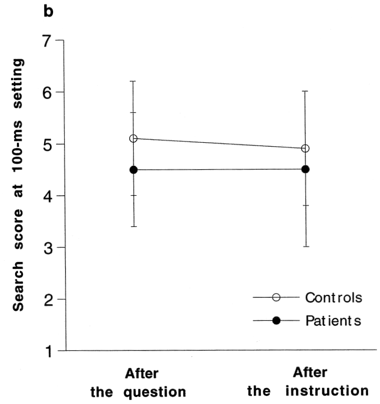


Fig. 7 The search scores for the first 5 s immediately after the question and the instruction: **a** search score at the 200-ms setting; **b** search score at the 100-ms setting

cantly lower than that for normal controls ($p < 0.01$). At the 100-ms setting, however, the responsive search score for the patients no longer differed from that for normal controls. In contrast, the instructed search score for the patients was not significantly different from that for normal controls either at the 100-ms or the 200-ms settings.

The scores of picture reproduction for all subjects at each condition are presented in Fig. 8. Repeated measures ANOVAs with scores of picture reproduction as the dependent variable yielded significant main effects of group ($F = 15.86$; $df = 1,28$; $p < 0.001$) and condition ($F = 10.55$; $df = 1,28$; $p < 0.01$), but there was no significant group-by-condition interaction ($F = 0.22$; $df = 1,28$; $p = 0.65$). The patients showed lower scores of picture reproduction than normal controls after the question ($p < 0.01$) or the instruction ($p < 0.01$) was given. In the patients, the scores of picture reproduction after the question correlated positively with the responsive search scores both at the 200-ms ($r = 0.56$, $p < 0.05$) and the 100-ms ($r = 0.65$, $p < 0.05$) settings.

There was no significant correlation between clinical symptoms and the search score or the score of picture reproduction. No significant correlation was observed

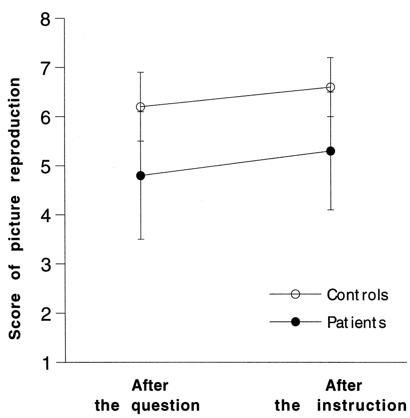


Fig. 8 The score of picture reproduction after the question and the instruction

between the neuroleptic dose and the search score or the score of picture reproduction.

Discussion

Exploratory eye movement on the different sizes of figures

The main effect of figure size and the interaction between group and size were not significant. Moreover, patients showed lower search scores than normal controls not only for the original-sized figure but also for the half-sized figure. These results suggest that restricted eye-scanning in schizophrenia is independent of the size of the object. This finding is consistent with the hypothesis that limited visual search of the patients is not due to poor eye movement, but may be related to impaired cognitive strategy. Cegalis et al. (1977, 1980) found that patients with acute schizophrenia utilized peripheral visual information more efficiently than normal control subjects. It is therefore likely that limited visual search is explained by the differential quantity of information processing within the functional visual fields between patients with schizophrenia and normal controls. However, this interpretation may not be relevant to the limited eye movement pattern in patients with chronic schizophrenia (Kojima, et al. 1989), as these subjects have been reported to show a reduction in the use of peripheral visual information (Cegalis et al. 1977, 1980). One alternative and reasonable explanation is that the restriction of visual search in the patients studied in this study may represent deficiency in redundant eye movements, by which normal controls confirm the patterns of a figure more precisely than do subjects with schizophrenia. The stationary visual field, defined as an area within which information is efficiently processed without eye or head movement, is reported to be an area between 0° and 20° to 30° (Sanders 1970). The amount of saccades that the normal subjects produced in the present study, therefore, may be associated with redundant scanning of the areas of the original S-shaped (display angles of 33° horizontally and 27.5° vertically) and the half-sized figures. Therefore, our results suggest decreased redundancy in some types of cognitive behavior in patients with schizophrenia.

The similar search scores for the original and the half-sized figure indicate that each individual inspects and scans the same regions of objects, and shows an identical pattern of eye-scanning tracks for these figures, since previous studies (Noton and Stark 1971a, b; Locher and Nodine 1974) have suggested that a fixed scan path specific to an individual appears when she/he views a figure.

Exploratory eye movement after a question and an instruction

Based on most previous studies investigating exploratory eye movement, we analyzed fixation data using the 200-ms setting. On this condition, the patients showed lower search scores than normal controls after the confirmative question was given, which is consistent with a series of reports by Kojima et al. (1986, 1989, 1990, 1992) who suggested that the responsive search score may be an indicator of an interpersonal response and a specific marker for schizophrenia. The present study further indicated that the direct instruction abolishes the difference in the search score between the patients and normal controls. It is possible that normal controls understood the implication of the question, which suggests exploring the figure all around to confirm their answers, whereas the patients were not fully aware of the implication until given the direct instruction for the generation of an adequate plan of action. According to the models proposed by Frith (1987) and Robbins (1990), plans of action originate from prefrontal cortical activity; followed by formation of a willed intention, which is subsequently translated into action. Robbins (1991) proposed that willed action depends upon a fronto-striatal system in which dopamine plays a crucial role. In the present study, the appropriate response was not triggered by a confirmative question alone in patients with schizophrenia, suggesting deficits in generating plans of action. On the other hand, the direct instruction improved the cognitive behavior in the patients. Thus, the direct instruction may have either facilitated the generation of plans of action or taken the place of a willed intention in the patients.

In contrast to the results at the 200-ms setting, no significant difference was observed in the responsive search score between the patients and normal controls at the 100-ms setting. The typical duration of an eye movement cycle is estimated to be 230 ms, with 110 ms required for cognitive operations. The minimum duration of the component of eye movement unrelated to cognitive operation is assumed to be about 70 ms (Russo 1978). Thus, approximately 200 ms or more should be required for the fixations in order for the cognitive system to be adequately operated. However, the patients in our study revealed the normal performance level even when the duration of longer than 100 ms was defined as the fixations. Therefore, the present result may provide additional evidence for impaired neurocognitive function in schizophrenia. Consistent with this, Matsui et al. (1995, 1997). reported that patients with schizophrenia showed more deviant scan paths than normal controls, and that some patients accurately tracked target points at the100-ms setting but not at the 200-ms setting.

Picture reproduction

A positive correlation was observed between the responsive search scores and the scores of picture reproduction in patients with schizophrenia. However, there were no significant correlations between the scores of picture reproduction and the search scores or the instructed search scores in patients with schizophrenia. These results indicate that the deficit in picture reproduction in schizophrenia was not entirely due to restricted eye-scanning.

Relationship between the search score vs. clinical symptoms and neuroleptics dose

There was no significant correlation between clinical symptoms, as assessed by SANS and SAPS, and the search score. These findings contrast with those obtained by Kojima et al. (1990, 1992), who reported a negative correlation between the responsive search score and negative symptoms, as assessed by SANS or Brief Psychiatric Rating Scale (Overall and Gorham 1962). The discrepant results between these previous studies and the present trial may be due to the differences in the mean duration of illness (mean 17.0 years in Kojima et al. vs. 5 years in this study) or the sample size (50 patients in Kojima et al. vs. 15 patients in this study).

There was no significant correlation between the dose of neuroleptics and the search score. Green and King (1998) have reported that treatment with chlorpromazine did not affect saccadic distractibility, although peak visually guided saccade velocity was decreased. Moriya (1979) and Kojima et al. [1990, 1992] found no significant correlation between exploratory eye movement and neuroleptic dose (chlorpromazine equivalent) in patients with schizophrenia. Furthermore, Kojima et al. (1989) and Obayashi et al. (2001) have reported that exploratory eye movements in schizophrenia did not change during treatment with neuroleptic drugs. Therefore, treatment with typical neuroleptics appears unlikely to influence exploratory eye movements, which is assumed to be a stable marker of schizophrenia. On the other hand, the effect of atypical neuroleptics on exploratory eye movement in schizophrenia deserves further study.

In conclusion, the findings of the present study suggest that restricted eye scanning in schizophrenia is associated with poor cognitive strategy rather than impaired oculo-motor functions. Our results also indicate that the direct instruction for performance, but not the size of the figure or the indirect suggestion, has the ability to improve the visual performance that is impaired in patients with schizophrenia.

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