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NSR-3756; No. of Pages 6

ARTICLE IN PRESS

Neuroscience Research xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Neuroscience Research

journal homepage: www.elsevier.com/locate/neures

Visual processing and social cognition in schizophrenia: Relationships among eye movements, biological motion perception, and empathy

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ARTICLE INFO

Article history:
Received 24 September 2014
Received in revised form 9 October 2014
Accepted 9 October 2014
Available online xxx

Keywords:
Biological motion perception
Eye movement
Attention
Empathy
Social cognition
Schizophrenia

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.

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

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http://dx.doi.org/10.1016/j.neures.2014.10.011
0168-0102/

Please cite this article in press as: Matsumoto, Y., et al., Visual processing and social cognition in schizophrenia: Relationships among eye movements, biological motion perception, and empathy. Neurosci. Res. (2014), http://dx.doi.org/10.1016/j.neures.2014.10.011

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-in. 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 $16^\circ \times 16^\circ$ square centered on the screen.

Following a 2-second central fixation point, a walker was displayed for 2 s 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-s 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 ms 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