Eye movement characteristics and visual information processing through restricted visual field in autism spectrum disorders

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Abstract

In order to investigate the visual processing in autistic spectrum disorder (ASD), individual eye movements and visual task performance were measured under a gaze-contingent restriction of visual field. Both the foveal or para-foveal visual field was restricted. Both the Navon task and the emotional face recognition task were employed. Longer reaction times and higher error rates for global visual tasks were shown in ASD individuals compared with those of typically developing (TD), indicating that ASD individuals display a deficit in peripheral visual processing and integrating local visual information. This tendency was also confirmed in the results of the emotional face recognition task. Eye movement distribution, and verbal reports from ASDs in the facial task suggested that masking the peripheral vision would enhance correct discrimination.

Keywords autism, restricted visual field, global-local visual processing, Navon task, facial expression

1 Introduction

Autism is a developmental disorder characterized by impaired social and communicative development. Individuals with autism spectrum disorders (ASD) display difficulties related to social skills, i.e., recognizing emotional expressions, making eye contact and judging eye-gaze direction. Many, as well as demonstrating underlying neural evidence studies, have reported atypical visual information acquisition and processing in individuals with ASD. In face processing, atypical eye movements in ASD has been reported [1]. Individuals with ASD look less towards eyes and more at mouths and/or the lower part of the face compared with typically developed (TD) [2]. TD individuals usually capture global aspects from the images displayed on the retina by using peripheral vision and then shift their attention or zoom-in to the local region of interest by using central vision. However, ASD individuals tend to give priority to local processing [1][3]. These findings suggest that ASD individuals utilize different functions in regard to both the foveal and para-foveal visual field and their information processing, compared with TD.

In this study, in order to investigate the visual processing of individuals with ASD, the eye movements and visual task performance of both ASD and TD individuals were measured under a gaze-contingent restriction of the visual field. Specifically, individuals in a state that has limited peripheral vision or central vision, performed both the Navon tasks and facial tasks.

2 Eye tracking and visual field restriction

The research utilized a Tobii 1750 eye-tracker run using the presentation of stimuli to record eye movements. The stimulus was presented with an overlapping mask to restrict the field of view. Stimuli were generated using MATLAB and the psychtoolbox. The restricted visual field was presented under three conditions: (i) peripheral visual fields masked (PM, Fig.1), (ii) central visual fields masked (CM, Fig.1), and (iii) the maskless condition (NM, Fig.1). In the CM condition, approximately 1.5 degrees of the central visual field was masked. In the PM condition, the region outside of the central 1.5 degrees visual field was masked. Participants sat approximately 40 cm from the monitor of the eye-tracker.

3 Experiment 1

3.1 The Navon task

A Navon task was used to examine both visual global and visual local processing. The stimulus consisted of a global letter formed by the configuration of local letters. The letters used were Japanese phonetic letters, Japanese hiragana. Global and smaller local letters subtended approximately 7-8 and 0.7-0.8 degrees of visual angle, when the letters were viewed from 40 cm. Participants were instructed to report verbally their perception of either global or local letters. Their reaction times and accuracy of target letter identification was recorded.
3.2 Participants

Three men with ASD (aged 15.3+/-0.6 years old) and seven typically developing individuals (four men and three women, aged 23.4+/-2.2 years old) with no eye disease participated. The visual acuity and visual field of TD participants was 0.3 or more, and more than 180 degrees, respectively. Participants with ASD had been diagnosed by psychiatrists and satisfied the diagnostic criteria for autism according to the DSM-IV. Two participants demonstrated the Asperger's disorder among the ASD participants, and one participant was diagnosed as displaying high-functioning autistic Asperger’s disorder. Their visual acuity of these three participants was 0.4 or more, and their visual field was greater 170 degrees.

3.3 Experimental conditions

Eighteen stimuli (3 visual restrictions × 2 Navon letter conditions × 3 instructions) were presented for each TD. The condition for each TD was as follows:
- Visual restrictions: with (i) central, (ii) peripheral, and (iii) without restriction.
- Letters in the Navon task: (i) congruent, and (ii) incongruent global and local letters (Fig.2).
- Instructions: participants were instructed to report recognition of (i) the global letter, (ii) the local letter, or (iii) either.

Nine stimuli (3 visual restrictions × 1 incongruent Navon letter conditions × 3 instructions) were presented for each ASD participant.

3.4 Results

In both ASD and TD participants, the reaction time was longest under the peripheral mask condition. As shown below in Fig.3, eye movements were widely distributed, and the participants of both groups seemed to visually scan the whole field of each stimulus under the global letter replying condition. In the condition, the mean correct answer rate of the response was 0% in ASD participants, while that of TD participants was 61% (Fig.4).

Under the central mask condition, in which only peripheral vision can be observed, TD participants preferentially reported the global letter with a short reaction time. In contrast, all ASD participants preferentially reported the local letter within a short time. In addition, although the eye movement of ASD participants was globally distributed in the case of the instruction to report a global letter (Fig.5), ASD participant’s correct rate was low at 33% (Fig.4).
4.2 Participants

Seven men with ASD (aged 14.1+/−2.3 years old) and eight TD participants (four men and four women, aged 23.1+/−2.22 years old) with normal eye function participated in the experiment. Visual acuity and visual field of TD participants was 0.3 or more, and more than 180 degrees, respectively. Participants with ASD had been diagnosed by psychiatrists and satisfied the diagnostic criteria for autism according to the DSM-IV. One person demonstrated autistic Asperser type and one person demonstrated high-functioning autistic Asperser type. The visual acuity of all seven participants was 0.01 or more, and their visual field was more, than 160 degrees. Diagnosis of VIQ as determined using the (WISC-III) was more than 84.

4.3 Experimental conditions

Twelve stimuli (3 visual restrictions × 2 color conditions × 2 expression conditions) were repeated twice. Fifty-four stimuli, including 30 placebo tasks, were presented for each TD participant. Each condition for TD was as follows;
- Visual restrictions: with (i) central, (ii) peripheral, and (iii) without restriction.
- Color: (i) color and (ii) black-and-white
- Facial expression: (i) neutral and (ii) fearful face (Fig.6).
Six stimuli (3 visual restrictions × 1 color image × 2 expression facial images) were presented for each ASD. After each task, participants were asked to report which part of the face was used to judge the facial expression.

4.4 Results

The results of four participants with ASD were excluded due to insufficient eye movement recording, and insufficient verbal reports.

The results of eye movement indicated that TD participants gazed at the eyes of the stimulus face to determine the facial expression. Eye movement was widely distributed (Fig.7) and the reaction time was longest for the peripheral vision mask condition. However, their error rate was not notably different from that under a maskless condition.

For the peripheral mask condition, the longest reaction time was also obtained from ASD participants. The mean reaction time of ASD participants was 27.1 seconds, longer than that of TD participants (6.4 sec). This suggests that ASD participants may have difficulty regarding perceptual integration.

Table 1 shows the ASD participants reported facial parts that they used to discriminate the facial expression. Except for the peripheral mask condition, ASD participants did not use eyes, but the mouth and/or other facial features. These findings are consistent with results obtained in a previous study [2]. However, under a peripheral mask condition and the stimulus of fearful face, ASD used the eyes and reported negative emotion which is close to the correct response (Fig.8). The results suggest that masking the peripheral vision may result in the making of a correct judgement, although it has been reported that ASD have difficulty in making a judgement of a fearful face.

<table>
<thead>
<tr>
<th>mask</th>
<th>maskless</th>
<th>peripheral mask</th>
<th>central mask</th>
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<tbody>
<tr>
<td></td>
<td>neutral</td>
<td>fearful</td>
<td>neutral</td>
</tr>
<tr>
<td>face ASD 1</td>
<td>jaw, mouth</td>
<td>fore-head</td>
<td>face form</td>
</tr>
<tr>
<td>ASD 2</td>
<td>no features</td>
<td>mouth</td>
<td>no features</td>
</tr>
<tr>
<td>ASD 3</td>
<td>face form, mouth,</td>
<td>mouth, eyebrow</td>
<td>mouth</td>
</tr>
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Table 1: Features and facial parts reported by three ASD (ASD1, 2, and 3) used for discrimination of the facial expression.
5 Discussions

In this study, the functions of central and peripheral visual fields in ASD participants were examined by using a gaze-contingent restriction of visual field. Under a central mask condition, the mask size was set and fixed at a visual angle of 1.5 degrees depending on the fovea size. In these experiments, no head fixation system was used, and participants were instructed not to widely move their head or body. Some participants showed difficulty with head and posture fixation during the session, so their recorded data were excluded from the analysis.

The results of experiment 1 indicated that ASD participants tend to give the priority to local letters, while TD participants preferentially reported global letters with a comparatively short reaction time. In addition, ASD participants had difficulty with perceptual integration. These results are consistent with previous studies using the Navon task [4] and describing WCC (weak central coherence) [5].

In experiment 2, the VIQ of three ASD participants, whose responses were analyzed, was sufficient enough to discriminate and report the facial expression. We also confirmed their recognition of the facial parts and their smooth eye movements before the recording. The results of experiment 2 showed that TD used the eyes of the stimulus face to discriminate the facial expression, but ASD did not. In addition, under the visual restriction conditions (PM or CM), correct discrimination was obtained from TDs. This result was also confirmed in the Navon task. In contrast to TD, the eye movement of ASD did not distribute around the eye area of the stimulus, and ASD verbal reports (Table 1) did not include “eyes,” except for the fearful face stimulus under the peripheral mask condition. Previous studies have demonstrated that individuals with ASD look at mouths and/or the lower part of the face and discriminate the facial expression without looking at the eyes [2]. However, for the fearful face stimulus under peripheral mask condition, the eye movement of ASD distributed around the eye area of the stimulus (Fig.7) and correct discrimination was obtained (Fig.8). Discrimination of the response of the amygdala to the stimulus of a fearful face is well understood, with discrimination of the fearful face being most difficult for ASD [1]. The amygdala responds to fearful face especially, while atypical development of the amygdala in ASD has been reported [6]. The activity of the amygdala is greater for facial stimulus with a low spatial frequency component than with a high spatial frequency [7]. It has been reported that it is easy for ASD individuals to discriminate a facial expression with high spatial frequency [8]. In addition, it is suggested that ASD’s ability for discriminating expression may improve by using and moving their attention to the information that TDs use [9]. Correct discrimination of a fearful face in ASD, shown in experiment 2, suggested that the peripheral masking (displaying precise central visual information only) may assist them in making correct discrimination.

6 Conclusions

It is suggested that in order to enhance the ability of ASD’s to discriminate facial expressions, the processes used by TD’s to perform such tasks must be identified and applied to ASD’s to improve their visual discrimination ability. Eye movements and visual task performance under a restriction of visual field suggested ASD’s deficit in peripheral visual processing and integrating local visual information. This tendency was confirmed in the results of the Navon task and the emotional face recognition task. Eye movement distribution and verbal reports from ASD’s suggest that masking the peripheral vision may result in correct discrimination.

References


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