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A review of impaired visual processing and the daily visual world in patients with schizophrenia

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ABSTRACT

Several studies have investigated perceptual processes in patients with schizophrenia. Research confirms that visual impairments are one of the most important features of schizophrenia. Many studies, using behavioral and psychological experiments, confirm that visual impairments can be used to determine illness severity, state, and best treatments. Herein, we review recent research pertaining to visual function in patients with schizophrenia and highlight the relationship between laboratory findings and subjective, real-life reports from patients themselves. The purpose of this review is to 1) describe visual impairments that manifest in patients with schizophrenia, 2) examine the relationship between visual dysfunction, assessed by laboratory tests, and the experiences of patients themselves, and 3) describe real-life experiences related to visual function in this population. In this review, the impairments of motion and color perception, perceptual organization, and scan paths are summarized, along with the relationship between laboratory findings and patients' real-world subjective experiences related to visual function.

Keywords: schizophrenia, visual impairment, motion and color perception, scan path, real life

INTRODUCTION

Studies investigating impaired cognition in patients with schizophrenia focus on cognitive processes such as consciousness, attention, and executive function. There is a general consensus that patients with schizophrenia exhibit impairments in global intellectual functioning, including memory, language, executive function, and attention.[1,2] Green used the term "neurocognition" and investigated the relationship between functional outcomes and neurocognitive deficits.[3] This study indicated that, despite the varied means of measuring neurocognitive deficits, consistent associations existed between various neurocognitive functions like verbal memory, attention, and executive function and the outcomes they predict.

These cognitive functions are localized within the frontal lobe, which controls decision making, planning, and social behavior under complex situations. Therefore, in patients with schizophrenia, cognitive disturbances are key features of the illness, and the focus of many

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clinical therapies and treatments. Moreover, impairments in perceptual processes such as visual, auditory, or somatosensory are also key features. The Cognitive Neuroscience Treatment Research to Improve Cognition in Schizophrenia[4] project suggested that, in patients with schizophrenia, perceptual dysfunction relates to the patient's overall clinical status, particularly when focusing on visual processing in patients with schizophrenia. Some studies have investigated the relationship between visual processing and social perception[5,6] or functional status,[7,8] and showed that visual processing impairments influence social perception and functional outcomes. However, Silverstein and Keane examined PubMed citations in 2010 and showed that, compared to other cognitive domains, such as attention, memory, and language, less was known about visual processing in patients with schizophrenia.[9] Afterward, numerous studies reaffirm that visual function is a key factor that relates to illness severity, state, and treatment.

Visual perception research pursues various aims and structural and physiological targets including the eyes, brain circuitry, and patients' visual self-experiences. For example, studies have shown that patients with schizophrenia have anomalous eye structures (see review by Silverstein and Rosen[10]), while other studies focus instead on the structure of visual processing.[11] This review 1) summarizes various elements of visual impairments in patients with schizophrenia, 2) focuses on the relationship between visual dysfunction assessed by laboratory tests and subjective, real-world experiences, and 3) examines daily life disturbances related to visual dysfunction. Included studies are summarized in Table 1. We focus on studies related to motion and color perception, perceptual organization, and scan path as these modalities are commonly subjected to laboratory tests and likely relate to patients' subjective and real-world visual experiences. Experiential anomalies have been related to impairment in perceptual organization tasks in patients with schizophrenia.[12]

Table 1 A list of studies examining visual functions in patients with schizophrenia

Authors	Number of Participants (SZ: patients with schizophrenia, HC: healthy controls)	Task	Summary of key findings in patients with schizophrenia
Motion perception			
Stuve *et al.*[14]	SZ=19, HC=19	Coherent motion paradigm (dots)	Increased threshold of motion perception Negative correlation between smooth pursuit gain and threshold of motion perception
Chen *et al.*[15]	SZ=15, HC=8	Velocity discrimination paradigm (gratings)	Increased threshold of velocity discrimination only in small velocity discrimination
Chen *et al.*[16]	SZ=15, HC=8	Velocity discrimination paradigm (gratings)	Increased threshold of mid-velocity detection Correlation of velocity detection and initial acceleration of smooth pursuit
Chen *et al.*[17]	SZ=20, Relatives=24, HC=20	Velocity discrimination paradigm (gratings)	Increased threshold of mid-velocity detection Correlation of velocity detection and initial acceleration of smooth pursuit Relatives of SZ showed similar tendency to SZ

Li[18]	SZ=13, HC=14	Coherent motion paradigm (dots)	Increased threshold of motion perception
Chen *et al.*[19]	SZ=23, HC=26	Coherent motion paradigm (dots) Direction discrimination paradigm (gratings)	Increased threshold of coherent motion paradigm Intact direction discrimination of gratings
Chen *et al.*[20]	SZ=29, Relatives=20, Bipolar disorder=19, HC=33	Coherent motion paradigm (dots)	Increased threshold only in SZ compared to HC
Slaghuis *et al.*[21]	SZ=35, HC=35	Coherent motion paradigm (dots)	Increased detection threshold at 6 deg/s, but intact performance at 12 and 24 deg/s
Chen *et al.*[22]	SZ=34, HC=17	Velocity discrimination paradigm (low and high contrast gratings)	Increased threshold of both low and high contrast conditions
Bidwell *et al.*[23]	SZ=44, HC=40	Velocity discrimination paradigm (gratings)	Increased threshold independent of their age
Chen *et al.*[24]	SZ=25, Bipolar=16, HC=25	Velocity discrimination paradigm (gratings)	Increased threshold at high, mid and low speed in bipolar patients Increased threshold at high speed in SZ
Kim *et al.*[25]	SZ=14, HC=16	Velocity discrimination paradigm (dots)	Increased threshold in velocity discrimination
Clementz *et al.*[26]	SZ=18, HC=17	Velocity discrimination paradigm (dots)	Increased threshold in velocity discrimination
Slaghuis *et al.*[27]	SZ=24 (positive symptoms=12, negative symptoms=12), HC=12	Direction detection paradigm (gratings)	Increased threshold only in SZ with negative symptoms
Kelemen *et al.*[30]	SZ=52, HC=30	Coherent motion paradigm (dots)	Increased threshold and correlation with dysfunction of theory of mind
Color perception			
Shuwairi *et al.*[31]	SZ=16, HC=14	Standardized color discrimination task	More errors independent of age, education, symptoms and dosage of anti-psychotic medications
Ungar *et al.*[34]	SZ=15, HC=15	Color stroop paradigm (color names vs. color of font)	Greater activation in the medial parietal regions under the stroop effect condition
Jahshan *et al.*[35]	SZ=148, HC=54	Color priming paradigm (short and long stimuli onset asynchrony)	No difference in color priming effect between short and long SOA
David *et al.*[36]	SZ=22, Depression=14, HC=16	Color perception of left or right visual fields (naming and matching)	More errors in color matching across half visual field
Perceptual organization			
Carter *et al.*[38]	SZ=23, HC=14	Global-local task	Impairments in local targets detection correlated with auditory hallucination
Buchanan *et al.*[39]	SZ=39 (deficit form=18, non-deficit form=21), HC=30	Visual closure task	Poor performance in visual closure task in deficit form of SZ

Cox *et al.*[40]	SZ=30 (paranoid=15, non-paranoid=15), Psychiatric controls=15	Embedded figures task	Poor performance in patients with non-paranoid form
Parnas *et al.*[41]	SZ=19 (chronic=10, first admission=9), Prodromal schizophrenia patients=10, HC=14	Contour detection task	Poor performance in chronic SZ
Silverstein *et al.*[42]	SZ=23, Psychiatric patients=19, HC=17	Contour integration task	Poor performance correlated with disorganized symptomatology
Uhlhaas *et al.*[43]	Schizotypal=32, Non-schizotypal=37	Contour integration task	Schizotypal participants with thought disorder showed poor performance
Uhlhaas *et al.*[44]	SZ=47 (disorganized=14, non-disorganized=33), Other psychotic=19, Psychiatric controls=25	Contour integration task visual closure task	SZ with disorganized symptoms showed impairment in perceptual organization The impairments improved after treatment
Scan path			
Holzman *et al.*[47]	Psychotic patients=25 (SZ=18), Psychiatric controls=8, HC=33	Smooth pursuit of oscillating pendulum suspended	Deviant smooth pursuit in eye-tracking patterns
Holzman *et al.*[48]	SZ=69, schizoaffective disorders=6, Other psychotics=9, nonpsychotics=19, Relatives of SZ=34, Relatives of nonschizophrenic patients=19, HC=72	Smooth pursuit of oscillating pendulum suspended	SZ and their relatives showed deviant eye-tracking patterns
Moriya *et al.*[49]	SZ=24, HC=20	Free-viewing of pictures (human figures and “S” shape figure)	Fewer fixations and limited moving range of gaze
Gaebel *et al.*[50]	SZ=20, HC=20	Free-viewing of pictures (situation of interpersonal communication)	Staring-scanning had more negative symptoms, and extensive scanning had more positive symptoms
Williams *et al.*[51]	SZ=63, Psychiatric controls=60	Free-viewing of normal and degraded faces	Fewer fixations and inattention of salient features
Quirk *et al.*[52]	SZ=20, Addiction recovery patients=10	Free-viewing of emotional pictures	Fewer regions of interest only in neutral conditions
Sprenger *et al.*[53]	SZ=32, HC=33	Free-viewing of pictures regarding daily situations	Longer fixation times and fewer fixations independent of cognitive or emotional content
Streit *et al.*[54]	SZ=16, HC=18	Viewing of faces during facial affect recognition	More frequent fixations on the specific region
Loughland *et al.*[55]	SZ=65, HC=61	Viewing of faces during facial affect recognition	Inattention to salient features
Loughland *et al.*[56]	SZ=63, Relatives=37, HC=61	Viewing of faces during face recognition and facial affect recognition task	Fewer fixations compared to HC and relatives of SZ Relatives of SZ showed fewer fixations of specific regions

MOTION PERCEPTION

Motion perception refers to the visual mechanism for detecting the displacement of optical images over time. Motion is perceived when a certain threshold level is exceeded.[13] In patients with schizophrenia, disturbances in motion perception are examined using tasks that ask the patient to identify the speed or direction of moving objects. In an earlier study, Stuve *et al.* showed that patients with schizophrenia had abnormal motion perception related to smooth pursuit gain deficits.[14] This study employed a motion detection, smooth pursuit (eye-movement recording), and attention (Continuous Performance Task) to determine the relationships among the three tasks. A moving dot motion paradigm was used to measure the perceptual threshold for motion detection. In the coherent motion trial, some moving dots correlated with velocity and direction (left or right) while others moved in random patterns. Participants were asked if the correlated motion dots moved left or right. Here, motion detection impairments were related smooth pursuit, rather than the attention, dysfunction in patients with schizophrenia. This study also suggested that motion perception operated independently of visual attention.

Impaired motion perception associated with schizophrenia was extensively reported by other studies. Chen *et al.* used speed discrimination tasks, where participants were asked to identify which of two horizontal moving grated stimuli was moving faster, to study motion perception. Results obtained during the easy (15°/s vs 5°/s), and difficult (11°/s vs 9°/s), speed discrimination trials showed that patients with schizophrenia showed significantly lower contrast sensitivity for speed, compared to healthy controls, during only the difficult trial.[15] Chen *et al.* also investigated the relationship between impaired speed discrimination and smooth pursuit eye movement. In this study, eye movement was evaluated using two tasks that required the patient to track the movement of predictable and unpredictable targets. The results showed that contrast sensitivity for speed discrimination was significantly correlated with both initial acceleration and peak gain in patients with schizophrenia. These findings suggested that speed discrimination impairments were related to the dysfunction of smooth pursuit.[16]

Another similar study revealed that the first-degree relatives of patients with schizophrenia also had impairments in smooth pursuit and motion perception.[17] Other studies suggesting impairments of motion perception in schizophrenia used the coherent motion paradigm,[18-21] velocity discrimination paradigm,[22-26] and the direction detection paradigm.[27] With regard to eye movement, several studies have demonstrated that patients with schizophrenia possessed both smooth pursuit and saccadic abnormalities,[28,29] affecting perception of rapid displacement. Other reports indicate that impaired motion perception in patients with schizophrenia is related to the theory of mind.[30]

In summary, the results of these studies indicate that motion perception deficits in patients with schizophrenia exist independently of other deficits in attention, smooth pursuit, and saccade. Therefore, observations of motion perception are important clinical signs for investigating patients' daily lives.

COLOR PERCEPTION

Although motion perception has been investigated extensively in schizophrenia, the same cannot be said for color perception. Shuwairi *et al.* investigated color discrimination in patients with schizophrenia and healthy controls.[31] Patients with Parkinson's disease[32] and cocaine withdrawal[33] exhibited blue-color discrimination impairments. Notably, both conditions involve dopaminergic dysregulation. Because patients with schizophrenia also exhibit dopaminergic dysregulation, this study investigated color discrimination in patients with schizophrenia as well. The authors found

that patients with schizophrenia made more blue-color discrimination errors than did healthy controls; however, in patients with schizophrenia the error patterns differed from those observed in patients with either Parkinson's disease or cocaine withdrawal. Patients with schizophrenia showed more errors than healthy controls, and the errors were observed in three color conditions: red, green, and blue. These results suggested that, in patients with schizophrenia, observed impairments were not specific to a particular hue, but rather reflected a general perceptual disorder.

Ungar *et al.* investigated Stroop task performance in healthy controls and patients with schizophrenia and compared their brain activation patterns using functional magnetic resonance imaging.[34] Here, patients with schizophrenia showed greater activation in the medial parietal regions than the healthy controls under the Stroop effect condition. Another study investigated color priming effects during the early visual processing stages of schizophrenia.[35] The authors used the color priming paradigm that used short and long stimuli onset asynchrony under both unconscious and conscious conditions. Patients with schizophrenia showed dysfunction under the conscious, but not the unconscious condition, suggesting that patients with schizophrenia might have intact neuronal function from the retina to the early visual cortex. A classic experiment using a tachistoscope showed that patients with schizophrenia exhibited differences in brain laterality (left visual field vs. right visual field) for color perception, compared to healthy controls.[36]

PERCEPTUAL ORGANIZATION

In patients with schizophrenia, deficits in perceptual organization are widely established. Perceptual organization involves grouping and segregating processes.[37] Empirical investigations of perceptual organization, involving global-local,[38] visual closure,[39] embedded figures,[40] and contour detection tasks,[41] have been applied to patients with schizophrenia. Silverstein *et al.* reported that patients with chronic schizophrenia had impairments in the contour integration task.[42] Additionally, patients with schizophrenia who performed poorly on the contour detection task exhibited symptoms consistent with severe disorganization.

Contour integration, the ability to detect the closed contour composed of discontinuous elements from a picture containing distractors, was the focus of other studies. Uhlhaas *et al.* examined whether participants with schizotypal personality traits had impaired perceptual organization in nonclinical situations.[43] Schizotypal participants with thought disorders had poor performance on contour detection tasks, suggesting that impaired perceptual organization was a common dysfunction in schizophrenia and schizotypal personalities. Uhlhaas *et al.* also examined the relationship between the dysfunction of perceptual organization and clinical outcomes of patients with schizophrenia.[44] Patients with schizophrenia with disorganization showed impairments in perceptual organization, which improved during remission.

In summary, these findings suggest that an impairment in perceptual organization is related to various clinical and nonclinical traits. At present, there are limited studies investigating the relationship between anomalies of perceptual organization and brain activity in patients with schizophrenia and further investigations are needed (see review by Uhlhaas & Silverstein, and Silverstein & Keane[45,46]).

SCAN PATH

Early research findings indicated patients with schizophrenia exhibit abnormal eye-tracking patterns.[47] Holzman *et al.* also showed that both patients with schizophrenia, and their relatives,

had eye-tracking dysfunctions.[48] These studies required participants to pursue moving objects with their eyes and revealed dysfunction in smooth pursuit in patients with schizophrenia. Moreover, many studies recorded the eye movement of schizophrenia patients, and observed atypical behaviors during visual exploration tasks. Moriya *et al.* reported that eye movement patterns in patients with schizophrenia differed from those observed in healthy controls.[49] This study employed free-viewing of four pictures containing human figures and geometric figures like the letter "S." The eye movement pattern was analyzed by recording eye fixation patterns. Patients with schizophrenia showed different patterns from those of healthy controls, and shifted fixation points on pictures less frequently than healthy controls. These results indicated that healthy controls tended to view the pictures widely, whereas patients with schizophrenia tended to gaze at only one section of a picture at a time.

Other studies that employed free-viewing tasks showed different eye movement patterns between patients with schizophrenia and controls. Experimental constructs that involve free-viewing tasks are beneficial because they provide information about a participant's voluntary behaviors. This information is useful for understanding behaviors in real-world settings. Gaebel *et al.* investigated eye movement in patients with schizophrenia, using free-viewing tasks.[50] The authors used pictures that depicted a situation of interpersonal communication, within the context of a proverb. They found that patients with schizophrenia used two types of scanning patterns: staring-scanning and extensive scanning. Patients who used the staring-scanning method had more negative symptoms, while patients who used extensive scanning had more positive symptoms of schizophrenia.

A study by Williams *et al.* showed that patients with schizophrenia did not pay attention to remarkable characteristics while viewing pictures of faces.[51] Patients with schizophrenia observed significantly fewer fixation points than healthy controls. In schizophrenia, atypical visual scanning might impair complex object cognition, such as face perception. Quirk and Strauss investigated the relationship between emotional perception and visual exploration using free-viewing tasks with digitalized photographs from the International Affective Picture System.[52] This study recorded fixation patterns and compared regions of interest (ROI) between patients with schizophrenia and healthy controls. Under neutral picture conditions, patients with schizophrenia gazed at fewer ROIs than controls. However, under emotional picture conditions, there were no between-group differences in ROIs. The authors concluded that patients with schizophrenia may only have intact patterns of visual exploration when viewing emotional pictures.

Sprenger *et al.* investigated visual exploration patterns in patients with schizophrenia, using daily, social pictures that contained cognitive and emotional elements.[53] The pictures used in this study were evaluated in terms of cognitive complexity and emotional constraint, as in the previous study. The authors analyzed whether both the cognitive and emotional elements affected visual exploration behaviors. Patients with schizophrenia had longer fixation times and fewer fixation shifts than healthy controls. However, in both groups, cognitive and emotional elements significantly affected visual exploration. In patients with schizophrenia, atypical exploration may apply to general elements without cognitive or emotional content.

Other studies measured the scan path of patients with schizophrenia during various experimental tasks, such as facial recognition and facial affect recognition. Streit *et al.* reported that patients with schizophrenia showed atypical scan paths during the facial affect recognition test, compared to healthy control subjects.[54] Loughland *et al.* examined the relationship between facial affect recognition and scan path features in patients with schizophrenia.[55] Here, patients with schizophrenia showed different and restricted scan path styles, as compared to healthy controls, with fewer fixations and inattention to significant features. In addition, the first-degree relatives of patients with schizophrenia also showed restricted scan path patterns.[56]

Scan path studies that involved social situational elements, such as the facial affect recognition paradigm, showed that patients with schizophrenia had atypical scan path styles, compared to control subjects. These findings support the theory of a relationship between social cognition and vision. Thus, in patients with schizophrenia, atypical scan paths are considered a trait or state marker of the illness (see review by Beedie *et al.*[57]). Eye movement assessments are easy and noninvasive for patients, and further research is needed, in clinical settings, to evaluate potential relationships between disease characteristics and social functioning in patients with schizophrenia.

SUBJECTIVE REPORTS OF VISUAL PERCEPTION IN SCHIZOPHRENIA

Although a significant amount of behavioral experimental work has indicated abnormal visual functions in patients with schizophrenia (also see summary of key findings in Table 1), these studies were conducted under laboratory conditions. Of equal importance is the determination of how patients with schizophrenia perceive the visual world in daily life. Chapman investigated the subjective experiences of patients with early-stage schizophrenia and reported that, while the patients had no symptoms of depression, they exhibited perceptual disturbances, including abnormal visual experiences.[58] Phillipson and Harris also investigated the changes in subjective experiences before and after illness onset using a retrospective survey. They found that more than half of patients experienced visual distortions, such as visual changes of brightness contrast, motion, color, and shape.[59]

Regarding self-experience in patients with schizophrenia, Bunney *et al.* developed the Structured Interview for Assessing Perceptual Anomalies for reporting anomalous experiences.[60] This study showed that more than 80% of patients with schizophrenia experienced perceptual anomalies of visual, tactile, olfactory, and gustatory modalities. Some patients reported peculiar visual processing, such as intense colors and brightness. The researchers developed other assessments of anomalous experiences, including the Bonn Scale for the Assessment of Basic Symptoms (BSABS)[61] and the Examination of Anomalous World Experience.[62] Klosterkotter, *et al.* investigated symptoms of schizophrenia in a prodromal phase and found that the BSABS was able to detect the onset of schizophrenia.[63] This study also showed that some items contained visual perception disturbances, and BSABS was one of the core predictive factors.

As mentioned above, anomalous-visual experiences are well-documented in patients with schizophrenia; however, earlier studies have not integrated laboratory findings and abnormal visual experiences in this population. Silverstein *et al.* suggested that there are two factors that contribute to this limitation: the absence of suitable methods for measuring subjective experiences, and the absence of tests that incorporate subjective experiences into the field of laboratory research.[64] Consequently, the relationship between visual abnormalities and laboratory findings is not well investigated. Further research is required to clarify the interactive relationships among subjective reports of visual disturbances, particularly in daily life settings, and laboratory findings regarding vision in patients with schizophrenia.

BASIC VISUAL IMPAIRMENT AND DAILY VISUAL PERFORMANCE

Numerous daily activities involve vision; for example, driving a car requires complex visual processing, including detection of moving objects. Brunnauer *et al.* investigated driving behaviors in patients with mental disorders in Germany and reported that having a diagnosis of schizophrenia increased the likelihood that an individual would be unable to drive a car.[65] Few studies

have investigated the capability to drive, for example, by using a laboratory cognitive test[66,67] or a driving simulator.[68,69] Therefore, further research is needed to assess driving performance in patients with schizophrenia.

Recently, the development of wearable eye tracking devices allows mental health professionals assess patients' eye tracking data in real-life settings, such as home and public places.[70] Several eye trackers produce video-based records of patients' eye movements and moving sight. Dowiasch *et al.* recently investigated eye movements of patients with schizophrenia in daily life settings.[71] In this study, eye movements were recorded by mobile eye trackers during four different task conditions (gazing at static objects and free gaze conditions, while sitting and walking). Their results indicated that patients with schizophrenia had different eye tracking patterns compared to healthy controls, relative to task difficulty. During free gaze upon stationary targets while walking, the deviation of the retinal target velocity was significantly higher in patients than in healthy controls, suggesting that patients with schizophrenia had less precise tracking compared to healthy controls. However, during free gaze upon stationary targets with walking, there were no differences in eye movement between patients with schizophrenia and controls. Dowiasch *et al.* concluded that these results were contradictory to previous laboratory findings regarding smooth pursuit and further analyzes were needed to compare the relationship between laboratory and natural environments.

This potential difference should be taken into consideration when critically evaluating laboratory findings according to previous research, task strategies, and other sensory inputs. As reported, mobile eye tracking devices can analyze participants' gaze position during real-world and movement-centered tasks; therefore, these devices permit investigation of actual driving performance of patients. Future investigations involving other real-world settings, and evaluating complex behaviors (like shopping behaviors, where some patients with schizophrenia are less accurate and efficient[72]) are needed since few studies use real-time data acquisition and field analyses. Clinicians and researchers in the psychiatric field stress the importance of measuring actual behaviors in patients with schizophrenia. Previously, performance measures involved restricting access to daily activities; however, newer, wearable devices can obtain accurate and reliable data anywhere, in real time, and within natural settings. Wearable devices are useful for conducting research and detailed behavioral analyses in patients with schizophrenia.

CONCLUSION

This review summarizes research on visual impairments in patients with schizophrenia. In this field, many studies have investigated various levels of impairment. Both laboratory findings in controlled settings and reports of subjective experiences indicate that visual impairment is a general characteristic, recognized both by clinicians and patients. Further work is needed to clarify the relationship between visual performance and social functioning. The resultant data will be useful for improving available treatments and enhancing our understanding of these patients' visual worlds.

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