Title

Visual Processing and Social Cognition in Schizophrenia: Relationships among Eye Movements, Biological Motion Perception, and Empathy

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Abstract

Schizophrenia patients have impairments at several levels of cognition including visual attention (eye movements), perception, and social cognition. However, it remains unclear how lower-level cognitive deficits influence higher-level cognition. To elucidate the hierarchical path linking deficient cognitions, we focused on biological motion perception, which is involved in both the early stage of visual perception (attention) and higher social cognition, and is impaired in schizophrenia. Seventeen schizophrenia patients and 18 healthy controls participated in the study. Using point-light walker stimuli, we examined eye movements during biological motion perception in schizophrenia. We assessed relationships among eye movements, biological motion perception and empathy. In the biological motion detection task, schizophrenia patients showed lower accuracy and fixated longer than healthy controls. As opposed to controls, patients exhibiting longer fixation durations and fewer numbers of fixations demonstrated higher accuracy. Additionally, in the patient group, the correlations between accuracy and affective empathy index and between eye movement index and affective empathy index were significant. The altered gaze patterns in patients indicate that top-down attention compensates for impaired bottom-up attention. Furthermore, aberrant eye movements might lead to deficits in biological motion perception and finally link to social cognitive impairments. The current findings merit further investigation for understanding the mechanism of social cognitive training and its development.

Keywords

biological motion perception; eye movement; attention; empathy; social cognition; schizophrenia

Highlights

- We examined eye movements during biological motion perception in schizophrenia.
- Patients exhibiting longer fixation durations demonstrated higher accuracy.
- Eye movements as well as biological motion perception were correlated with empathy.
- Altered gaze patterns in patients indicate compensatory top-down attention.
- Eye movements might link to social cognition through biological motion perception.

1. Introduction

In our daily life, adequate social interaction arises from action observation and reading others' intentions and feelings. The human visual system can perceive motion of others' actions, i.e., biological motion (BM) from only point-light displays, which depicts movements of actor's main joints. Point-light displays have been widely used to investigate bodily motion perception (Johansson, 1973; Verfaillie, 2000). Previous studies have shown that BM provides relevant social information regarding intention (Blakemore and Decety, 2001; Runeson and Frykholm, 1983) and emotion (Dittrich et al., 1996; Pollick et al., 2001) as well as perceptual characteristics.

In BM perception, similarly to face recognition, visual attention plays an important role. Attention is modulated by bottom-up and top-down processing (Desimone and Duncan, 1995; McMains and Kastner, 2011). Bottom-up attention is stimulus-driven mechanisms and contributes to the early stage of visual perception (Itti and Koch, 2001), whereas top-down attention is goal-directed mechanisms. Although automatic bottom-up processing has been empathized, top-down processing is also involved in BM perception when the task difficulty is high (Thompson and Parasuraman, 2012). Attention is closely related to eye movements for selecting visual information (Fischer and Weber, 1993; Kowler et al., 1995).

Schizophrenia patients have attentional impairment (Heinrichs and Zakzanis, 1998) and aberrant eye movement patterns (Levy et al., 2010). Previous studies on eye movements during face recognition have demonstrated that schizophrenia patients fixate less on feature regions including eyes and mouth compared to healthy controls (Green et al., 2003; Loughland et al., 2002; Phillips and David, 1998). These results indicate impaired bottom-up attention in schizophrenia. Moreover, a previous study reported that attention training in which schizophrenia patients were instructed to look at stimuli's eyes and mouth improved the performance of face recognition (Combs et al., 2008). This result would suggest that top-down attention compensates for abnormal bottom-up attention in schizophrenia.

Recently, it has become evident that schizophrenia patients have impaired BM perception (Kim et al., 2013, 2011, 2005). However, it remains unclear how abnormal attention or eye movements influence BM perception in schizophrenia. In the present study, we investigated the strategy of eye movements during BM perception in schizophrenia. Our prediction was that patients would exhibit different gaze patterns compared to healthy subjects, if top-down attention compensates for impaired bottom-up attention during BM perception in a similar manner as during face recognition.

Meanwhile, because BM perception is a hallmark of social cognition (Pavlova, 2012), altered BM perception could lead to social dysfunction in schizophrenia. Previous studies using point-light stimuli have shown that impairment in BM perception correlates with social functioning in schizophrenia (Kim et al., 2013, 2005). We previously reported that decreased activation in the extrastriate body area in response to body movements was associated with symptomatic severity in schizophrenia (Takahashi et al., 2010).

Although a direct link between higher social cognitive deficits and dysfunctional outcome is widely acknowledged (Couture et al., 2006), recent reports suggested a model in which the early stage of visual perception or attention could indirectly affect the final functional outcome, with social cognition as a mediator (Green et al., 2012; Sergi et al., 2006). Therefore, we hypothesized that aberrant eye movements would lead to deficits in BM perception and finally be linked to social cognitive impairments. Because empathy is a core feature of social cognition, and is conceptually divided into affective (bottom-up) empathy and cognitive (top-down) empathy (Decety and Lamm, 2006; Decety and Moriguchi, 2007), we focused on empathy. Specifically, we predicted that deficits in automatic bottom-up attention during BM perception would be observed in schizophrenia, and this would be associated with affective empathy rather than cognitive empathy.

2. Materials and methods

2.1. Participants

Seventeen schizophrenia patients diagnosed with the patient edition of the Structured Clinical Interview for DSM-IV Axis I Disorders (SCID) were recruited. None of the patients had comorbid psychiatric disorders. Predicted IQ was measured by the Japanese Version of the National Adult Reading Test short form (Matsuoka and Kim, 2006; Matsuoka et al., 2006), which is considered to reflect the premorbid IQ of patients with schizophrenia. The Positive and Negative Syndrome Scale (PANSS) (Kay et al., 1987) was used to assess the severity of clinical symptoms with three subscales — positive, negative, and general psychopathology.

Eighteen healthy controls, matched with the patient group in terms of age, gender, handedness, and predicted IQ, were recruited. The controls had no history of psychiatric illness, as screened by the non-patient edition of SCID, and it was also confirmed that their first-degree relatives had no history of psychotic disorders. Exclusion criteria for all individuals included a history of head trauma, neurological illness, serious medical or surgical illness, and substance abuse. All participants were physically healthy and had normal or corrected-to-normal (eye glasses) vision.

We assessed empathic abilities in all subjects using the Japanese version of the Interpersonal Reactivity Index (IRI) (Davis, 1983; Sakurai, 1988), which consists of four 7-item subscales. Two subscales were designed to measure cognitive empathy: Perspective Taking scale (PT) and Fantasy Scale (FS). The second pair was designed to measure affective empathy: Empathic Concern (EC), and Personal Distress scale (PD). PT assesses the tendency to take the point of view of another person. FS assesses shifting oneself into feelings of fictional characters. EC measures the tendency to feel compassion and concern toward others, and PD measures the personal feelings of anxiety and discomfort resulting from observing another's stressful situation. Higher scores of each subscale mean higher empathic tendency. Cognitive empathy was evaluated using the mean score of PT and FS subscales, whereas affective empathy was assessed using the mean score of EC and PD subscales (Shamay-Tsoory et al., 2009). **Table 1** presents the participants' demographic information.

The study design was approved by the Committee on Medical Ethics of Kyoto University. After receiving a complete description of the study, all participants gave written informed consent.

2.2. Stimulus

Participants performed two tasks: ‘Object motion (OM) vs. BM perception task’ and ‘BM detection task’. Details of the stimuli are given in Supplementary Material.

2.3. Procedure

During the following tasks, a Tobii TX300 eye tracker with Tobii Studio 3.1.2 software (Tobii Technology, Danderyd, Sweden), controlled by E-Prime software and E-Prime Extensions for Tobii (Psychology Software Tools Inc., Pittsburgh, PA, USA)**,** was used to present stimuli and collect data, The Tobii system recorded eye movements at 300 Hz using infrared lights integrated with a 23-inch screen. Participants sat at a viewing distance of approximately 65 cm from the screen.

2.3.1. Experiment 1: OM vs. BM perception task

This task was used to examine whether schizophrenia patients exhibit difficulties in the perception of BM specifically or both BM and OM compared to healthy controls. Rotating wheel animation was used to detect the simple motion perception (OM) without “biological” motion (see Supplementary Material for more details).

2.3.2. Experiment 2: BM detection task

The purpose of this task was to assess the discrimination ability for BM. Subjects were presented with the same point-light walker (leftward or rightward) used in Experiment 1, but noise dots moving in random directions were introduced to manipulate the task difficulty (**Fig. S1**). The number of noise dots changed between 0, 20, 40, 60, 80, or 100. The targets and the noise moved in a 16° × 16° square centered on the screen.

Following a 2-second central fixation point, a walker was displayed for 2 seconds with the eye tracker recording eye position data. Participants were instructed to indicate the direction of the target's movement by pressing one of two pre-assigned keys on the computer's keyboard as fast and accurately as possible. There was a 2-second time limit to respond in each trial. Six difficulty levels and two walking directions combined made a total of 12 possible stimuli. Each of them was repeated five times, resulting in a total of 60 trials presented in random order.

2.4. Data Analysis

2.4.1. Test performance

In Experiments 1 and 2, reaction times and accuracy rates (proportion of correct answers) were measured by E-Prime.

2.4.2. Eye movements

In Experiment 2, the number of fixation points per second and the mean fixation duration were calculated with Tobii Studio 3.1.2 software. A fixation was defined as the remaining period of gaze within a fixation-radius of 30 pixels for 100 msec or more. For analysis, we extracted the fixations that followed the target in order to exclude outliers due to subjects' distraction from the task.

As shown in **Fig. S2**, the gaze acquisition rate (number of eye tracking samples/number of attempts) of schizophrenia patients varied. We therefore calculated the corrected number of fixations for all participants by dividing the measured number of fixations by the gaze acquisition rate.

2.4.3. Statistics

All statistics were calculated with SPSS 19.0 (SPSS Inc., Chicago, IL, USA). In Experiment 1, we conducted 2 × 2 repeated measures ANOVA to assess the effect of group (schizophrenia and control) and stimulus (OM and BM) on performance (accuracy and reaction time).

As for Experiment 2, performance (accuracy and reaction time) and eye movements (number of fixations/second, fixation duration) were entered into 2 × 6 repeated measures ANOVA with group (schizophrenia and control) as the between-subjects variable and difficulty (noise dots: 0, 20, 40, 60, 80, and 100) as the repeated measures variable. In addition, correlation analysis was performed to examine the relationships between accuracy and eye movements for both groups separately.

Additional correlation analysis was performed to evaluate associations between IRI scores and accuracy for the patient group. Furthermore, to assess the direct connection between eye movements and empathy, we performed correlation analysis between the number of fixations and IRI scores for the patient group.

3. Results

3.1. Experiment 1: OM vs. BM perception task

As for accuracy, neither a main effect of group nor an interaction between group and stimulus was significant, indicating that schizophrenia patients could perceive OM and BM at the same level as healthy subjects. Details are given in Supplementary Material.

3.2. Experiment 2: BM detection task

3.2.1. Test performance

Two-way ANOVA (group × difficulty level) for accuracy revealed a significant main effect of group [$F(1, 33) = 9.94$, $p = 0.003$], indicating lower accuracy for patients compared to controls. A main effect of difficulty was also revealed, indicating that accuracy became lower with increasing difficulty [$F(1, 33) = 35.99$, $p < 0.001$]. There was a significant interaction between group and difficulty [$F(1, 33) = 2.82$, $p = 0.025$] (**Fig. 1A**).

Reaction times were longer for patients than controls as shown by a main effect of group [$F(1, 33) = 14.45$, $p = 0.001$]. There was also a main effect of difficulty [$F(1, 33) = 64.27$, $p < 0.001$], indicating longer reaction time for higher difficulty. The interaction between group and difficulty was not significant [$F(1, 33) = 0.35$, $p = 0.762$] (**Fig. 1B**).

3.2.2. Eye movements

Two-way ANOVA (group × difficulty level) for the average number of fixations revealed a significant main effect of difficulty [$F(1, 33) = 15.42$, $p < 0.001$], with subjects fixating less often at higher difficulty. Neither main effect of group [$F(1, 33) = 1.70$, $p = 0.202$] nor interaction between group and difficulty [$F(1, 33) = 0.93$, $p = 0.454$] was significant (**Fig. 2A**).

As to the mean fixation duration, a main effect of difficulty was revealed [$F(1, 33) = 16.98$, $p < 0.001$], indicating longer fixation duration for higher difficulty. A main effect of group tended to be significant [$F(1, 33) = 3.91$, $p = 0.056$], suggesting that patients tended to fixate longer than controls. The interaction between group and difficulty was not significant [$F(1, 33) = 1.66$, $p = 0.171$] (**Fig. 2B**).

3.2.3. Relationships between eye movements and accuracy

We conducted correlation analysis to explore the relationships between accuracy and eye movements (number of fixations, fixation duration) for both groups separately. We utilized the accuracy calculated as mean accuracy at difficulty levels of 40 to 100, at which group differences of accuracy were significant. Accordingly, the indices of eye movements were also calculated as averages at the difficulty levels of 40-100.

3.2.3.1. Relationships between number of fixations and accuracy

In the control group, the average number of fixations was significantly correlated with accuracy [$r = 0.49$, $p = 0.041$], indicating larger number of fixations for higher accuracy (**Fig. 3A**). By contrast, in the patient group, the relationship tended to be negatively significant [r = -0.45, p = 0.070], with larger number of fixations for lower accuracy (**Fig. 3B**).

3.2.3.2. Relationships between fixation duration and accuracy

In the control group, the mean fixation duration tended to be negatively correlated with accuracy [r = -0.41, p = 0.094], indicating shorter fixation duration for higher accuracy (**Fig. S4A**). However, in the patient group, longer fixation duration was significantly associated with higher accuracy [r = 0.51, p = 0.037] (**Fig. S4B**).

3.2.4. Association with empathy

3.2.4.1. Relationships between IRI scores and accuracy

To examine associations between IRI scores and accuracy, correlation analysis was performed in the patient group. We used the mean score of PT and FS subscales as the index of cognitive empathy, and the mean score of EC and PD subscales as the index of affective empathy. Here we also adopted the average of accuracy at difficulty levels of 40-100.

The mean score of EC and PD was significantly correlated with accuracy [r = 0.50, p = 0.039], indicating increasing affective empathy with increasing accuracy (**Fig.**

4A). There was no relationship between cognitive empathy and accuracy [r = 0.08, p = 0.758].

3.2.4.2. Relationships between IRI scores and number of fixations

To assess the direct connection between attention and empathy, we performed correlation analysis between the number of fixations and IRI scores for the patient group. We adopted the average number of fixations at difficulty levels of 40-100 as the number of fixations. Each IRI subscale was entered into correlation analysis.

EC was significantly correlated with the number of fixations [r = -0.50, p = 0.042], indicating decreasing EC with increasing number of fixations (**Fig. 4B**). There were no relationships between other IRI subscales and number of fixations [PD; r = -0.33, p = 0.194] [PT; r = 0.22, p = 0.395] [FS; r = 0.21, p = 0.408].

4. Discussion

The present study examined the strategy of eye movements during BM perception in schizophrenia. Schizophrenia patients showed lower accuracy only in detecting BM stimuli, and had different gaze patterns compared to healthy controls.

Schizophrenia patients fixated longer than healthy controls. In addition, patients who exhibited longer fixation durations and fewer numbers of fixations demonstrated higher accuracy. Furthermore, in the patient group, significant correlations were observed between accuracy and affective empathy index and between eye movement index and affective empathy index.

Our data with regard to lower accuracy and longer reaction time in the patient group indicate that schizophrenia has a deficit in BM perception. This finding is in agreement with previous studies (Kim et al., 2013, 2011, 2005). In particular, ANOVA for accuracy revealed significant main effects of group and difficulty and an interaction between group and difficulty, indicating more severe impairment for higher difficulty in BM perception in schizophrenia. The result is consistent with a previous study reporting that the severity of impairment changes according to task difficulty (Kim et al., 2013).

Regarding eye movements, schizophrenia patients exhibited longer fixation durations than healthy controls, suggesting that top-down attention compensates for abnormal bottom-up attention in schizophrenia. Generally, during execution of visual task, bottom-up processing, in which fixation durations are shorter, acquires broad information at the beginning, and subsequently top-down processing, in which fixation durations are longer, acquires detailed information (Fischer et al., 2013; Pannasch et al., 2008; Unema et al., 2005). In the present study, it seems that bottom-up and top-down attention interacted to process visual information effectively in healthy subjects. That is, bottom-up attention is mainly used when the difficulty of BM task is low, while top-down attention is combined with bottom-up attention when the task difficulty is high (Thompson and Parasuraman, 2012). Therefore, fixation durations would become longer with increasing difficulty in healthy subjects. On the other hand, in schizophrenia, top-down attention might be used regardless of difficulty due to impaired bottom-up attention, resulting in longer fixation durations than controls.

The correlations between accuracy and eye movement indices also suggested the compensatory top-down strategy in schizophrenia. While healthy subjects exhibiting shorter fixation durations and a greater number of fixations demonstrated higher accuracy, patients exhibiting longer fixation durations and a smaller number of fixations demonstrated higher accuracy. In healthy subjects, the fixation duration nearly reflects the time for stimulus discrimination (Hooge and Erkelens, 1999). Thus, in the control group, subjects exhibiting shorter fixation durations and a greater number of fixations might discriminate stimuli efficiently in the central processor and demonstrate higher accuracy. In contrast, schizophrenia patients could obtain necessary information only with the compensatory top-down strategy. This may account for the result that patients who exhibited longer fixation durations and a smaller number of fixations demonstrated higher accuracy.

Not surprisingly, the affective empathy index on IRI scale was positively correlated with accuracy in the patient group. In fact, a recent study also reported similar correlation between BM perception and empathy (Miller and Saygin, 2013; Sevdalis and Keller, 2011). Affective empathy has been considered to arise from automatic simulation, which relies on embodied representation of others' action and emotional expression in the observer (Preston and de Waal, 2002). Such simulation process could facilitate understanding of others' mental states and form an important aspect of social cognition. Interestingly, in the patient group, EC, which composes a part of affective empathy, was negatively correlated with the number of fixations. Affective empathy is an automatic bottom-up component of empathy (Decety and Lamm, 2006; Decety and Moriguchi, 2007), and a smaller number of fixations might reflect the deficit in automatic early visual processing (Fischer et al., 2013; Pannasch et al., 2008; Unema et al., 2005). Thus, impairments of apparently higher social cognition, i.e., empathy, might partly stem from deficits in early bottom-up visual processing. As empathy is influenced by both eye movements and BM perception, eye movements might link to empathy with BM perception as mediator. This is conceptually consistent with the path model proposed by

Green (Green et al., 2012), in which the early stage of visual perception could indirectly affect the final functional outcome with lower social cognition as a mediator.

One limitation of our study is that we were not able to remove the effects of elementary oculomotor anomalies of extraocular muscles in schizophrenia (Holzman et al., 1974; Toyota et al., 2004). Another limitation is that we did not assess the effects of antipsychotic medication. Studies on relationships between antipsychotic medication and eye movements have produced mixed findings, including reports of relevance (Williams et al., 2003) and non-relevance (Streit et al., 1997).

5. Conclusions

Although schizophrenia patients have deficits in BM perception, their altered gaze patterns indicate that top-down attention compensates for impaired bottom-up attention. Our findings suggested that aberrant eye movements lead to deficits in BM perception and finally link to social cognitive impairments. A recent study reported that BM perception is facilitated by attentional cueing (Parasuraman et al., 2009), suggesting that cognitive training that enhances top-down attention may improve patients' BM perception and thus social cognition in clinical practice. We hope our findings will contribute to a better understanding of the mechanism of social cognitive training for schizophrenia and its development.

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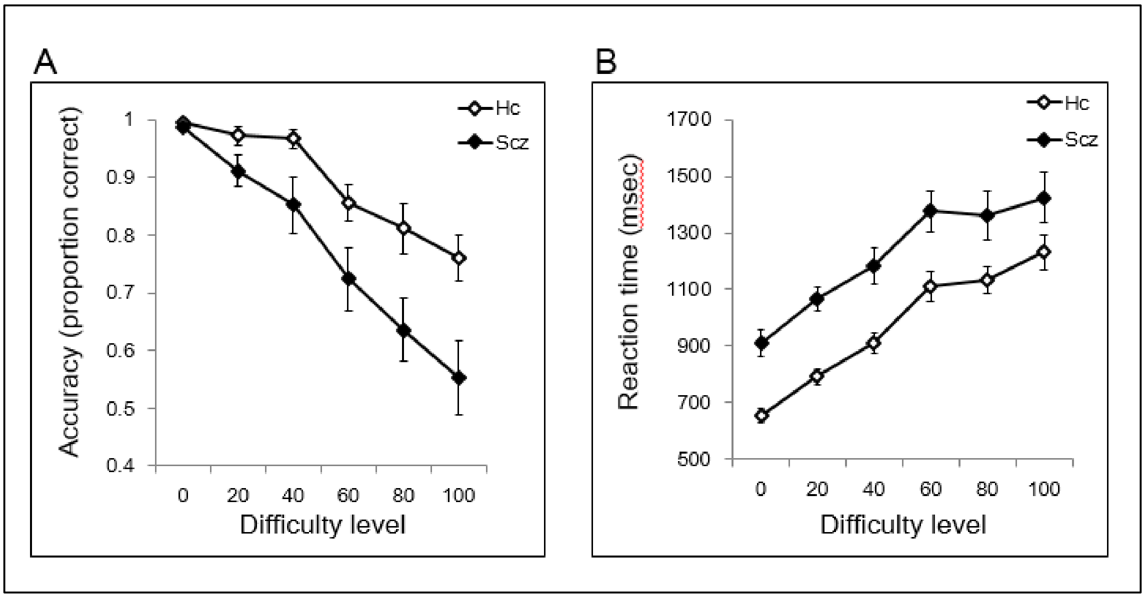

Fig. 1. Test performance in Experiment 2 (BM detection task). A, Accuracy (proportion correct). B, Reaction times. Error bars represent one standard error (SE).

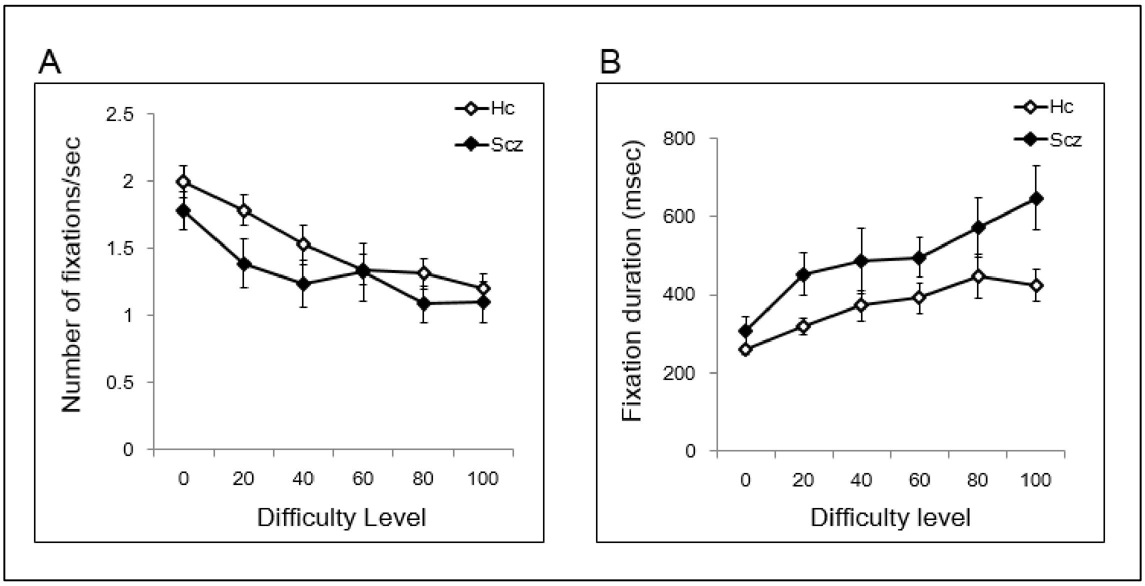

Fig. 2. Eye movements in Experiment 2. A, Number of fixations/sec. B, Fixation duration. Error bars represent one standard error (SE).

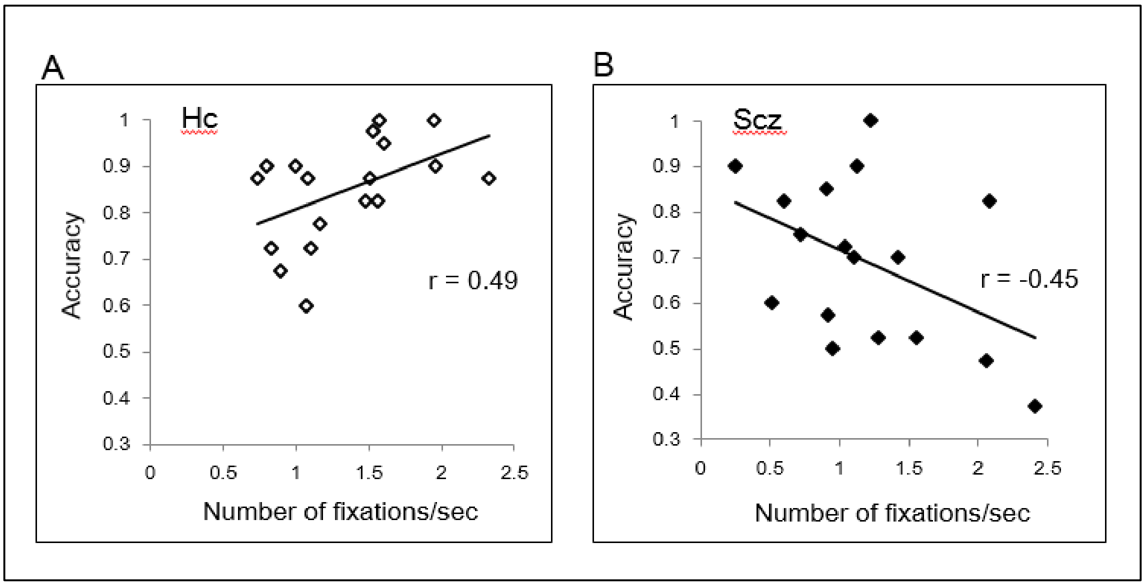

Fig. 3. Correlation between accuracy and number of fixations/sec in Experiment 2. A, Healthy controls (Hc). B, Schizophrenia patients (Scz).

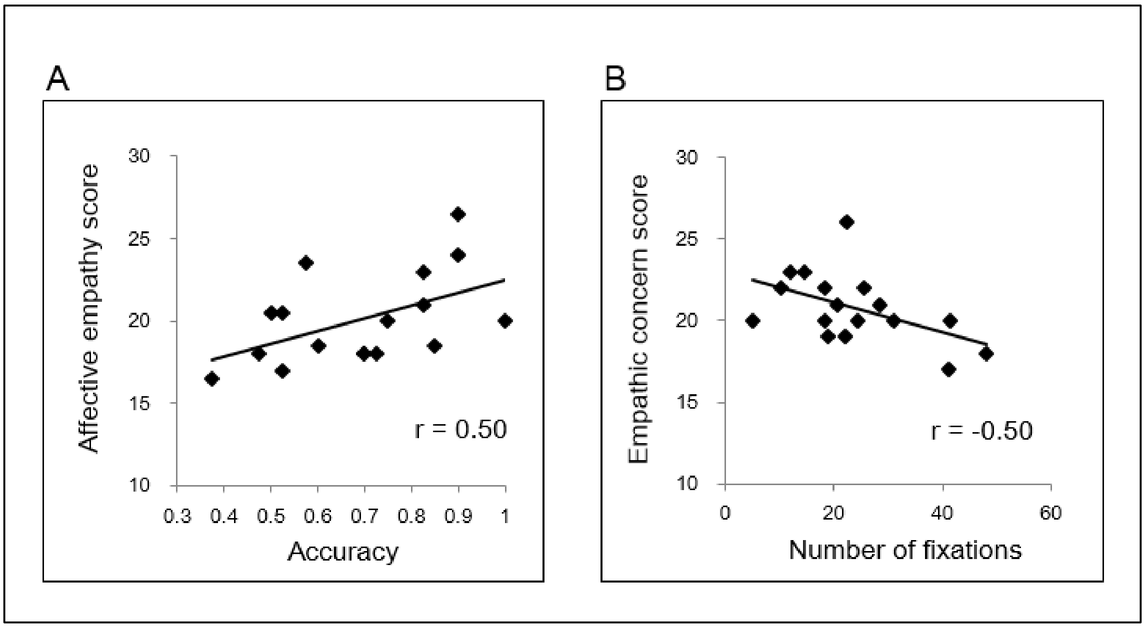

Fig. 4. Correlation between empathy indices and accuracy (A) and number of fixations (B) in schizophrenia patients.

Supplementary Material

Stimulus

To generate two types of PLD stimuli, 11 reflective markers were attached to the head and major joints of a human body for BM, while 8 markers were attached to a rotating wheel for OM. Each motion was captured by FinePix camera (Fujifilm, Tokyo, Japan). After the camera session, frames of the scene were rendered as audio-video interleaved (avi) movie files, which were subsequently converted to JPEG files at a frame rate of 30 Hz with VideoImpression software (ArcSoft Inc., Fremont, CA, USA). The data were processed to calculate the coordinates of the markers using original scripts. The 2-D coordinates were displayed as white dots against a black background and depicted as point-light animations. The size of the walker was approximately 12° × 5° and the wheel's diameter was 12° in visual angle. The targets moved in a 16° × 16° square centered on the screen.

Experiment 1: OM vs. BM perception task

The stimulus was a point-light animation of a walker (BM) or a rotating wheel (OM), which moved leftward or rightward. Following a 2-s central fixation point, the walker or the wheel was displayed for 2 s. Participants were instructed to indicate the direction of the target's movement by pressing one of the two pre-assigned keys on the computer's keyboard as fast and accurate as possible. There was a 2-s time limit to respond. Each combination of stimulus condition and moving direction was repeated three times, and the series of 12 trials was presented in random order.

Test performance in Experiment 1

Two-way ANOVA (group × stimulus) on accuracy revealed a significant main effect of stimulus [$F(1, 33) = 5.42$, $p = 0.026$], indicating higher accuracy for BM compared to OM. No difference in accuracy was revealed between groups [$F(1, 33) = 0.07$, $p = 0.788$]. The interaction between group and stimulus was not significant [$F(1, 33) = 0.70$, $p = 0.410$] (**Fig. S3A**).

The reaction times were longer for patients than controls as shown by a main effect of group [$F(1, 33) = 8.58$, $p = 0.006$]. A main effect of stimulus was also shown, indicating longer reaction times for OM than BM [$F(1, 33) = 9.35$, $p = 0.004$]. The interaction between group and stimulus was not significant [$F(1, 33) = 0.01$, $p = 0.946$] (**Fig. S3B**).

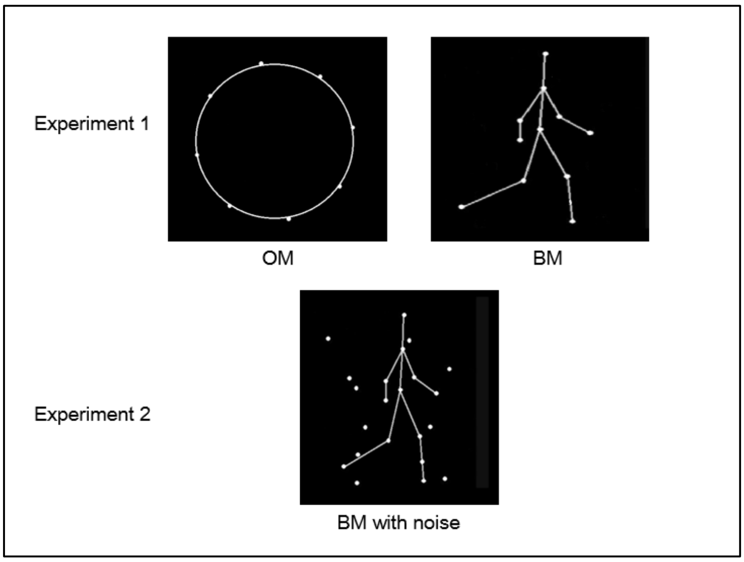

Fig. S1. Illustrations of stimuli used in Experiment 1 (OM vs. BM perception task) and 2 (BM detection task). Top: a single frame of OM (rotating wheel) and BM (walker) from Experiment 1, bottom: a single frame of BM embedded in dynamic noise dots. White lines are for illustration purpose here and were not shown in the actual experiment.

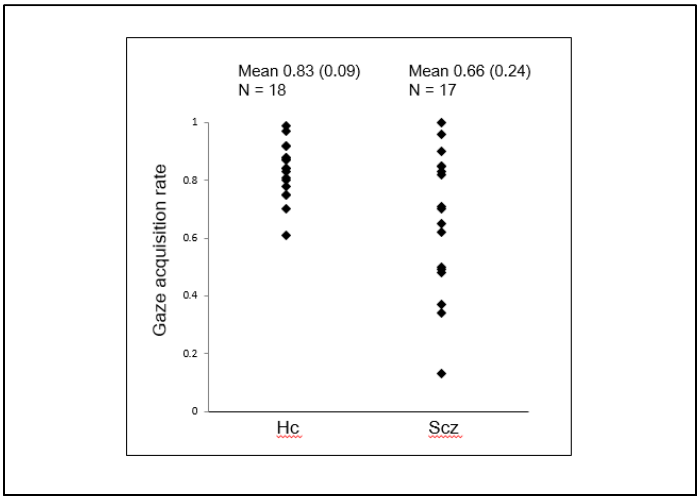

Fig. S2. Gaze acquisition rate in Experiment 2. Each dot represents an individual gaze acquisition. Mean (SD) values were given in the panel.

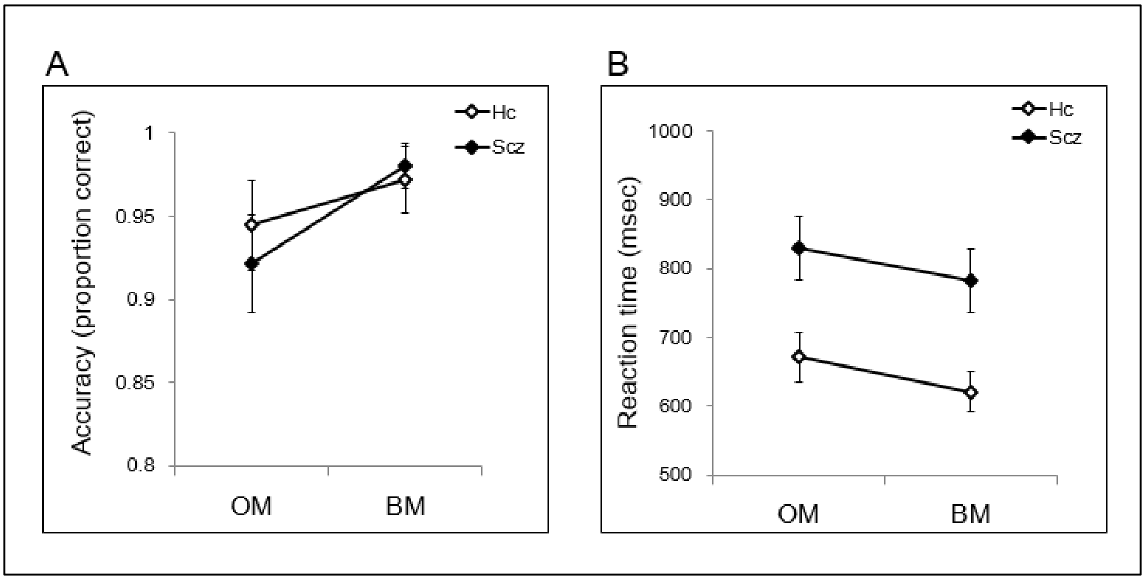

Fig. S3. Test performance in Experiment 1 (OM vs. BM perception task). (A) Accuracy (proportion correct) and (B) reaction times. Error bars represent one standard error (SE).

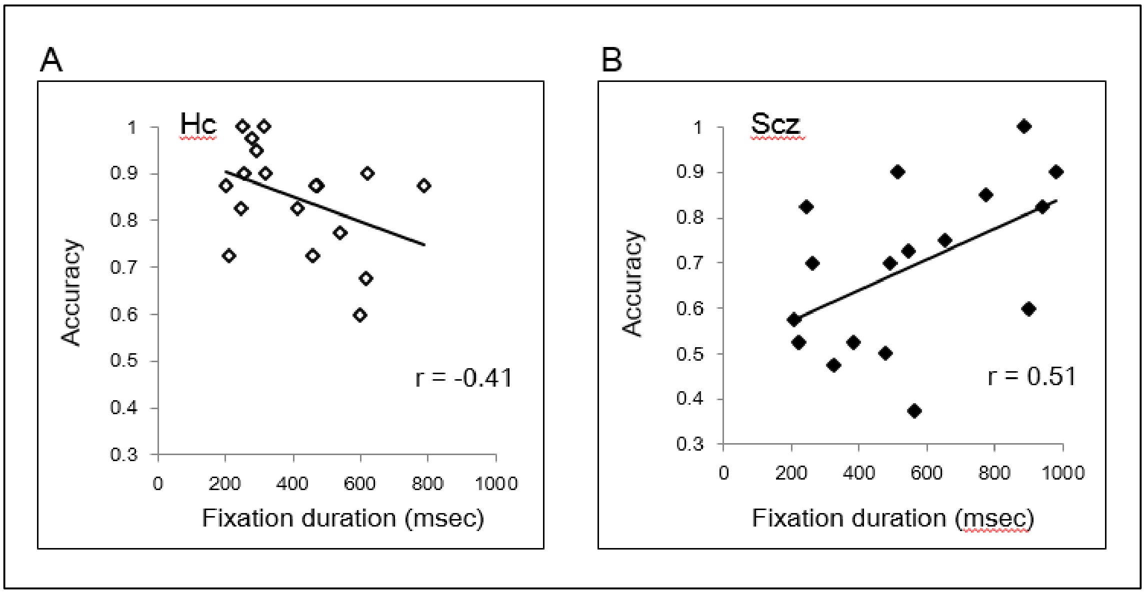

Fig. S4. Correlation between accuracy and fixation duration in Experiment 2. (A) Healthy controls (Hc) and (B) Schizophrenia patients (Scz).