Eye movements during natural actions in patients with schizophrenia

Céline Delerue, PhD; Mary Hayhoe, PhD; Muriel Boucart, PhD

Delerue, Boucart — Laboratoire de Neurosciences Fonctionnelles et Pathologies, Université Lille — Nord de France, CNRS, Lille, France; Hayhoe — Center for Perceptual Systems, University of Texas, Austin, Tex., USA

Background: Visual scanning and planning of actions are reported to be abnormal in patients with schizophrenia. Most studies that monitored eye movements in these patients were performed under free-viewing conditions and used 2-dimensional images. However, images differ from the natural world in several ways, including task demands and the dimensionality of the display. Our study was designed to assess whether abnormalities in visual exploration in patients with schizophrenia generalize to active-viewing tasks in realistic conditions of viewing and to examine whether disturbances in action sequencing in these patients are reflected in their visual scanning patterns while executing natural tasks. **Methods:** We monitored visual scan paths in patients with schizophrenia and healthy controls. Participants performed several tasks in which they were asked to look at a realistic scene on a table (free-viewing) and perform 2 active-viewing tasks: a familiar task (sandwich-making) and an unfamiliar task (model-building). The scenes contained both task-relevant and task-irrelevant objects. **Results:** We included 15 patients and 15 controls in our analysis. Patients exhibited abnormalities in the free-viewing condition. Their patterns of exploration were similar to those of controls in the familiar task, but they showed scanning differences in the unfamiliar task. Patients were also slower than controls to accomplish both tasks. **Limitations:** Patients with schizophrenia were taking antipsychotic medications, so the presence of medication effects cannot be excluded. **Conclusion:** People with schizophrenia present a basic psychomotor slowing and seem to establish a less efficient planning strategy in the case of more complex and unfamiliar tasks.

Introduction

Eye movement disturbances in visual exploration have been reported in patients with schizophrenia, and visual scan path abnormalities have been proposed to serve as a trait marker for the disorder.[1,2] Benson and colleagues[3] have even suggested that simple eye movement tests, such as smooth pursuit, fixation stability or free-viewing tasks, can distinguish between schizophrenia and the control condition in case–control studies. Studies monitoring eye movements have found reduced visual scan paths on photographs of faces[1,4–8] and various other stimuli, such as complex scenes;[9] geometric shapes;[10] Rorschach stimuli;[11] and photographs of landscapes, fractals and meaningless patterns.[12] In most of these studies, visual scanning was examined under free-viewing conditions,[4,12] and in some,[1,5,7] participants were asked to determine the facial expression. Moreover, these studies used 2-dimensional (2-D) images; however, 2-D images differ from the natural world in several ways, including task demands and the dimensionality of the display. One of the objectives of our study was to assess whether abnormalities in visual exploration in patients with schizophrenia generalize to active-viewing tasks under realistic viewing conditions.

Numerous studies have documented various forms of disturbances of action production, such as poverty of action, disorganization behaviour, stereotyped and incoherent actions, in patients with schizophrenia. Psychomotor slowing is considered an important clinical characteristic of schizophrenia, but its exact nature remains unclear, as it involves multiple aspects, including goal selection, inhibition, planning, sequencing and execution. Several studies have provided evidence of psychomotor slowing and planning deficits in patients with schizophrenia. Jogems-Kosterman and colleagues[13] reported that patients with schizophrenia were slower than controls in copying tasks. This slowing was found in initiation time (i.e., before starting an action) and in movement time (i.e., during

Correspondence to: C. Delerue, CHU Lille, Hôpital Roger Salengro, Laboratoire de Neurosciences Fonctionnelles et Pathologies, F-59037 Lille, France; celine.b.delerue@wanadoo.fr

J Psychiatry Neurosci 2013;38(5):317-24.

Submitted July 25, 2012; Revised Dec. 6, 2012, Feb. 3, 2013; Accepted Feb. 5, 2013.

DOI: 10.1503/jpn.120143

the execution period). Moreover, increased figure complexity, or decreased familiarity, lengthened the initiation time. Grootens and colleagues[14] demonstrated that psychomotor planning deficits were already present in the early stages of schizophrenia and involved deficient planning but intact motor action. In figure-copying tasks, patients with recent-onset schizophrenia were substantially slower than controls in the initiation of motor actions as soon as they encountered a minor increase in complexity, such as unfamiliar figures or the planning of a motor sequence. Using a sequential pointing task, Delevoye-Turrell and colleagues[15] found that patients with schizophrenia executed the sequences less fluently than controls, particularly when sequences of action were required, and that the patients' fluency deficit increased with sequence complexity. In a computerized version of the Tower of London task, Pantelis and colleagues[16] found that increased task complexity prolonged the duration of the execution period more strongly in patients with schizophrenia than in controls. This result suggests that patients need more time during the task for further planning and monitoring of their movements. Semkovska and colleagues[17] and Stip and colleagues[18] suggested that deficits in executive functions have a detrimental impact on typical activities of daily living. With a standardized behavioural scale of action sequences, these studies have assessed patients' ability to perform daily activities, such as choosing a menu, shopping and cooking. Patients with schizophrenia showed more planning, sequencing, repetition and omission errors than controls. Despite many studies on action planning deficits in patients with schizophrenia, their ability to plan and to accomplish a sequence of actions has, to our knowledge, not yet been studied using eye movement recording. Therefore, we sought to examine whether disturbances in action sequencing in patients with schizophrenia are reflected in their visual scanning patterns while executing well-learned or less familiar natural actions.

We examined the pattern of eye movements in patients with schizophrenia using the sandwich-making task,[19] as its pattern is well known in healthy observers. In studies on food preparation, there are periods of search, particularly before the actual task begins. During these periods, objects are located, and at least some of their positions are memorized, but without any manipulative action. Then, more commonly, both hands are engaged with the same object, and in a few cases, the 2 hands have separate roles. Very few irrelevant objects are fixated during the execution of the task in healthy participants. The gaze moves from one task-relevant object to the next, ignoring all other objects not involved in the task, even when they are salient objects in the environment. The authors[19] concluded that, in real tasks, the eyes are driven much more by top–down information from the script of the activity, and very little by salient features, such as contrast. They also observed that the fixations are precisely linked in time to actions, such as placing or grasping an object. Gaze moves to locations where information critical for manipulation is obtained, and fixation precedes action by a short interval, usually less than a second.[19–21] Observers appear to use gaze to select the specific information required for a point in the task. This aspect of natural behaviour has been called a "just-in-time" strategy.[22]

Based on previous findings, especially reduced visual exploration, the fact that patients with schizophrenia exhibit substantial difficulties with planning and organization of action, and that these patients show an exaggerated susceptibility to distraction,[23] we expected that patients would explore less, exhibit fewer fixations to the relevant objects and more fixations to irrelevant objects than controls, and that the familiar task would be better accomplished than the unfamiliar task.

Methods

Participants

We recruited medicated in- and outpatients fulfilling the DSM–IV diagnostic criteria for schizophrenia[24] and age- and sex-matched healthy controls without a psychiatric diagnosis (Axis I and II) and without a family history of mental illness to participate in the experiment. Patients were recruited from the Department of General Psychiatry in Lille University Medical Center and from the Psychology Center in Béthune (France). Controls were recruited among students and members of the medical staff. The inclusion criterion for all groups was normal or corrected-to-normal vision (assessed by the Snellen chart). Exclusion criteria were recent history of substance abuse, ocular disease, epilepsy and other neurologic disorders, and failure to understand the instructions. We rated schizophrenia symptoms using the Positive and Negative Syndrome Scale (PANSS).[25] The study was approved by the Ethics Committee of Lille University Hospital. All participants provided informed consent.

Stimuli

Different "familiar sandwich" scenes (Fig. 1A) were built containing 7 task-relevant objects required to make a butter and jelly sandwich and pour a glass of water, as well as 7 task-irrelevant objects. All objects were laid out on a table. When the participant was seated at the table, with all objects within reach, the plate close to the observer subtended about 20° of the visual angle and the butter and jelly subtended about 7°.

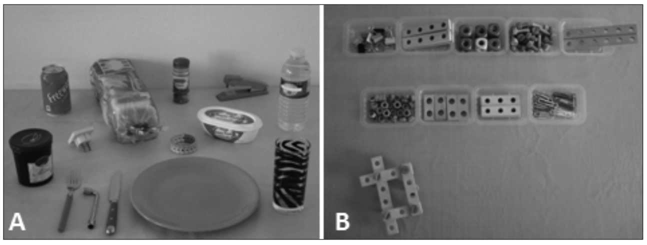

Fig. 1: Examples of the 2 scene layouts used. (**A**) The "familiar sandwich" scene contained both task-relevant (bread, butter, jelly, knife, plate, glass, water bottle) and irrelevant objects (fork, tool, plug, tape measure, stapler, soda, spice jar). (**B**) The "unfamiliar construction set" scene contained both task-relevant (model pieces, screws, nuts) and irrelevant objects (2 other pieces from construction set that were not necessary, 2 different kinds of paperclips).

All objects were located within a region covering 90°.

An "unfamiliar construction set" scene (Fig. 1B) was also built containing a display model and several pieces from a child's construction set in 9 plastic containers on another table. Three containers held the model pieces that had to be manipulated; 2 contained screws and nuts, respectively; and 4 contained distractor pieces. All containers were within reach of the participants.

The 2 scenes were occluded by a white board showing the calibration points, which was removed once the calibration was completed. Only 1 scene was visible at a time.

Equipment

We monitored monocular (right) eye position using the iViewX HED (SensoMotoric Instruments) eye tracker with a scene camera. The video-based eye tracker is head-mounted and uses infrared reflection to provide an eye-in-head signal at a sampling rate of 50 Hz and an accuracy of about 1°. The scene camera mounted on the head was positioned so that its field of view was centred on the participant's field of view. Calibration was performed using a 5-point grid. Following calibration, the eye tracker creates a cursor, indicating eye-in-head position, which is merged with the video from the scene camera. The scene camera moves with the head, so the eye-in-head signal indicates the gaze point. The eye tracker thus provides a video recording of eye position from the participant's perspective, and the data analysis is based on the video, as there is no separate numerical data stream. We analyzed the video recordings on a frame-by-frame basis, recording the time of initiation and termination of each eye and hand movement, the location of the fixations and the nature of the hand actions. Saccades appeared in the large displacements of the cursor between video frames. The beginning and end of each saccade was identified and recorded using a video analysis tool. Fixations are defined visually when the cursor stays within a given location (less than a degree) defined by the noise level of the tracker. Thus, fixations are defined jointly by position and velocity. Blinks are detected by occlusion of the pupil, and the cursor is occluded during the blink.

Procedure

Participants started with a free-viewing task in which they were asked to look at a realistic scene ("sandwich scene") on a table for 10 seconds. Then, participants performed 2 active-viewing tasks. The first was to make a butter and jelly sandwich and pour a glass of water (familiar task), and the second was to assemble 4 wooden slats from a child's construction set using screws and nuts according to a display model (unfamiliar task). The order of tasks was randomized.

Before the experiments, the layout was occluded by a white board showing the 5 calibration points, enabling the participants to be calibrated on the plane of the working surface. The participant had to fixate the targets (coloured dots) while his/her eye positions were recorded by the system. Once the calibration was completed, the white board was removed, and the participant immediately started the task. A recalibration procedure occurred after each task. The entire session lasted about 30 minutes.

Data analysis

We tested 2 experimental conditions: free versus active viewing and familiar versus unfamiliar task. We measured the duration of individual fixations and the total gaze duration on specific objects in instances where several successive fixations were made on the same object. Gaze duration on both relevant and irrelevant objects was then determined. Eye movement variables were submitted to analyses of variance (ANOVAs) using the STATISTICA software from StatSoft (version 7.1). We examined possible confounding effects of medication, illness duration, positive and negative symptom categories (indexed by PANSS), patient categories, sex and handedness. For patients with schizophrenia, there were no significant correlations between medication, illness duration or symptom category on one hand and any of the scan path variables on the other. We computed associations between sex or handedness and scan path variables for both groups. No statistically significant correlations emerged.

Results

Participants

Fifteen patients with schizophrenia and 15 age- and sex-matched healthy controls took part in the experiment. Participant demographic and clinical characteristics are summarized in Table 1.

Free versus active viewing

Fixation durations

The fixation duration refers to the mean duration across all fixations. A 2 (group: patients/controls) × 2 (task: free/active

Table 1: Demographic and clinical characteristics of patients with schizophrenia and healthy controls performing free-viewing and active-viewing tasks

	Group; mean (SD)*	
Characteristic	Schizophrenia, *n* = 15	Control, *n* = 15
Age, yr	35.1 (7.1)	33.9 (8.7)
Sex, no. male:female	13:2	13:2
Handedness, no. right:left	12:3	12:3
Antipsychotic medication, mg chlorpromazine equivalent	469.8 (186.8)	—
Benzodiazepine medication, mg diazepam equivalent	154.5 (40.9)	—
Illness duration, yr	11.4 (8.2)	—
PANSS score		
Positive symptom	19.1	—
Negative symptom	21.2	—
General psychopathology	37.7	—
Total	78.0	—

*Unless otherwise indicated.
PANSS = Positive and Negative Syndrome Scale;[25] SD = standard deviation.

viewing) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28}$ = 23.3, p < 0.001, ηp^2 = 0.45) and task ($F_{1,28}$ = 49.6, p < 0.001, ηp^2 = 0.64) on the fixation durations. There was also a significant interaction between group and task ($F_{1,28}$ = 10.8, p = 0.003, ηp^2 = 0.28). Patients exhibited longer fixation durations in the free-viewing condition ($F_{1,28}$ = 56.5, p < 0.001, ηp^2 = 0.67), but did not differ from controls in the active-viewing condition ($F_{1,28}$ = 1.8, p = 0.19, ηp^2 = 0.06; Fig. 2).

A contrast analysis for patients and controls showed that both groups had longer fixation durations in the active-viewing condition (patients: free v. active viewing, $F_{1,28}$ = 7.1, p = 0.013, ηp^2 = 0.20; controls, free v. active viewing, $F_{1,28}$ = 53.2, p < 0.001, ηp^2 = 0.66).

Gaze durations on relevant and irrelevant objects

A 2 (group: patients/controls) × 2 (task: free/active viewing) × 2 (objects: relevant/irrelevant) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28}$ = 13.8, p < 0.001, ηp^2 = 0.33), task ($F_{1,28}$ = 29.4, p < 0.001, ηp^2 = 0.51) and objects ($F_{1,28}$ = 115.3, p < 0.001, ηp^2 = 0.80) on the gaze durations. There was no significant interaction between group, task and objects ($F_{1,28}$ = 2.1, p = 0.15, ηp^2 = 0.07), but there was a significant interaction between group and task ($F_{1,28}$ = 14.1, p < 0.001, ηp^2 = 0.34) and between task and objects ($F_{1,28}$ = 164.7, p < 0.001, ηp^2 = 0.85; Fig. 3).

Free-viewing condition

Patients with schizophrenia exhibited longer gaze durations than controls on objects in general in the free-viewing condition (relevant objects, $F_{1,28}$ = 49.5, p < 0.001, ηp^2 = 0.64; irrelevant objects, $F_{1,28}$ = 15.4, p < 0.001, ηp^2 = 0.35).

Patients and controls looked equally at relevant and irrelevant objects in the free-viewing condition (patients, relevant v. irrelevant objects, $F_{1,28}$ = 3.2, p = 0.08, ηp^2 = 0.10; controls, relevant v. irrelevant objects, $F_{1,28}$ = 1.3, p = 0.26, ηp^2 = 0.05).

Active-viewing condition

Patients did not differ from controls in the realistic task (relevant objects, $F_{1,28}$ = 0.01, p = 0.91, ηp^2 = 0.01; irrelevant objects, $F_{1,28}$ = 2.8, p = 0.10, ηp^2 = 0.10).

Patients and controls looked more at relevant objects in the active-viewing condition (patients, relevant v. irrelevant objects, $F_{1,28}$ = 77.4, p < 0.001, ηp^2 = 0.73; controls, relevant v. irrelevant objects, $F_{1,28}$ = 88.9, p < 0.001, ηp^2 = 0.76).

Free- versus active-viewing conditions

Patients looked more at relevant objects and less at irrelevant objects in the real task, as did controls (patients: relevant objects, free v. active viewing, $F_{1,28}$ = 25.3, p < 0.001, ηp^2 = 0.47; irrelevant objects, free v. active viewing, $F_{1,28}$ = 52.6, p < 0.001, ηp^2 = 0.65; controls: relevant objects, free v. active viewing, $F_{1,28}$ = 85.2, p < 0.001, ηp^2 = 0.75; irrelevant objects, free v. active viewing, $F_{1,28}$ = 12.4, p < 0.001, ηp^2 = 0.29).

Familiar versus unfamiliar task

Performance task durations

Total task duration: A 2 (group: patients/controls) × 2 (task: familiar/unfamiliar) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28}$ = 44.1, p < 0.001, ηp^2 = 0.61) and task ($F_{1,28}$ = 51.4, p < 0.001, ηp^2 = 0.65) on the task durations. There was a significant interaction between group and task ($F_{1,28}$ = 19.9, p < 0.001, ηp^2 = 0.42). For accomplishing the familiar task, patients needed on average 1.54 minutes, whereas controls needed 1.19 minutes ($F_{1,28}$ = 22.1, p < 0.001, ηp^2 = 0.44). In the unfamiliar task, these values were 3.20 minutes for patients and 1.57 minutes for controls ($F_{1,28}$ = 33.3, p < 0.001, ηp^2 = 0.54). Patients took longer in the unfamiliar than the familiar task ($F_{1,28}$ = 67.7, p < 0.001, ηp^2 = 0.71), but there was no significant difference between the 2 tasks among controls ($F_{1,28}$ = 3.7, p = 0.07, ηp^2 = 0.12).

Pretask duration: We examined visual scanning after the scene was initially exposed by removing the calibration display and before the first reaching movements, which indicated that participants had begun the task. This period was called "pretask." A 2 (group) × 2 (task) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28}$ = 88.4, p < 0.001, ηp^2 = 0.76) and task ($F_{1,28}$ = 24.5, p < 0.001, ηp^2 = 0.47) on the pretask durations. There was a significant interaction between group and task ($F_{1,28}$ = 5.2,

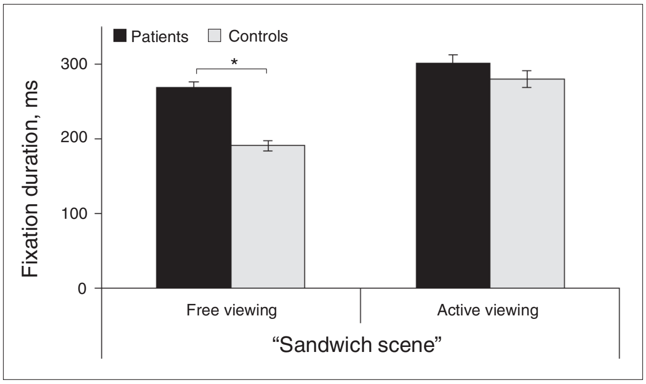

Fig. 2: Mean fixation durations for patients and controls in the sandwich-making task as a function of viewing condition (free v. active viewing). *p < 0.001.

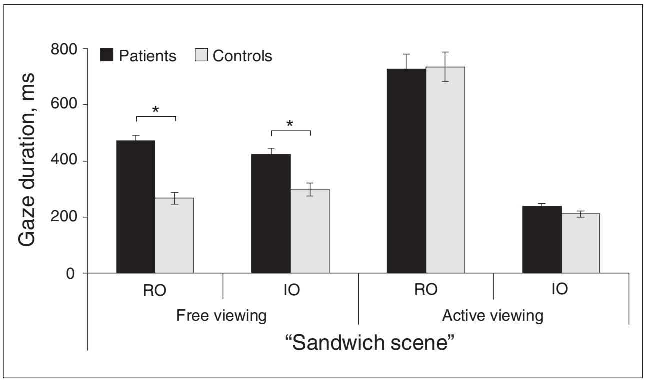

Fig. 3: Gaze durations for patients and controls in the sandwich-making task as a function of viewing condition (free v. active viewing). *p < 0.001. IO = irrelevant objects, RO = relevant objects.

$p = 0.030$, $\eta p^2 = 0.16$). Relative to controls, the pretask was significantly longer in patients both in the familiar task ($F_{1,28} = 22.0$, $p < 0.001$, $\eta p^2 = 0.44$) and in the unfamiliar task ($F_{1,28} = 47.6$, $p < 0.001$, $\eta p^2 = 0.63$), and the pretask duration was even longer in the more complex unfamiliar task ($F_{1,28} = 26.1$, $p < 0.001$, $\eta p^2 = 0.48$). Patients needed on average 4.9 seconds (compared with 3.1 s in the control group) to make the first move in the familiar task. In the unfamiliar task, these values were 7.6 seconds for patients and 4.0 seconds for controls. Patients were slower than controls in the pretask.

Gaze durations on relevant and irrelevant objects

To examine visual exploration on the objects, we determined 2 time periods for the 2 tasks: the pretask (i.e., period before the first reaching movement) and the "working" period (i.e., period during which participants accomplished the task).

A 2 (group: patients/controls) × 2 (task: familiar/unfamiliar) × 2 (period: pretask/working) × 2 (objects: relevant/irrelevant) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28} = 17.9$, $p < 0.001$, $\eta p^2 = 0.39$), task ($F_{1,28} = 11.9$, $p = 0.002$, $\eta p^2 = 0.30$), period ($F_{1,28} = 110.2$, $p < 0.001$, $\eta p^2 = 0.80$) and objects ($F_{1,28} = 244.4$, $p < 0.001$, $\eta p^2 = 0.90$) on the gaze durations. Moreover, there was a significant interaction between group, task and period ($F_{1,28} = 6.0$, $p = 0.021$, $\eta p^2 = 0.18$; Fig. 4).

Familiar task (sandwich-making)

There was only 1 difference between the groups. Patients exhibited longer gaze durations than controls on irrelevant objects in the pretask period of the familiar task ($F_{1,28} = 8.9$, $p = 0.006$, $\eta p^2 = 0.24$).

In the 2 periods, both groups had longer gaze durations on relevant objects (patients: pretask, relevant v. irrelevant objects, $F_{1,28} = 10.4$ $p = 0.004$, $\eta p^2 = 0.27$; working, relevant v. irrelevant objects, $F_{1,28} = 107.8$, $p < 0.001$, $\eta p^2 = 0.79$; controls: pretask, relevant v. irrelevant objects, $F_{1,28} = 16.9$, $p < 0.001$, $\eta p^2 = 0.38$; working, relevant v. irrelevant objects, $F_{1,28} = 119.4$, $p < 0.001$, $\eta p^2 = 0.81$).

Moreover, when patients and controls accomplished the task, they looked more at relevant objects (patients: relevant objects, pretask v. working, $F_{1,28} = 13.6$, $p < 0.001$, $\eta p^2 = 0.33$; controls: relevant objects, pretask v. working, $F_{1,28} = 12.1$, $p = 0.002$, $\eta p^2 = 0.30$) and less at irrelevant objects (patients: irrelevant objects, pretask v. working, $F_{1,28} = 5.9$, $p = 0.021$, $\eta p^2 = 0.18$; controls: irrelevant objects, pretask v. working, $F_{1,28} = 4.4$, $p = 0.045$, $\eta p^2 = 0.14$).

Unfamiliar task (model-building)

Patients presented the same scanning pattern as controls in the pretask period of the unfamiliar task. The 2 groups looked at relevant and irrelevant objects equally in this period. There was no significant difference between the groups in the pretask (all $F < 1$, all $p > 0.05$).

In the working period, patients had longer gaze durations on relevant objects and on irrelevant objects than controls (relevant objects, $F_{1,28} = 9.9$ $p = 0.004$, $\eta p^2 = 0.26$; irrelevant objects, $F_{1,28} = 96.9$, $p < 0.001$, $\eta p^2 = 0.78$).

Moreover, patients and controls looked more at relevant objects when they accomplished the task (patients: relevant objects, pretask v. working, $F_{1,28} = 94.6$, $p < 0.001$, $\eta p^2 = 0.77$; controls: relevant objects, pretask v. working, $F_{1,28} = 35.7$, $p < 0.001$, $\eta p^2 = 0.56$), but there was 1 difference between the 2 groups on irrelevant objects. When they accomplished the task, patients looked more at irrelevant objects (pretask v. working, $F_{1,28} = 39.4$, $p < 0.001$, $\eta p^2 = 0.58$), whereas controls looked less at irrelevant objects during this same period (pretask v. working, $F_{1,28} = 5.5$, $p = 0.026$, $\eta p^2 = 0.16$).

A separate ANOVA revealed that patients had to look more at the display model than controls to accomplish the task correctly ($F_{1,28} = 17.6$, $p < 0.001$, $\eta p^2 = 0.39$; Fig. 4).

Number of errors

If the participant used an irrelevant object, an error was recorded. The 2 groups did not make any mistakes in the familiar task, but patients made significantly more mistakes than controls in the unfamiliar task (patients, mean 3.3 errors; controls, mean 0.5 errors; $F_{1,28} = 27.4$, $p < 0.001$, $\eta p^2 = 0.49$).

"Look-ahead" fixations

During the execution of natural tasks, study participants sometimes fixate objects that are not yet manipulated but will be grasped a few seconds later. Such early looks are known

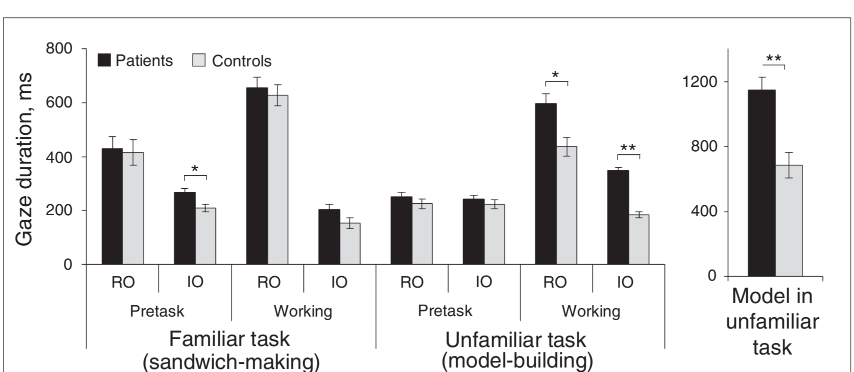

Fig. 4: Gaze durations for patients and controls as a function of the task (familiar/unfamiliar) and on the display model in the unfamiliar task. *$p < 0.01$, **$p < 0.001$. IO = irrelevant objects, RO = relevant objects.

as “look-ahead fixations.”[26] They are identified as a look-ahead if the participant looks back to the original object before subsequently returning (within 3 s) to manipulate the target of the look-ahead. They are not artifacts of “look-backs,” as participants do not look back at objects once they have finished with them, even if these objects remain in full view. Look-ahead fixations occur on average 3 seconds before the reach, and their frequency is influenced by task sequence, suggesting that they are purposeful and are thought to reflect planning of the next action.[27]

A 2 (group: patients/controls) × 2 (task: familiar/unfamiliar) repeated-measures multivariate ANOVA showed a significant main effect of group ($F_{1,28} = 6.9$, $p = 0.013$, $\eta p^2 = 0.20$) and task ($F_{1,28} = 12.1$, $p = 0.002$, $\eta p^2 = 0.30$) on the percentage of look-ahead fixations. There was also a significant interaction between group and task ($F_{1,28} = 4.4$, $p = 0.044$, $\eta p^2 = 0.14$).

Patients exhibited fewer look-aheads in the unfamiliar task ($F_{1,28} = 16.1$, $p < 0.001$, $\eta p^2 = 0.37$), but did not differ from controls in the familiar task ($F_{1,28} = 0.03$, $p = 0.87$, $\eta p^2 = 0.01$). In the unfamiliar task, patients’ look-aheads accounted for 15.1% of the fixations compared with 21.2% in the control group. In the familiar task, these values were 22.7% for patients and 23.0% for controls.

A contrast analysis for patients and controls showed that patients made fewer look-ahead fixations in the unfamiliar task ($F_{1,28} = 15.6$, $p < 0.001$, $\eta p^2 = 0.36$), whereas there was no significant difference between the 2 tasks for controls ($F_{1,28} = 0.9$, $p = 0.34$, $\eta p^2 = 0.03$).

Discussion

Much of the work on fixation patterns in scenes has been performed using 2-D images. However, images differ from the natural world in several ways, including the nature of the task demands, the dimensionality of the display, and the familiarity and the complexity of the tasks. In natural behaviour, fixation patterns are highly task-dependent.[19,21,26,28–31] Each task has a characteristic and flexible pattern of eye movements that accompanies it, and this pattern is similar among individuals. To investigate the role of these factors in gaze patterns, we monitored eye movements in patients with schizophrenia and healthy participants under a free-viewing condition versus an active-viewing condition with realistic scenes as stimuli and in a familiar task (sandwich-making) versus an unfamiliar task (model-building) condition.

Consistent with previous eye movement studies using images as stimuli,[12] our results show that patients with schizophrenia exhibited abnormalities in the free-viewing condition with longer fixation durations and fewer fixations than controls. Patients did not differ from controls in the active-viewing condition in which both groups looked more at relevant objects to accomplish the action, ignoring the distractors. This result can be related to studies on attentional control and cognitive flexibility in patients with schizophrenia.[23] Patients are able to normalize their patterns of exploration when they are actively involved in more demanding tasks.[32,33]

The second part of our work was designed to study the planning deficits in eye movement patterns in patients with schizophrenia. Thus, we have monitored eye movements in both patients and controls under 2 realistic active-viewing conditions (familiar/unfamiliar). Our results show that patients were slower than controls in both tasks. Patients were also significantly slower than controls in the initiation of motor actions (pretask) in both tasks, and the pretask duration was even longer in the more complex unfamiliar task. These results are consistent with those of previous studies showing a general psychomotor slowing in patients with schizophrenia.[13] Longer initiation times for more complex tasks suggest increased difficulties in preplanning the entire sequence before its initiation; however, when the task was more difficult, patients in our study did not seem to use more initiation time to memorize and plan the required actions. Similarly, using “grip” actions, Delevoye-Turrell and colleagues[34] have shown that patients with schizophrenia are characterized by an abnormal allocation profile: more attention was allocated for execution than for planning. In our study, patients performed relatively worse in the unfamiliar task (i.e., patients made more mistakes than controls in copying the display model).

Problems in the planning of movements in patients with schizophrenia could result from the effects of the complexity and unfamiliarity that are greater in people with schizophrenia. These observations are consistent with those in studies demonstrating that complexity increased planning deficits.[13,14,16] A study using the Tower of London task[16] mentioned the possibility that patients with schizophrenia may not plan the required sequence of actions fully in advance; this hypothesis was supported by their finding that these patients needed more moves to complete the trials and produced fewer perfect solutions.

In our study, patients presented patterns of exploration quite similar to those of controls in the familiar task, but showed scanning differences in the unfamiliar task. One explanation could be that the sandwich task is a well-learned task — a familiar daily activity involving less demanding cognitive resources. In the unfamiliar task, patients looked more at distractors. It is known that patients with schizophrenia are more sensitive to distraction than healthy controls.[23,35] In our study, it might be that a salient feature in the object (e.g., colour, contrast edges) automatically captured the patients’ attention and that they found it difficult to disengage their attention from that feature. Moreover, studies using the antisaccade paradigm have demonstrated that patients show difficulty inhibiting a reflexive saccade.[36] However, our results showed that patients also looked more at task-relevant objects than controls in the execution period. Furthermore, patients made fewer “look-ahead” fixations in the unfamiliar task. This suggests that people with schizophrenia tend to plan their actions less in advance in the case of more complex, unfamiliar tasks. Hayhoe and colleagues[19] and Land and colleagues[21] have observed that about one-third of reaching and grasping movements were preceded a few seconds earlier by a fixation on the object. In a similar construction task, Mennie and colleagues[27] reported a 20% rate of look-aheads, a value similar to that found in our study. Thus, patients seem to establish a less efficient planning strategy than controls.

It has recently been reported that a patient with action disorganization syndrome resulting from lesions in the frontal cortex produced fewer anticipatory fixations than healthy participants in a tea-making task.[37] Failure to complete behavioural routines is attributed to degradation of a stored action schema.[38] For example, if patients have a degraded stored action schema, their eye movements may be less constrained by the task and more likely to be driven by salient objects in the environment.

Land and colleagues[21] have challenged the idea that everyday tasks are automatic in the sense that they normally require no online monitoring or feedback from "higher-level" control systems, such as the Supervisory Attentional System (SAS) of the Norman and Shallice[39] control-of-action model. When the action is novel or complex, the SAS is required for selection of a desired response sequence. It is thus involved particularly in tasks demanding initiation, planning, mental set-shifting, strategy allocation, monitoring and inhibition. Consequently, impairment in this system would be expected to result in the inability to formulate a goal, to plan and to choose between alternative sequences of behaviour to reach a particular goal. The results obtained with the Tower of London task strongly suggest that the SAS planning function is impaired in patients with schizophrenia.[40] Our patients' results in the unfamiliar task could be plausibly understood as a failure at the level of the SAS.

Our results are also in line with those of a study showing a motor-planning deficit (i.e., pointing to a target) when the planning involved an internal representation of a stimulus sequence.[15] Hayhoe and colleagues[41] provided evidence of the existence of sophisticated internal models of the structure of the environment. Cohen and Servan-Schreiber[42] have suggested that a disturbance in the internal representation of contextual information might provide a common explanation for deficits in several attention-related tasks in patients with schizophrenia. In our study, this is suggested by the fact that patients needed to look more at the display model than controls did to accomplish the unfamiliar task. Patients had difficulty maintaining a mental representation of the task to perform. Our unfamiliar task probably involved higher working memory requirements, and our results could be explained by working memory deficit. Lee and Park[43] have suggested that working memory deficits in patients with schizophrenia are robust and independent of study modality.

Furthermore, Cohen and Servan-Schreiber[42] suggest that this behavioural deficit may be explained by a specific biological disturbance (i.e., a reduction in the effects of dopamine [DA] in the prefrontal cortex). Evidence implicates DA dysregulation related to prefrontal dysfunction in patients with schizophrenia.[44,45] It is also well known that Parkinson disease is associated with a progressive dysfunction of the dopaminergic neurotransmission in the basal ganglia.[46] Deficits in executive functions have been documented in this disease;[47] patients have been shown to be impaired in the Wisconsin Card Sorting Test,[48] the Tower of London test[49] and the Stroop test,[50] thus suggesting planning deficits. They also exhibit visual scanning deficits, such as longer fixation times on faces.[51] Therefore, DA level in the prefrontal cortex might play a critical role in cognitive processes in patients with schizophrenia.

Limitations

Although in our study antipsychotic dosage equivalents did not appear to be correlated to various eye movement variables, we cannot exclude an effect of medication. Kojima and colleagues[52] have reported that neither the number of fixations nor scan path length were correlated with the chlorpromazine equivalent dosage in 50 patients with chronic schizophrenia, and this was confirmed by Matsushima and colleagues,[53] Streit and colleagues[7] and Loughland and colleagues,[5] who found no relation between dysfunctional scan paths and medication in patients with schizophrenia, whereas Williams and colleagues[54] reported that patients treated with risperidone showed greater attention to salient features, and Reilly and colleagues[55] showed that pharmacological treatment might have an effect on eye movement control in saccadic tasks.

Another possible limitation is that we used only 1 trial per condition. Thus, measures of reliability come from average performance over fixations within a task and similarity among participants, as indicated by the standard error measures. However, the magnitude of the reported effects indicates that this is not a major concern.

Conclusion

Overall, patients with schizophrenia seem to present deficient planning but intact motor action in more complex, unfamiliar tasks, which could make higher demands on cognitive processing than the well-learned task. There is some evidence in favour of abnormal connectivity between brain areas in patients with schizophrenia. A future area of research could be to explore whether abnormal connectivity between frontal and parietal regions is associated with problems in the sequencing of planned motor actions.

Acknowledgements: The authors are grateful to all of the patients who accepted to take part in the study and the psychiatrists who gave access to their patients and their staff. The study was funded by a PhD grant to C. Delerue by the region Nord-Pas de Calais and the Lille University Hospital. M. Hayhoe's participation was supported by National Institutes of Health grant EY-05729.

Competing interests: As above for C. Delerue and M. Hayhoe. Otherwise, none declared.

Contributors: C. Delerue and M. Boucart designed the study. C. Delerue acquired the data. All authors analyzed the data, wrote and reviewed the article, and approved its publication.

References

1. Loughland CM, Williams LM, Gordon E. Schizophrenia and affective disorder show different visual scanning behaviour for faces: A trait versus state-based distinction? *Biol Psychiatry* 2002;52:338-48.
2. Loughland CM, Williams LM, Harris AW. Visual scanpath dysfunction in first-degree relatives of schizophrenia probands: Evidence for a vulnerability marker? *Schizophr Res* 2004;67:11-21.
3. Benson PJ, Beedie SA, Shephard E, et al. Simple viewing tests can

detect eye movement abnormalities that distinguish schizophrenia cases from controls with exceptional accuracy. *Biol Psychiatry*. In press.
4. Green MJ, Williams LM, Davidson D. Visual scanpaths to threat related faces in deluded schizophrenia. *Psychiatry Res* 2003;119:271-85.
5. Loughland CM, Williams LM, Gordon E. Visual scanpaths to positive and negative facial emotions in an outpatient schizophrenia sample. *Schizophr Res* 2002;55:159-70.
6. Phillips ML, David AS. Visual scan paths are abnormal in deluded schizophrenics. *Neuropsychologia* 1997;35:99-105.
7. Streit M, Wölwer W, Gaebel W. Facial-affect recognition and visual scanning behaviour in the course of schizophrenia. *Schizophr Res* 1997;24:311-7.
8. Williams LM, Loughland CM, Gordon E, et al. Visual scanpaths in schizophrenia: Is there a deficit in face recognition? *Schizophr Res* 1999;40:189-99.
9. Gaebel W, Ulrich G, Frick K. Visuomotor performance of schizophrenic patients and normal controls in a picture viewing task. *Biol Psychiatry* 1987;22:1227-37.
10. Obayashi S, Msatsushima E, Ando H, et al. Exploratory eye movements during the benton visual retention test: characteristics of visual behavior in schizophrenia. *Psychiatry Clin Neurosci* 2003;57: 409-15.
11. Minassian A, Granholm E, Verney S, et al. Visual scanning deficits in schizophrenia and their relationship to executive functioning impairment. *Schizophr Res* 2005;74:69-79.
12. Bestelmeyer PE, Tatler BW, Phillips LH, et al. Global visual scanning abnormalities in schizophrenia and bipolar disorder. *Schizophr Res* 2006;87:212-22.
13. Jogems-Kosterman BJ, Zitman FG, Van Hoof JJ, et al. Psychomotor slowing and planning deficits in schizophrenia. *Schizophr Res* 2001; 48:317-33.
14. Grootens KP, Vermeeren L, Verkes RJ, et al. Psychomotor planning is deficient in recent-onset schizophrenia. *Schizophr Res* 2009; 107:294-302.
15. Delevoye-Turrell Y, Giersch A, Wing AM, et al. Motor fluency deficits in the sequencing of actions in schizophrenia. *J Abnorm Psychol* 2007;116:56-64.
16. Pantelis C, Barnes TR, Nelson HE, et al. Frontal-striatal cognitive deficits in patients with chronic schizophrenia. *Brain* 1997;120: 1823-43.
17. Semkovska M, Bédard MA, Godbout L, et al. Assessment of executive dysfunction during activities of daily living in schizophrenia. *Schizophr Res* 2004;69:289-300.
18. Stip E, Sablier J, Sephery AA, et al. Kitchen and schizophrenia: a crossroad activity of an ecological, occupational and neuropsychological assessment. *Sante Ment Que* 2007;32:159-79.
19. Hayhoe MM, Shrivastava A, Mruczek R, et al. Visual memory and motor planning in a natural task. *J Vis* 2003;3:49-63.
20. Johansson RS, Westling G, Bäckström A, et al. Eye-hand coordination in object manipulation. *J Neurosci* 2001;21:6917-32.
21. Land M, Mennie N, Rusted J. The roles of vision and eye movements in the control of activities of daily living. *Perception* 1999;28: 1311-28.
22. Ballard DH, Hayhoe MM, Pelz JB. Memory representations in natural tasks. *J Cogn Neurosci* 1995;7:66-80.
23. Ducato MG, Michael GA, Thomas P, et al. Attentional capture in schizophrenia: failure to resist interference from motion signals. *Cogn Neuropsychiatry* 2008;13:185-209.
24. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders*. 4th ed. Washington: The Association; 1994.
25. Kay SR, Opler LA, Fiszbein A. *Positive and negative syndrome scale (PANSS)*. North Tonawanda (NY): Multi-Health Systems Inc.; 1986.
26. Pelz JB, Canosa R. Oculomotor behavior and perceptual strategies in complex tasks. *Vision Res* 2001;41:3587-96.
27. Mennie N, Hayhoe M, Sullivan B. Look-ahead fixations: anticipatory eye movements in natural tasks. *Exp Brain Res* 2007;179:427-42.
28. Land MF. Eye movements and the control of actions in everyday life. *Prog Retin Eye Res* 2006;25:296-324.
29. Land MF, Lee DN. Where we look when we steer. *Nature* 1994;369: 742-4.
30. Land MF, McLeod P. From eye movements to actions: how batsmen hit the ball. *Nat Neurosci* 2000;3:1340-5.
31. Patla AE, Vickers JN. Where and when do we look as we approach and step over an obstacle in the travel path? *Neuroreport* 1997;8: 3661-5.
32. Delerue C, Laprévote V, Verfaillie K, et al. Gaze control during face exploration in schizophrenia. *Neurosci Lett* 2010;482:245-9.
33. Tonoya Y, Matsui M, Kurachi M, et al. Exploratory eye movements in schizophrenia. Effects of figure size and the instruction on visual search. *Eur Arch Psychiatry Clin Neurosci* 2002;252:255-61.
34. Delevoye-Turrell YN, Thomas P, Giersch A. Attention for movement production: abnormal profiles in schizophrenia. *Schizophr Res* 2006;84:430-2.
35. Ducato MG, Thomas P, Monestes JL, et al. Attentional capture in schizophrenia and schizotypy: effect of attentional load. *Cogn Neuropsychiatry* 2008;13:89-111.
36. Hutton SB, Ettinger U. The antisaccade task as a research tool in psychopathology: a critical review. *Psychophysiology* 2006;43:302-13.
37. Forde EM, Rusted J, Mennie N, et al. The eyes have it: an exploration of eye movements in action disorganisation syndrome. *Neuropsychologia* 2010;48:1895-900.
38. Humphreys GW, Forde EME. Disordered action schema and action disorganisation syndrome. *Cogn Neuropsychol* 1998;15:771-811.
39. Norman DA, Shallice T. Attention to action: willed and automatic control of behavior. In: Davidson RJ, Schwartz GE, Shapiro D, editors. *Consciousness and self-regulation. Advances in research and theory.* Vol. 4. New York: Plenum Press; 1986. p. 1-18.
40. Marczewski P, Van der Linden M, Laroi F. Further investigation of the supervisory attentional system in schizophrenia: planning, inhibition, and rule abstraction. *Cogn Neuropsychiatry* 2001;6:175-92.
41. Hayhoe M, Mennie N, Sullivan B, et al. The role of internal models and prediction in catching balls. *Proceedings of AAAI Fall Symposium Series*; Menlo Park (CA); Nov. 4–6, 2005. Available: www.aaai.org/Library/Symposia/Fall/fs05-05.php (accessed 2013 Feb. 25).
42. Cohen JD, Servan-Schreiber D. Context, cortex, and dopamine: a connectionist approach to behavior and biology in schizophrenia. *Psychol Rev* 1992;99:45-77.
43. Lee J, Park S. Working memory impairments in schizophrenia: a meta-analysis. *J Abnorm Psychol* 2005;114:599-611.
44. Bunney WE, Bunney BG. Evidence for a compromised dorsolateral prefrontal cortical parallel circuit in schizophrenia. *Brain Res Brain Res Rev* 2000;31:138-46.
45. Callicott JH, Bertolino A, Mattay VS, et al. Physiological dysfunction of the dorsolateral prefrontal cortex in schizophrenia revisited. *Cereb Cortex* 2000;10:1078-92.
46. Evans AH, Lees AJ. Dopamine dysregulation syndrome in Parkinson's disease. *Curr Opin Neurol* 2004;17:393-8.
47. Dubois B, Pillon B. Cognitive deficits in Parkinson's disease. *J Neurol* 1997;244:2-8.
48. Lees AJ, Smith E. Cognitive deficits in the early stages of Parkinson's disease. *Brain* 1983;106:257-70.
49. Owen AM, James M, Leigh PN, et al. Fronto-striatal cognitive deficits at different stages of Parkinson's disease. *Brain* 1992;115: 1727-51.
50. Dubois B, Pillon B, Malapani C, et al. Subcortical dementia and Parkinson's disease: What are the cognitive functions of the basal ganglia? In: Wolters EC, Scheltens P, editors. *Mental dysfunction in Parkinson's disease. Current issues in neurodegenerative diseases.* The Netherlands: ICG Publications; 1994. p. 194-210.
51. Clark US, Neargarder S, Cronin-Golomb A. Visual exploration of emotional expressions in Parkinson's disease. *Neuropsychologia* 2010;48:1901-13.
52. Kojima T, Matsushima E, Nakajima K, et al. Eye movements in acute, chronic, and remitted schizophrenics. *Biol Psychiatry* 1990;27: 975-89.
53. Matsushima E, Kojima T, Ohbayashi S, et al. Exploratory eye movements in schizophrenic patients and patients with frontal lobe lesions. *Eur Arch Psychiatry Clin Neurosci* 1992;241:210-4.
54. Williams LM, Loughland CM, Green MJ, et al. Emotion perception in schizophrenia: an eye movement study comparing the effectiveness of risperidone vs. haloperidol. *Psychiatry Res* 2003; 120:13-27.
55. Reilly JL, Lencer R, Bishop JR, et al. Pharmacological treatment effects on eye movement control. *Brain Cogn* 2008;68:415-35.