BIROn - Birkbeck Institutional Research Online

Senju, Atsushi and Kikuchi, Y. and Hasegawa, T. and Tojo, Y. and Osanai, H. (2008) Is anyone looking at me? Direct gaze detection in children with and without autism. Brain and Cognition 67 (2), pp. 127-139. ISSN 0278-2626.

Downloaded from: https://eprints.bbk.ac.uk/id/eprint/2565/

Usage Guidelines:
Please refer to usage guidelines at https://eprints.bbk.ac.uk/policies.html or alternatively contact lib-eprints@bbk.ac.uk.

BIROn - Birkbeck Institutional Research Online

Enabling open access to Birkbeck's published research output

Is anyone looking at me? Direct gaze detection in children with and without autism

Journal Article

http://eprints.bbk.ac.uk/2565

Version: Accepted (Refereed)

Citation:

Senju, A.; Kikuchi, Y.; Hasegawa, T.; Tojo, Y.; Osanai, H. (2008)
Is anyone looking at me? Direct gaze detection in children with and without autism –
Brain and Cognition 67(2), pp.127-139

© *2008* Elsevier

Publisher version

All articles available through Birkbeck ePrints are protected by intellectual property law, including copyright law. Any use made of the contents should comply with the relevant law.

Deposit Guide

Contact: lib-eprints@bbk.ac.uk

Brain and Cognition 67 (2008) 127-139. doi:10.1016/j.bandc.2007.12.0001

Is anyone looking at me? Direct gaze detection in children with and without autism

Atsushi Senju[a], Yukiko Kikuchi[b], Toshikazu Hasegawa[b], Yoshikuni Tojo[c] and Hiroo Osanai[d]
[a]Birkbeck, University of London, London, UK
[b]University of Tokyo, Tokyo, Japan
[c]Ibaraki University, Ibaraki, Japan
[d]Musashino Higashi Gakuen, Tokyo, Japan

Correspondence concerning this paper should be sent to Atsushi Senju, Centre for Brain and Cognitive Development, Department of Psychology, Birkbeck, University of London, The Henry Wellcome Building, Torrington Square, London WC1E 7HX, UK
Tel: +44 207 631 6231; Fax: +44 207 631 6587; E-mail: a.senju@bbk.ac.uk

Abstract

Atypical processing of eye contact is one of the significant characteristics of individuals with autism, but the mechanism underlying atypical direct gaze processing is still unclear. This study used a visual search paradigm to examine whether the facial context would affect direct gaze detection in children with autism. Participants were asked to detect target gazes presented among distracters with different gaze directions. The target gazes were either direct gaze or averted gaze, which were either presented alone (Experiment 1) or within facial context (Experiment 2). As with the typically developing children, the children with autism, were faster and more efficient to detect direct gaze than averted gaze, whether or not the eyes were presented alone or within faces. In addition, face inversion distorted efficient direct gaze detection in typically developing children, but not in children with autism. These results suggest that children with autism use featural information to detect direct gaze, whereas typically developing children use configural information to detect direct gaze.

Keywords:
Autism, Autism Spectrum Disorder, Gaze, Direct Gaze, Face Processing, Visual Search, Search Asymmetry, Face Inversion Effect

Acknowledgments
We would like to thank all the participants and parents who supported our study. We acknowledge Yura Kunihira and Hironori Akechi for help in data collection, Gergely Csibra, Laurence Conty, Mayada Elsabbagh, Nathalie George, Mark H Johnson and Sarah Lloyd-Fox for discussions and comments on earlier version of the draft, Kikue Sakaguchi for allowing us to use her photographs as stimuli in Exp. 1, and Bruce Hood for allowing us to use the stimuli in Exp. 2. This study was supported by the Japan Society for the Promotion of Science, 21st Century COE Program J05, "Center for Evolutionary Cognitive Sciences at the University of Tokyo", and AS was supported by an ESRC/MRC Joint Postdoctoral Fellowship.

Introduction

Information gained from another person's eyes plays a crucial role in human social communication. Among various functions of gaze processing, detection of direct gaze or eye contact is essential in social interaction and communication. Direct gaze signals the intention of the gazer towards the perceiver. Eye contact also plays a major role in communication and affective bonding (Kleinke, 1986; Robson, 1967; Robson, Pedersen, & Moss, 1969). Csibra and Gergely (2006) argue that perceived eye contact signals communicative ostention, and initiates referential communication.

Experimental studies have found that direct gaze affects perception, cognition and attention. For example, in visual search, target faces with direct eye gaze are detected faster and more efficiently than those with averted eye gaze (Conty, Tijus, Hugueville, Coelho, & George, 2006; von Grünau & Anston, 1995; Senju et al., 2005; Senju, & Hasegawa, 2006). In addition, when the gaze direction of others is ambiguous and difficult to perceive, people are biased to judge the gaze as "looking at me" (Martin, & Jones, 1982; Martin, & Rovira, 1981, 1982). Direct gaze also holds attention and makes it difficult to disengage from the face (Senju & Hasegawa, 2005). In addition, faces with direct gaze were remembered better than faces with averted gaze (Hood, Macrae, Cole-Davies & Dias, 2003; Vuilleumier, George, Lister, Armony, & Driver, 2005; Mason, Hood & Macrae, 2004; Smith, Hood & Hector, 2006). It is also known that a stranger gazing directly at the perceiver increases autonomic arousal in adults (Gale, Kingsley, Brookes, & Smith, 1978; Gale, Spratt, Chapman, & Smallbone, 1975; Nichols, & Champne, 1971).

Failure to develop typical mutual gaze behavior is one of the core symptoms of severe social and communicative disorders, and of autism (American Psychiatric Association, 1994; Baron-Cohen, 1995). Retrospective home video analyses found that from the first year of life, infants who were later diagnosed with Autism Spectrum Disorders (ASD) orient less to faces than typically developing infants (Baranek, 1999; Clifford, Young, & Williamson, 2007; Maestro et al., 2005; Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002; Werner & Dawson, 2005). Hobson and Lee (1998) also reported that older children and adolescents with ASD make eye contact less in a communicative context (greeting) than those without ASD. Studies with eye-tracking techniques confirm these observations and revealed that individuals with ASD fixate less to eyes compared to typically developing individuals (Dalton et al., 2005; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Neumann, Spezio, Piven, & Adolphs, 2006; Pelphrey, Sasson, Reznick, Paul, Goldman, & Piven, 2002; Spezio, Adolphs, Hurley, & Piven, 2007, but see also van der Geest, Kemner, Verbaten, & van Engeland, 2002).

Although these observation studies are very informative for spontaneous behaviour, they do not clarify how individuals with ASD process direct gaze, or whether perceived direct gaze affects cognition in individuals with ASD. Moreover, there are few studies which have empirically examined the cognitive and neural basis of eye contact processing in ASD. Furthermore, of these experimental studies that investigate eye contact processing in ASD, the findings are inconsistent. A series of experimental studies byour group found that individuals with ASD failed to show the facilitated behavioural (Senju, Yaguchi, Tojo, & Hasegawa, 2003) and event-related potential (ERP) (Senju, Tojo, Yaguchi, & Hasegawa, 2005b) responses associated with direct gaze. On the other hand, other neurophysiological studies reported that individuals with ASD elicited large ERP or magnetoencephalography signals in response to direct gaze, whereas this was not apparent in typically developing individuals (Grice, Halit, Farroni, Baron-Cohen, Bolton, & Johnson, 2005; Kylliäinen, Braeutigam, Hietanen, Swithenby, & Bailey, 2006). In addition, Kylliäinen and Hietanen (2006) presented looming faces with direct or averted gaze, and found that looming faces with either gaze direction, elicited a similar skin conductance response (SCR) in typically developing individuals. However, individuals with ASD, elicited a larger SCR in response to a looming face with direct gaze than one with averted gaze. It is difficult to interpret the cognitive and/or affective basis of the SCR response because the looming feature of the stimuli differed from other studies, and because the SCR response was smaller in individuals with ASD compared to typically developing individuals. However, at least, the differential response to gaze suggests that individuals with ASD possess a sensitivity to others' direct gaze.

Interestingly, one of our previous studies (Senju, Hasegawa & Tojo, 2005a) found conflicting results about direct gaze detection in autism. This study adopted a visual search paradigm initially used by von Grünau and Anston (1995), in which eye stimuli with various gaze directions were presented. Participants were instructed to detect targets of a particular eye direction, i.e. direct gaze, within a set of distracters of a different eye direction, i.e. averted gaze (Figure 1). There were two versions of the task, in the first we used schematic eyes (Figure 1a) as used by von Grünau and Anston (1995), and in the second we used photographs (Figure 1b). In the first experiment, children with autism, as well as typically developing children, showed the 'stare-in-the-crowd' effect (or asymmetry in search performance), performing better for the detection of direct gaze than the detection of averted gaze. In contrast, when the gazes were presented in photographs of laterally oriented faces, typically developing children were faster to detect direct gaze than averted gaze, but gaze direction did not affect search performance in children with autism. In addition, the faster detection of direct gaze in typically developing children was limited within the context of an upright face, when given inverted face stimuli their search performance between different gazes was no longer significantly different.

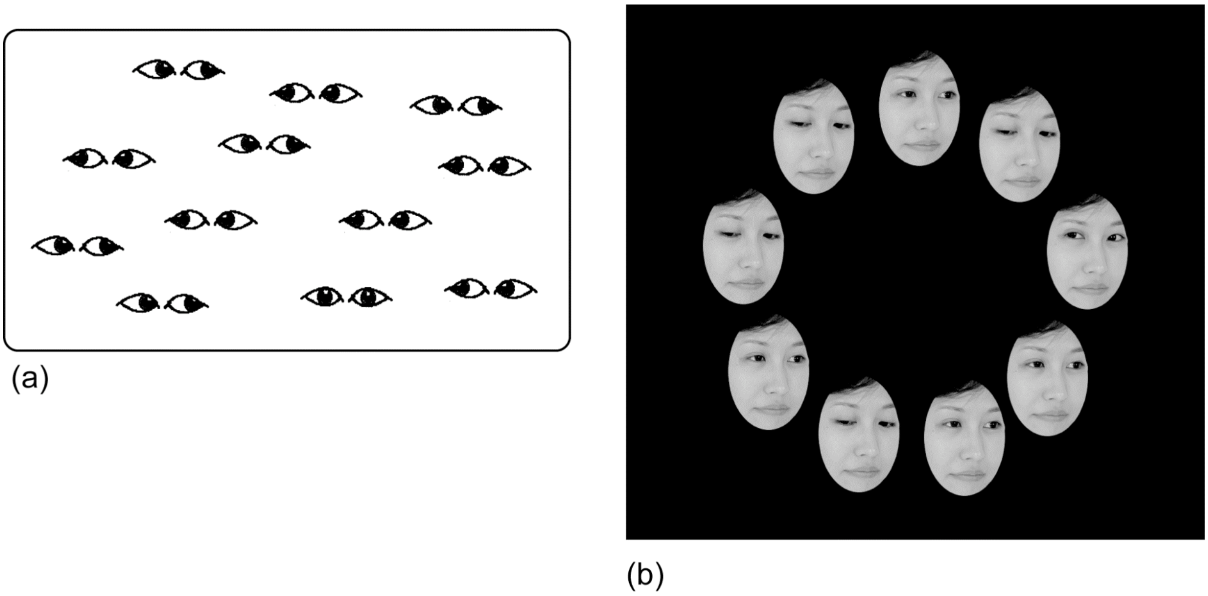

Figure1. Examples of the stimulus display used in Senju et al. (2005a). (a) An example of schematic eye stimuli. This figure depicts a direct-gaze condition with a target (direct gaze, appeared to the lower right) present among distracters (rightward- and leftward-gaze). (b) An example of laterally oriented face stimuli. This figure depicts a direct-gaze condition with a target (direct gaze, appeared to the right position of the stimulus array) present among distracters (rightward gaze and downward gaze).

There are several possibilities why children with ASD were faster to detect direct gaze in schematic eyes but not in laterally oriented photographic faces. Firstly, as Conty and colleagues argued (Conty et al, 2006), features specific to the schematic stimuli such as an unrealistically close distance between the two eyes or the high contrast of the eyes against the white background may have helped children with autism to detect direct gaze. Secondly, the presence of a whole face may have distracted children with autism and interfered with their attention. For example, while observing faces, individuals with autism fixate less to the eye region than typically developing individuals (Dalton et al., 2005; Klin et al., 2002; Neumann et al., 2006; Pelphrey et al., 2002; Spezio et al., 2007, but see also van der Geest et al., 2002). Finally, they may have failed to integrate the eye direction and the facial orientation to detect the gaze direction in the visual search task. Although individuals with ASD show the face inversion effect, they can recognize a face when presented with parts of a face just as well as when presented with a whole face. The results contrasted with typically developing individuals who benefited from the presence of whole face (Joseph & Tanaka, 2003; Teunisse & de Gelder, 2003). Since other studies have shown the presence of configural face processing capacities in individuals with ASD (Lahaie, Mottron, Arguin, Berthiaume, Jemel, & Saumier, 2006; Rouse, Donnelly, Hadwin, & Brown, 2004), these results may not suggest an impairment in configural face processing, but rather the presence of a cognitive style that spontaneously prefers featural processing and/or enhances an individual’s perceptual ability to process details. Therefore, in the aforementioned study (Senju, Hasewaga & Tojo, 2005a) one needs to perceive eye direction within the context of facial orientation (Wollaston, 1824) in order to detect direct gaze in laterally oriented face. Thus it is possible that the individuals with ASD fail to show faster detection for direct gaze when the gaze can only be perceived with reference to facial orientation.

In the current paper, we used a visual search paradigm to examine the three hypotheses outlined above. Typically in a visual search paradigm, a target is presented within a varying number of distracters, and one’s task is to detect the target as fast as possible (e.g. Treisman & Souther, 1985; Wolfe, 2001). Previous studies demonstrated that individuals with ASD are faster at a visual search task than typically developing individuals when non-social stimuli were used as targets and distracters (O'Riordan, 2004; O'Riordan & Plaisted, 2001; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). They also show a shallower ‘search slope’ (the search latency divided by the number of distracters), suggesting that their search performances are more efficient. It is advantageous to use such tasks because any atypical performance in individuals with ASD cannot be attributed to the general difficulty of the task involved. To date, at least two studies have used social stimuli in a visual search task with individuals with ASD (Ashwin, Wheelwright & Baron-Cohen, 2006; Senju et al., 2005a). Both studies failed to find superior visual search performance in the ASD group, but found that their speed and accuracy equaled that of typically developing individuals.

The current experiments used the same design as Senju and colleagues (Senju et al, 2005a; Experiment 2) but with different stimuli. The stimuli in Experiment 1 were static images of the eye region taken from forward-facing photographs of faces (Figure 2). The aim of Experiment 1 was to test the first hypothesis that specific features of schematic stimuli used in Senju et al. (2005a) helped children with autism to detect direct gaze. If the faster direct gaze detection found in children with ASD is limited to the specific information contained in schematic eyes used in Senju et al. (2005a), the search performance of children with autism would not be modulated by the gaze direction in response to photographic eyes. Experiment 2 used images of front-view faces to test the second hypothesis that the presence of the face would interfere with direct gaze detection in children with autism. If the mere presence of facial context interrupts attention of children with autism, they should show the 'stare-in-the-crowd' effect in Experiment 1, but not in Experiment 2. In contrast, if the difficulty in direct gaze detection in children with autism is limited to the integration of face and eye directions, they should be faster to detect direct gaze than averted gaze both in Experiments 1 and 2. As a result, when the isolated eyes were presented (Experiment1), children with ASD were faster to detect direct gaze than averted gaze, just like typically developing children. When the whole faces were presented, typically developing children demonstrated faster direct gaze detection only when the faces were presented right side up, but children with ASD were faster to detect direct gaze regardless of the facial orientation (upright or inverted). These results suggest that children with ASD rely on featural information to detect direct gaze, whereas typically developing children use configural information to detect direct gaze.

Experiment 1

This experiment was designed to investigate whether children with autism show the 'stare-in-the-crowd' effect when the real images of eye regions were used as stimuli. Stimuli were images of eye regions with various gaze directions, which were cropped from photographs of the same female face (see Figure 2). Targets were either direct gaze or averted gaze. If children with autism have sensitivity to realistic direct gaze, they should be faster and more efficient to detect targets with direct gaze than with averted gaze (i.e. there should be a decrease in search time per item, creating a 'search asymmetry' in the slope of the search function (Wolfe, 2001). In addition, eyes were presented upside down as well as upright, because several studies have reported that inversion of eye regions may affect configural processing of the eyes (Jenkins & Langton, 2003; Senju & Hasegawa, 2006). If configural processing of eyes are involved in the 'stare-in-the-crowd' effect, inversion of the stimuli should distort the search asymmetry.

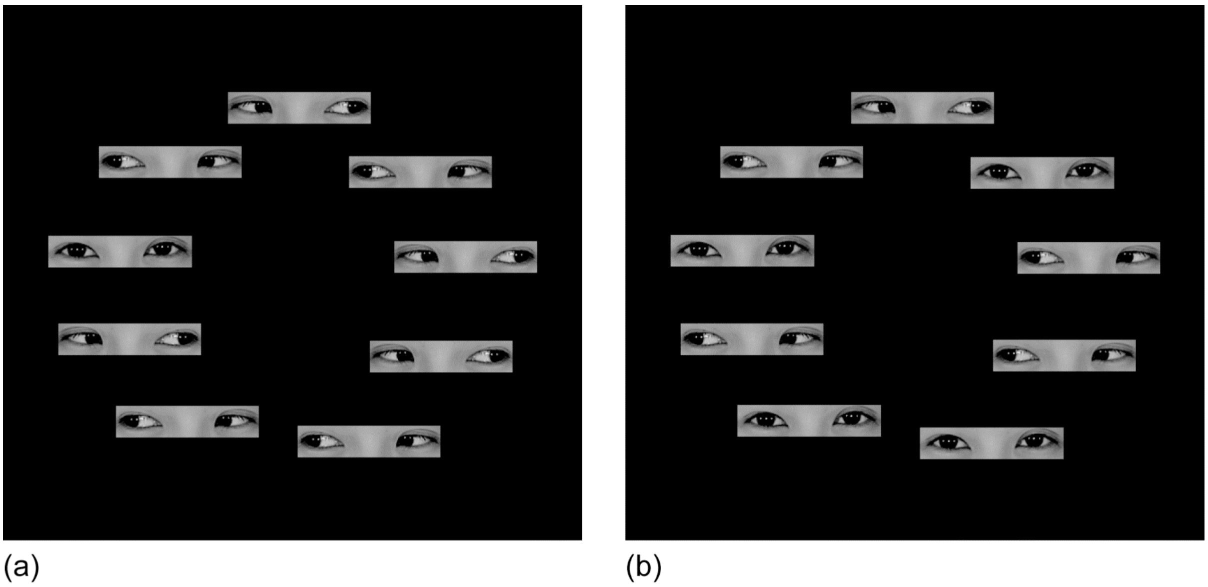

Figure2. Examples of the stimulus display in Experiment 1. (a) The direct-gaze condition with a target (direct gaze, appeared to the left position of the stimulus array) presented among distracters (rightward- and leftward-gaze). (b) The averted-gaze condition with a target (rightward-gaze, appeared to the upper position of the stimulus array) presented among distracters (direct- and leftward-gaze).

Method

Fourteen children with autism (1 female and 13 males) and 27 typically developing children (10 female and 17 males) participated in the experiment (Table 1). All children were students of, or had graduated from, a primary school for children both with and without autism. All the children with autism were diagnosed by at least one child psychiatrist when they entered the school. In addition, experienced clinical psychologists (KY, YT) confirmed the diagnosis based on the parental interview and clinical observation, according to the DSM-IV criteria (American Psychiatric Association, 1994). Children were tested with a Japanese version of Raven's Colored Progressive Matrices (RCPM) to assess their levels of non-verbal intelligence (Raven, 1956; Sugishita & Yamazaki, 1993). Neither age nor RCPM score are different between groups (all $t < 1.5$, $p > .1$). All children had normal or corrected-to-normal visual acuity. Written informed consent was obtained from all the participants and their parents. The study was approved by the University of Tokyo Research Ethics Committee.

Table 1 Age and the scores of Raven' Coloured Progressive Matrices (RCPM) of the participants in Experiment 1.

	Autism (n=14)		Typical Development (n=27)	
	M (SD)	range	M (SD)	range
Age (y;m)	12;10 (2;0)	9;5 – 14;2	11;11 (1;11)	8;4 – 15;2
RCPM	32.4 (3.6)	25 - 36	33.1 (2.2)	27 - 36

M: mean, SD: standard deviation.

Apparatus & Stimuli. The experiment was conducted on a laptop PC with a 12-inch color LCD monitor, using Cedrus SuperLab Pro software (Cedrus Cooperation, San Pedro, CA). The participants were seated approximately 67 cm from the monitor. Their reaction times (RT) and accuracy were measured from their keyboard responses.

A fixation point consisting of a central cross that subtended 1º appeared on the screen, on which the participants were instructed to fixate before the experiment started. Each stimulus display consisted of five or nine pairs of eyes with varying gaze directions. The eyes were arranged in a circle, which centered on the central fixation point and subtended approximately 12.5º (Figure 2). Eye regions (4.1º wide and 1.0º high) were cut from coloured photographs of the same female face to produce the stimulus elements in the eye direction condition. These consisted of a direct gaze and two averted gaze, one to the left and the other to the right. The targets in each condition were faces with either a direct gaze or one of the averted gazes, with the other two stimuli types serving as distracters. The eye directions of the target in averted gaze condition were counterbalanced between participants.

Design & Procedure. The experiment consisted of four factors: eye direction of target face (target gaze; direct or averted), eye orientation (upright or inverted), number of presented faces (array size; five or nine items), and presence of the target (present or absent). One of the possible four combinations of the target condition (target gaze and eye orientation) served as one block, with at total of four blocks presented over the experiment. Within each block, the vertical orientation of distracters was always the same as targets, with only the gaze direction differing, and each array size appeared an equal number of times. Each block consisted of 32 test trials, preceded by 4 practice trials. Accordingly, each participant went through a total of 144 trials. Within each block, the target was presented in 50 % of the test trials, and was absent in the other 50 % (i.e., 16 trials each). The presentation order of each trial, as well as the order of the blocks, was randomized across participants. The number of trials was chosen to minimize the task demand to the children. In our previous study with typically developing adults (Senju et al., 2005a), we administered twice as many test trials as the current study (256 test trials per participant). To test whether the number of trials used in the present study would give reliable data, we used the data from the previous study (Senju et al, 2005a) to examine the correlation between the reaction times of the first half of the trials of each condition (i.e. 128 trials) with the reaction times for the whole set of trials (i.e. 256 trials). The correlation was very high (mean: $r = .92$), confirming that the number of trials used in the present study would give reliable data.

Participants were instructed to fixate on the central cross before each trial, and to respond as soon as possible by pressing a key on the computer keyboard corresponding to the presence or absence of the target (i.e. to press one key when the target is present, and to press another key when the target is absent), using their preferred hand. Four practice trials preceded the test trials for each block, in order to familiarize participants with the task and the target stimuli. Practice trials were repeated until participants correctly respond in at least 3 out of 4 trials. Each trial started with presentation of the central fixation cross for 500 ms, which was then replaced with the stimulus array. The stimulus array remained on the display until the participant responded. Immediately after the participant's response, feedback was presented on the center of the screen for 500 ms ('Good job!' for correct response and '–' for incorrect response). The next trial started after a 1,000-ms interstimulus interval. Participants were allowed to take a brief rest between experimental blocks.

Results

Trials with reaction times (RTs) of less than 100 ms were regarded as anticipatory responses and disregarded from the analysis, less than 1% of the trials were eliminated in this way. In addition, trials with RTs longer than 3 standard deviations from each participant's overall average RT were removed from analyses (Miller, 1991; Ratcliff, 1993). Due to the small number of trials for each condition and relatively large individual variation in the RTs, mean RTs were used for the analyses (Miller, 1988). Note that all children had at least 6 valid trials for RT analyses for each condition.

Preliminary analyses for RTs and error rates found no significant main effects or interactions related to gender in both typically developing children and children with autism (all $F < 3.50$, all $p > .05$), so this factor was pooled for the subsequent analyses. The mean RTs for correct responses and the error rates (Table 2) were analyzed with a five-way analyses of variance (ANOVAs), with participant group (autism or typical development), target gaze (direct or averted), eye orientation (upright or inverted), array size (five or nine items), and presence of the target (present or absent) as independent variables.

Table 2. Mean reaction times with standard deviations and error rates for Experiment 1.

		Autism				Typical Development			
		Face Upright		Face Inverted		Face Upright		Face Inverted	
Gaze direction		Direct	Averted	Direct	Averted	Direct	Averted	Direct	Averted
Target present									
5 items	M	1836.2	2407.9	1778.1	2243.1	1464.2	1845.6	1624.7	1969.8
	SD	694.1	724.8	456.0	672.0	470.7	630.4	575.9	578.3
	%E	5.6	4.0	4.8	3.2	5.3	6.6	6.6	3.3
9 items	M	2402.6	2892.1	2136.5	2889.7	1802.1	2349.3	1969.4	2534.7
	SD	942.3	778.7	493.0	705.4	653.4	687.1	826.4	913.9
	%E	4.0	4.8	7.1	4.0	7.4	6.6	9.1	6.2
Target absent									
5 items	M	2261.0	2751.3	2202.8	2699.8	1861.3	2321.1	2012.9	2513.5
	SD	846.7	639.4	515.3	600.2	764.4	804.3	771.4	845.8
	%E	2.4	0.8	3.2	1.6	0.0	1.2	2.1	2.1
9 items	M	2990.0	3926.8	3039.0	3942.6	2721.8	3427.0	2980.8	3686.4
	SD	1032.8	1014.3	966.3	934.2	1159.3	1196.1	1155.6	1268.4
	%E	1.6	0.8	4.8	0.8	1.6	1.2	1.2	0.8

For RTs, a main effect of target gaze (F (1,39) = 73.8, $p < .001$, $\eta_p^2 = .65$) and an interaction between target gaze and array size (F (1,39) = 20.0, $p < .001$, $\eta_p^2 = .34$) were significant, which shows that search latency was shorter (i.e. fast detection) and search slope (search latency per array size) was shallower (i.e. efficient search) for targets with direct gaze. In addition, main effects of array size (F (1,39) = 255.8, $p < .001$, $\eta_p^2 = .87$) and presence of the target (F (1,39) = 130.9, $p < .001$, $\eta_p^2 = .77$), and an interaction between array size and presence of the target (F (1,39) = 70.3, $p < .001$, $\eta_p^2 = .64$) were significant. These results are in accordance with previous visual search experiments (e.g., von Grünau & Anston, 1995; Senju et al., 2005; Senju & Hasegawa, 2006; Treisman & Souther, 1985), indicating that search was dependent on the number of distracters, and that visual search was more exhaustive when the target was not present. Note that there was no overall difference between the groups and no differential effects of array size across the groups. Hence any contrasting effects of gaze cannot be attributed to overall differences in processing efficiency across the groups. In addition, no main effect or interactions including eye orientations reached significance. No other main effects or interactions were significant (all $F < 3.17$, $p > .05$).

For error rates, there was a main effect of the presence of the target (F (1,39) = 34.0, $p < .001$, $\eta_p^2 = .46$), indicating that participants made more errors by missing presented targets than false positive errors when targets were absent. In addition, the main effect of target gaze was also significant (F (1,39) = 7.03, $p < .05$, $\eta_p^2 = .15$). It is because participants made more errors for targets with direct gaze (4.2 %) than for averted gaze (3.0 %). Since it might suggest speed-accuracy trade off for direct gaze detection, we further examined the correlations between the RTs and error rates, and found a non-significant trend of negative correlation in typically developing children (r = -0.36, p = .06), but not in children with autism (r = -0.04, $p > .1$). Although it is highly unlikely that faster RTs for direct gaze is totally explained by speed-accuracy trade off, further study will be required to control the effect of strategic differences, especially for typically developing children.

Discussion

These results show that in children with autism, as well as in typically developing children, targets with direct gaze are detected faster and more efficiently than those with averted gaze. It excludes the possibility that faster RTs for direct gaze reported in Senju et al. (2005, Experiment 3) is limited to the specific schematic stimuli used in that experiment, and suggests that direct gaze facilitates detection in children with autism. The current results also suggest that the 'stare-in-the-crowd' effect for isolated eyes found in von Grünau and Anston (1995) and Senju et al. (2005a, Experiment 3) is not limited to the particular stimulus arrangement (spatially random presentation) but can be replicated with different layouts such as the circular stimulus used in the current study. In addition, it is possible that both groups of participants used relatively low-level psychophysical information such as bilateral symmetry of the eyes, rather than configural information, to detect direct gaze, since inversion of the eyes had no effect on search asymmetry. Together with the results of Senju et al. (2005a), the current results suggest that the impairment of children with autism for detecting direct gaze is based on either their difficulty in attending to eyes within a given facial context, or their difficulty in integrating face and eye direction. These two hypotheses, primarily the first, were tested in Experiment 2.

Experiment 2

In Experiment 2, we used whole, front-view faces (Figure 3) as stimuli to investigate whether the presence of facial context would impede the 'stare-in-the-crowd' effect in children with autism. As we described before, children with autism do not show the 'stare-in-the-crowd' effect when the eyes were presented in the context of laterally oriented faces (Senju et al., 2005a, Experiment 2, see also Figure 1b). Because Experiment 1 confirmed that children with autism, as well as typically developing children, show the 'stare-in-the-crowd' effect for realistic eyes in front view, there are at least two factors that could affect direct gaze detection in children with autism. Firstly, if the presence of facial context interferes with orientation or detection of eyes in children with autism, then the direction of the target gaze should not modulate search performance of children with autism. Alternatively, if their difficulty lies in the integration of face and eye directions to detect direct gaze, then children with autism should be faster to detect direct gaze than averted gaze: This is because the stimuli are front-view faces, so the same low-level information, such as bilateral eye symmetry, is available as in Experiment 1.

In addition, the stimuli were presented either upright or inverted, as in Experiment 1. In our previous study (Senju et al., 2005a), inversion of the face eliminated the 'stare-in-the-crowd' effect in typically developing children In contrast with the upright condition, reaction times were no longer significantly different for direct and averted gaze in inverted faces. Face inversion may effect configural facial processing (Valentine, 1988; Yin, 1969) in typically developing children, causing the advantage for direct gaze detection to diminish. Thus, face inversion could modulate search performance in typically developing children in the present experiment, as in Senju et al. (2005a). Alternatively, if children with autism process eyes featurally or rely on low-level information, face inversion would not affect their performances.

(a) (b)

Figure3. Examples of the stimulus display in Experiment 2. (a) The direct-gaze condition with a target (direct gaze, appeared to the upper position of the stimulus array) presented among distracters (rightward- and leftward-gaze). (b) The averted-gaze condition with a target (leftward-gaze, appeared to the right position of the stimulus array) presented among distracters (direct- and rightward-gaze).

Method

The stimuli, apparatus, experimental design and procedure were exactly the same as those of Experiment 1, except that the images of whole faces (4.1º wide and 2.5º high), rather than their eye regions, were used as stimuli (Figure 3). Twenty-two children with autism (5 female and 17 males) and 30 typically developing children (14 female and 16 males) participated in the experiment (Table 3). As in Experiment 1, all children were students of, or had graduated from, a primary school for children both with and without autism and all the children with autism were diagnosed by at least one child psychiatrist when they entered the school. In addition, experienced clinical psychologists (KY, YT) confirmed the diagnosis based on the parental interview and clinical observation, according to the DSM-IV criteria (American Psychiatric Association, 1994). Children were tested with an abbreviated Japanese WISC-III to assess their general intelligence (Japanese WISC-III Publication Committee, 1998). Since age, verbal IQ (VIQ), performance IQ (PIQ) and full IQ (FIQ) differed significantly between groups (all $t > 2.43$, all $p < .05$), these factors were introduced as covariates in the following analyses. All children had normal or corrected-to-normal visual acuity. As in Experiment 1, written informed consent was obtained from all the participants and their parents.

Table 3. Age, verbal IQ (VIQ), performance IQ (PIQ) and full IQ (FIQ) of the participants in Experiment 2.

	Autism (n = 22)		Typical Development (n = 30)	
	M (SD)	range	M (SD)	range
Age (y;m)	12;2 (2;2)	9;2 – 15;1	10;7 (2;4)	8;0 – 14;11
VIQ	88.0 (19.7)	58 – 124	103.4 (17.7)	70 – 136
PIQ	93.2 (24.5)	58 - 136	112.4 (17.3)	88 - 154
FIQ	90.6 (20.6)	61 - 127	107.9 (14.2)	85 - 142

M: mean, SD: standard deviation, VIQ: verbal intelligence quotient, PIQ: performance intelligence quotient, FIQ: full intelligence quotient.

Results

As in Experiment 1, trials with reaction times (RTs) of less than 100 ms were regarded as anticipatory responses and disregarded from the analysis, less than 1% of the trials were eliminated in this way. Trials with RTs longer than 3 standard deviations from each participant's overall average RT were removed from analyses (Miller, 1991; Ratcliff, 1993). As in Experiment 1, mean RTs were used for the analyses (Miller, 1988), due to the small number of trials for each condition and relatively large individual variation in the RTs. Note that all children had at least 4 valid trials for RT analyses for each condition.

Because age, VIQ, PIQ and FIQ differed significantly between groups and it may have affected the results, the mean RTs for the correct response and the error rates (Table 4) were analyzed with five-way analyses of covariance (ANCOVAs), with participant group (autism or typical development), target gaze (direct or averted), facial orientation (upright or inverted), array size (five or nine items), and presence of the target (present or absent) as independent variables, and the age, VIQ and PIQ as covariates. Results did not differ when the age and the FIQ were used as covariates. As in Experiment 1, preliminary analyses for RTs and error rates did not find any main effects or interactions related to the gender in typically developing children or children with autism (all $F < 3.88$, all $p > .05$), this factor was pooled for the main analyses.

Table 4. Mean reaction times with standard deviations and error rates for Experiment 2.

		Autism				Typical Development			
		Face Upright		Face Inverted		Face Upright		Face Inverted	
Gaze direction		Direct	Averted	Direct	Averted	Direct	Averted	Direct	Averted
Target present									
5 items	M	1848.7	2276.9	1840.7	2224.6	1608.3	2042.1	1761.2	2110.3
	SD	575.3	576.3	670.6	576.7	549.1	742.3	488.3	552.1
	%E	6.1	12.6	6.1	12.6	5.6	4.1	6.7	6.7
9 items	M	2020.1	2764.0	2229.3	3105.8	2009.7	2661.7	2265.0	2721.5
	SD	530.3	764.1	593.5	819.3	723.3	885.0	707.7	766.2
	%E	12.6	13.1	13.1	17.7	10.4	12.2	5.2	9.6
Target absent									
5 items	M	2234.0	2761.5	2435.6	3028.0	2122.4	2694.5	2404.7	2774.9
	SD	599.0	699.0	849.3	731.0	739.4	773.0	700.5	758.4
	%E	8.6	7.1	5.1	3.0	1.1	0.4	0.4	0.7
9 items	M	3041.2	3733.0	3076.3	4112.8	2919.7	3851.5	3313.5	4046.7
	SD	1034.3	659.7	877.8	857.3	1169.2	1209.7	1042.0	1128.5
	%E	7.1	8.1	4.5	7.1	1.9	2.6	2.6	1.9

As in Experiment 1, for RTs, the main effects of array size (F (1,49) = 14.8, $p < .001$, $\eta_p^2 = .24$) and presence of the target F (1,49) = 19.7, $p < .001$, $\eta_p^2 = .30$) were significant. Their interaction was also marginally significant (F (1,49) = 3.69, $p = .061$, $\eta_p^2 = .072$). This replicated previous findings regarding visual search (Treisman & Souther, 1985; von Grünau & Anston, 1995). As in Experiment 1, there was no overall difference between the groups and no differential effects of array size across the groups. Hence any contrasting effects of gaze cannot be attributed to overall differences in processing efficiency across the groups.

As in Experiment 1, a main effect of target gaze (F (1,49) = 13.4, $p < .001$, $\eta_p^2 = .22$), as well as interactions between target gaze and array size (F (1,49) = 7.60, $p < .01$, $\eta_p^2 = .14$) were significant, which shows that targets with direct gaze were detected faster, and the search slope for direct gaze targets was shallower, than for targets with averted gaze. In addition, an interaction between facial orientation and array size was significant (F (1,50) = 4.84, $p < .05$, $\eta_p^2 = .093$), because the search slope was shallower for the upright face condition than for the inverted face condition.

Importantly, analysis also revealed three significant four-way interactions. All of them included participant group and array size as two of the four factors, and each combination of two of the remaining three factors (target gaze, facial orientation and presence of the target) as the other two factors (all F (1,49) > 5.05, all $p < .05$, all $\eta_p^2 > .097$). Although it is difficult to interpret these four-way interactions, altogether they suggest that group differences of search slopes (i.e. search latency per array size) are under complex modulation by the other factors such as gaze direction of the target, facial orientation and the presence of the target. Since the main aim of our study is to investigate the effect of target gaze direction in each diagnostic group, we calculated the search slopes for each condition, subjected it to additional ANCOVA, and examined the effect of target gaze direction in each condition using pairwise comparisons (with bonferroni corrections, see Figure 4). For the 'target present' condition, typically developing children showed direct gaze advantage (i.e. a shallower search slope for the direct gaze target than for the averted gaze target) for upright faces (mean difference: 53.5

ms/item, $p < .05$), but not for inverted faces (mean difference: 16.6 ms/item, $p > .1$). On the other hand, children with autism showed direct gaze advantage both in the upright (mean difference: 80.4 ms/item, $p < .01$) and the inverted (mean difference: 137.1 ms/item, $p < .001$) faces. For the 'target absent' condition, typically developing children showed a significant direct gaze advantage both for upright and inverted face conditions (upright face condition, mean difference: 101.8 ms/item, $p < .01$, inverted face condition, mean difference: 95.7 ms/item, $p < .01$). Children with autism also showed a direct gaze advantage in the inverted face condition (mean difference: 104.3 ms/item, $p < .01$), but not in the upright face condition (24.8 ms/item, $p > .1$). No other main effects or interactions reached significance (all $F < 3.55$, $p > .05$).

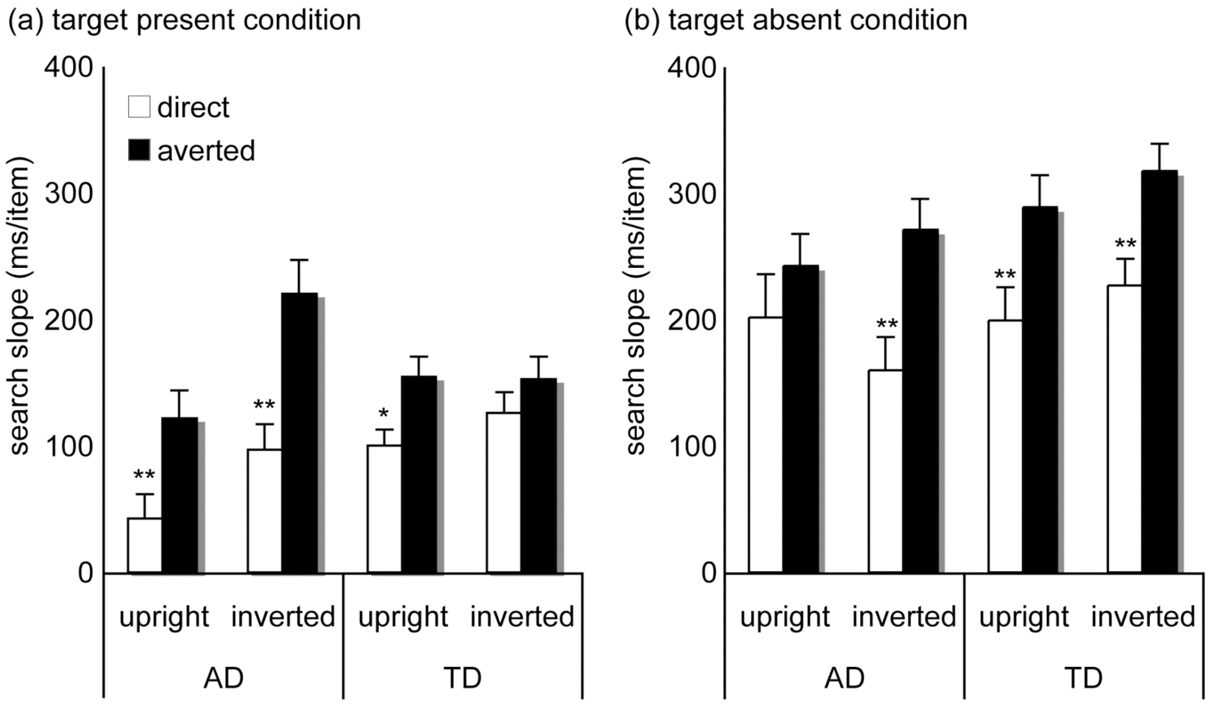

Figure 4. Average search slope with standard errors (in ms/item) from Experiment 2, of the (a) target present condition and the (b) target absent condition, as a function of participant group, facial orientation and target gaze direction. The white bars represent search slopes for targets with direct gaze and the black bars represent search slopes for targets with averted gaze. AD: children with autism, TD: typically developing children, *: $p < .05$, **: $p < .01$.

For the error rates, there was a main effect of group (F (1,50) = 6.59, $p < .05$, $\eta_p^2 = .12$), as well as an interaction between group, facial orientation and array size (F (1,50) = 5.16, $p < .05$, $\eta_p^2 = .10$) and group, facial orientation, array size and presence of target (F (1,50) = 4.62, $p < .05$, $\eta_p^2 = .09$). These interactions were due to the larger group differences for the inverted face, smaller array size or target present conditions. No other main effects or interactions approached significance. Note that no main effect or interactions including the target gaze factor was significant (all $F < 3.41$, $p > .05$). In addition, the correlation between the RT and error rates was non-significant in children with autism ($r = .33$, $p > .1$; typically developing children, $r = .26$, $p > .1$), which can clearly rebuff the possibility of speed-accuracy trade off.

Discussion

There are several important findings with the current results. First of all, results revealed that children with autism, as well as typically developing children, are faster and more efficient in detecting direct gaze than averted gaze, within the context of front-view faces. This does not support the hypothesis that the presence of facial context per se impedes children with autism when detecting direct gaze. Combining the current results with those in Experiment 1 and those of Senju et al. (2005a), these findings suggest that the difficulty in the efficient detection of others' direct gaze in autism is restricted to the condition when the gaze is presented in the context of laterally oriented faces. Thus, the current results suggest that children with autism have difficulty in integrating head and eye direction to detect direct gaze when the two cues conflict, which impedes the manifestation of the 'stare-in-the-crowd' effect for laterally oriented faces.

Secondly, inversion of the facial stimuli eliminated asymmetry in the search slope, or more efficient search for direct gaze than for averted gaze, in typically developing children (see Figure 4). It suggests that efficient direct gaze detection in typically developing children reliesd on configural facial processing, which is distorted by face inversion. Note that the face inversion effect was found in the 'target present' condition, but not in the 'target absent' condition. Since the judgment in 'target –absent' trials is thought to rely on top-down modulation of visual attention (Chun & Wolfe, 1996), it may suggest that both the bottom-up and top-down processing are involved in the 'stare-in-the-crowd' effect, and only the former was impeded by face inversion.

On the other hand, face inversion did not impede search asymmetry in children with autism. This suggests that the 'stare-in-the-crowd' effect found in children with autism does not rely on configural facial processing, but is based on relatively low-level psychophysical information such as bilateral symmetry of the eyes. Moreover, in children with autism, the differences of the search slope between direct and averted gaze target conditions were even larger for the inverted than for the upright face condition. From the current data only, it is not clear why search asymmetries are larger for inverted faces than upright faces in children with autism. Because the effects were present both in 'target present' and 'absent' conditions equally, it might reflect strategic, rather than perceptual, differences. Further work will be required to examine the effect of facial context on gaze processing in individuals with autism.

General Discussion

The current study utilized a visual search paradigm to investigate direct gaze detection in children with autism. The findings clearly demonstrate that children with autism detect direct gaze faster and more efficiently than averted gaze, regardless of whether the eyes were presented alone (Experiment 1) or within a facial context (Experiment 2). These results suggest that the direct gaze, at least within front-view faces, is salient for individuals with autism as well as for typically developed individuals.

The current finding may seem to contradict previous eye-tracking studies, which have revealed that individuals with autism fixate less to the eye region than typically developing individuals (e.g. Klin et al., 2002; Neumann et al., 2006; Pelphrey et al., 2002; Speer et al., 2007). However, it is possible that these apparent differences may rely on the task demand, or top-down modulation of attention induced by the task. For example, one of these studies (Neumann et al., 2006) conducted fine-tuned time course analysis of the fixation pattern during face observation, and found that decreased eye fixation in autism was not due to the lack of bottom-up attention to the eyes, but due to the top-down modulation of fixation to the mouth region. Thus it is possible that individuals with autism have intact bottom-up attention to the eyes but fail to develop a top-down strategy to voluntary attend to the eyes. Further studies will be beneficial to assess whether gaze direction modulates attention of individuals with autism when the task is irrelevant to the gaze.

Another interesting finding of the current study is that face inversion had different effects on direct gaze detection in children with and without autism. In Experiment 2, typically developing children located the direct gaze more efficiently than averted gaze only when faces were presented in the upright position. In contrast, face inversion did not distort the efficient search for direct gaze in children with autism. In contrast, eye inversion in Experiment 1, did not have any effect on performance in either of the participant groups. These results suggest that children with autism rely on featural information for the efficient direct gaze detection, even when the eyes are presented in the facial context. On the other hand, typically developing children process eyes featurally when they see them in isolation, but they process gaze direction configurally once they are presented within the whole face. Other studies also suggest that individuals with ASD spontaneously rely on featural, rather than configural, information in face processing (Joseph & Tanaka, 2003; Teunisse & de Gelder, 2003).

There are at least two hypotheses why facial context does not modulate gaze processing in children with autism. Firstly, gaze processing could derive from a ‘local bias’ in individuals with autism, which may be based on superior local processing (Mottron, Dawson, Soulieres, Hubert, & Burack, 2006) or a cognitive style that prefers local rather than global processing (Happé, 1999; Happé & Frith, 2006). Whatever the perceptual/cognitive basis presented, such ‘local bias’ would orient them to the featural details of the eyes without the influence of facial context. Alternatively, individuals with autism may have an impaired ‘social brain’ network; the cognitive/neural system specialized for the processing of socially relevant information (Johnson, Griffin, Csibra, Halit, Farroni, de Haan, Tucker, Baron-Cohen, & Richards, 2005; Sasson, 2006; Shultz, 2005). For example, Lopez, Donnelly, Hadwin and Leekam (2004) demonstrated that individuals with ASD could benefit from holistic information for face recognition tasks when they were verbally ‘cued’ to attend to the relevant facial features. Their study suggests that the lack of spontaneous use of configural face processing in ASD may be due to the difficulty they have in being able to spontaneously attend to the relevant information. It follows that individuals with autism may rely on alternative cognitive mechanisms to deal with social information such as eye gaze. Further, children with ASD may have been faster to detect direct gaze in the current study only because the stimuli contained salient low-level psychophysical properties such as bilateral symmetry, and individuals were not required to possess any awareness of it’s social relevance. Although these two arguments are not necessary mutually exclusive, further work will be required to reveal the cognitive and neural basis of atypical gaze processing in autism.

Further, this may explain why typically developing children showed the ‘stare-in-the-crowd’ effect for laterally oriented faces, but children with ASD did not (Senju et al., 2005a). To detect direct gaze in laterally oriented faces, one has to integrate eye direction with head orientation, which involves configural processing. Since the current results suggest that children with ASD rely on featural information to detect direct gaze, it is possible that the children with ASD that participated in Senju et al. (2005a) did not use configural information to effortlessly detect direct gaze. It contrasts with typically developing children, who are more likely to process eye gaze with reference to the facial configuration. Not only did the typically developing children effortlessly detect direct gaze in upright, laterally averted faces (Senju et al., 2005a), they also failed to show the faster detection of direct gaze in inverted front-view faces (Experiment 2, the current study), in which the salient low-level psychophysical property (i.e. bilateral symmetry) was available but facial configuration was distorted.

Such feature-based gaze processing may be affecting social interaction and communication in autism in their daily life. In the perceptual mechanism of typically developing individuals, the direction of eyes, head and even body postures are integrated (Langton, 2000; Langton, Watt, & Bruce, 2000; Seyama, & Nagayama, 2005), to calculate the direction of others' attention (Perrett, & Emery, 1994; Perrett, Hietanen, Oram, & Benson, 1992). Thus, failure to integrate eye direction with facial context would interfere with the detection of the direction of others' attention, thus impairing social interaction and communication in autism.

How do the current findings relate to previous research showing that direct gaze in a front-view face elicits larger neurophysiological (Grice et al., 2005; Kylliäinen et al., 2006) and physiological (Kylliäinen and Hietanen, 2006) responses compared with averted gaze in children with ASD, but not in typically developing children? Our results might suggest that such physiological and neurophysiological responses in ASD relate to atypical direct gaze processing in children with ASD, rather than a spared sensitivity, or oversensitivity, to others' direct gaze. The current results suggest that children with ASD rely on low-level psychophysical features, rather than facial context, to detect direct gaze. Thus it is possible that the physiological or neurophysiological response to direct gaze found in the previous studies (Grice et al., 2005; Kylliäinen et al., 2006; Kylliäinen and Hietanen, 2006) may be based on feature-based processing, which is dominant in children with ASD but not in typically developing children. However, since it is difficult to confirm a neural or physiological basis from behavioural data alone, further study will be required to examine the neurophysiological and physiological basis of configural/featural gaze processing.

There are several reasons why the current findings using a visual search paradigm may seem to contradict previous findings obtained from more naturalistic contexts, such as reduced eye contact in a communicative context (e.g. Hobson & Lee, 1998) or fewer face orienting in a naturalistic context (Baranek, 1999; Clifford et al., 2007; Maestro et al., 2005; Osterling & Dawson, 1994; Osterling et al., 2002; Werner & Dawson, 2005). Primarily, in social and communicative contexts, there are far more additional cues over and above eye contact, such as contingent responses, calling one by the name or waving hands, which are naturally used to attract the attention of the communicative partners (i.e. parents). Thus it is difficult to verify whether the lower level of social orienting seen in individuals with ASD derives from a failure to use configural information to detect eye contact, or a failure to notice any other social and communicative cues. Moreover, the participants in the current study were explicitly instructed to attend to the gaze direction. Thus it is also possible that individuals with ASD have a capacity to effortlessly detect direct gaze, but do not spontaneously attend to others' gaze direction. Further work will be required to examine how children with ASD process various social and communicative cues in both naturalistic and controlled contexts.

Another interesting and puzzling finding is that the error rate had a negative relationship with the RTs in Experiment 1, and a positive one in Experiment 2. This tendency was only found in typically developing children, whereas children with autism did not show any correlation between error rates and RTs in Experiment 1. One possible reason is that the relatively low task demand of the direct gaze condition in Experiment 1, suggested by the lower overall error rates, may affect the participants' strategy. Since the gaze direction of target eyes was fixed within each block, it is possible that typically developing children found the block with direct gaze condition less challenging and did not pay enough attention, which might have led to slightly higher error rates in this condition. As the correlations did not reach significance in either experiment, these comments are speculative and further research is required to investigate this potentially interesting effect.

A limitation of the current study is that we did not match the groups on their mental age, though differences in general cognitive abilities cannot fully account for the current findings for several reasons. Firstly, in Experiment 1, we did not find any group differences in visual search performance or gaze processing. Thus it is highly unlikely that the possible *differences* in general cognitive abilities contributed to the *equal* performance between groups. Secondly, in Experiment 2, we obtained both verbal and non-verbal IQ, and these background measures were used as covariates in order to control for their potential effects. However further research will be required to examine the wider range of mental age on the developmental trajectory of ASD. Moreover, though the present study and Senju and colleagues (2005a) found this typical and atypical direct gaze detection in 9 to 15 year olds, further work will be beneficial to examine whether younger children and/or adults with autism show similar atypical gaze processing. Furthermore, future work will be beneficial to assess the standardized measurements of autistic symptoms such as ADI and ADOS and examine the relationship between the individual differences in detailed clinical symptoms and atypical gaze processing in individuals with autism.

The current results may also suggest that children with autism can use some of the available social and communicative cues, when they are clearly defined by featural information and do not need integration. Further studies will be fruitful to examine whether locally or featurally defined social/communicative signal help individuals with autism in social interaction and communication. Such studies will be helpful to explore the effective ways of interventions and support for individuals with autism.

Conclusion

The current study used a visual search paradigm to investigate whether direct gaze in front-view faces facilitate detection of the target in children with and without autism. In Experiment 1, when isolated eyes were presented, both typically developing children and children with autism were faster to detect direct gaze compared to averted gaze, and no group differences were observed. In Experiment 2, when the images of whole, front-view faces were used as stimuli, typically developing children were faster to detect direct gaze only when the faces were presented right side up. On the other hand, children with autism were faster to detect direct gaze regardless of whether the faces were presented upright or upside-down. These results suggest that children with autism mainly rely on featural, or low-level psychophysical information such as bilateral symmetry to detect direct gaze, and are not affected by the facial context. In contrast, we suggest that typically developing children are required to process direct gaze within the facial configuration.

References

American Psychiatric Association, (1994). *Diagnostic and statistical manual of mental disorders (4th Edn.), DSM-IV*. Washington, DC : Author.

Ashwin, C., Wheelwright, S., & Baron-Cohen, S. (2006). Finding a face in the crowd: testing the anger superiority effect in Asperger Syndrome. *Brain and Cognition,* **61**, 78-95.

Baranek, G. T. (1999). Autism during infancy: a retrospective video analysis of sensory-motor and social behaviors at 9-12 months of age. *Journal of Autism and Developmental Disorders*, **29**, 213-224.

Baron-Cohen, S. (1995). *Mindblindness : An essay on autism and theory of mind*. Cambridge, MA : MIT Press.

Chun, M. M., & Wolfe, J. M. (1996). Just say no: How are visual searches terminated when there is no target present? *Cognitive Psychology*, **30**, 39-78.

Clifford, S., Young, R., & Williamson, P. (2007). Assessing the early characteristics of autistic disorder using video analysis. *Journal of Autism and Developmental Disorders*, **37**, 301-313.

Conty, L., Tijus, C., Hugueville, L., Coelho, E., George, N. (2006). Searching for asymmetries in the detection of gaze contact versus averted gaze under different head views: a behavioural study. *Spatial Vision*, **19**, 529-545.

Csibra, G., & Gergely, G. (2006). Social learning and social cognition: The case for pedagogy. In Y. Munakata & M. H. Johnson (Eds.), *Processes of change in brain and cognitive development. Attention and Performance XXI* (pp. 249-274). Oxford: Oxford University Press.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H. H., Alexander, A. L., & Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience*, *8*, 519-526.

Gale, A., Kingsley, E., Brookes, S., & Smith, D., (1978). Cortical arousal and social intimacy in human female under different conditions of eye contact. *Behavioural Processes*, **3**, 271-275.

Gale, A., Spratt, G., Chapman, A. J., & Smallbone, A., (1975). EEG correlates of eye contact and interpersonal distance. *Biological Psychology*, **3**, 237-245.

Grice, S. J., Halit, H., Farroni, T., Baron-Cohen, S., Bolton, P., & Johnson, M. H. (2005). Neural correlates of eye-gaze detection in young children with autism. *Cortex*, **41**, 342-353.

Happé, F. (1999). Autism: cognitive deficit or cognitive style? *Trends in Cognitive Science*, **3**, 216-222.

Happé, F., & Frith, U., (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, **36**, 5-25.

Hobson, R. P., & Lee, A. (1998). Hello and goodbye: a study of social engagement in autism. *Journal of Autism and Developmental Disorders,* **28**, 117-127.

Hood, B. M., Macrae, C. N., Cole-Davies, V., & Dias, M., (2003). Eye remember you: the effects of gaze direction on face recognition in children and adults. *Developmental Science*, **6**, 67-71.

Japanese WISC-III Publication Committee. (1998). *Nihonban WISC-III chinou kensahou* (Japanese Wechsler Intelligence Scale for Children Third Edition). Tokyo: Nihon Bunka Kagakusha.

Jemel, B., Mottron, L., & Dawson, M. (2006). Impaired face processing in autism: fact or artifact? *Journal of Autism and Developmental Disorders*, **36**, 91-106.

Jenkins, J., & Langton, S. R. (2003). Configural processing in the perception of eye-gaze direction. *Perception*, **32**, 1181-1188.

Johnson, M. H., Griffin, R., Csibra, G., Halit, H., Farroni, T., de Haan, M., Tucker, L., Baron-Cohen, S., & Richards, J. (2005). The emergence of the social brain network: Evidence from typical and atypical development. *Development and Psychopathology*,

17, 599-619.
Joseph, R. M., & Tanaka, J., (2003). Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry*, **44**, 529-542.
Kleinke, C. (1986). Gaze and eye-contact: A research review. *Psychological Bulletin*, **100**, 78-100.
Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D., (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*, **59**, 809-816.
Kylliäinen, A., Braeutigam, S., Hietanen, J. K., Swithenby, S. J., & Bailey, A. J. (2006). Face- and gaze-sensitive neural responses in children with autism: A magnetoencephalographic study. *European Journal of Neuroscience*, **24**, 2679-2690.
Kylliäinen, A., & Hietanen, J. K. (2006). Skin conductance responses to another person's gaze in children with autism. *Journal of Autism and Developmental Disorders*, *36*, 517-525.
Lahaie, A., Mottron, L., Arguin, M., Berthiaume, C., Jemel, B., & Saumier, D. (2006). Face perception in high-functioning autistic adults: evidence for superior processing of face parts, not for a configural face-processing deficit. *Neuropsychology,* **20**, 30-41.
Langdell, T. (1978). Recognition of faces: an approach to the study of autism. *Journal of Child Psychology and Psychiatry*, **19**, 255-268.
Langton, S. R. (2000). The mutual influence of gaze and head orientation in the analysis of social attention direction. *Quarterly Journal of Experimental Psychology*, **53A**, 825-845.
Langton, S. R., Watt, R. J., & Bruce, V., (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences*, **4**, 50-59.
Lopez, B., Donnelly, N., Hadwin, J. A., & Leekam, S. R. (2004). Face processing in high-functioning adolescents with autism: Evidence for weak central coherence. *Visual Cognition,* **11**, 673-688.
Maestro, S., Muratori, F., Cavallaro, M. C., Pecini, C., Cesari, A., Paziente, A., Stern, D., Golse, B., & Palacio-Espasa, F. (2005). How young children treat objects and people: An empirical study of the first year of life in autism. *Child Psychiatry and Human Development*, *35*, 383-396.
Martin, W. W., & Jones, R. F., (1982). The accuracy of eye-gaze judgment - a signal-detection approach. *British Journal of Social Psychology*, **21**, 293-299.
Martin, W. W., & Rovira, M. L., (1981). An experimental-analysis of discriminability and bias in eye-gaze judgment. *Journal of Nonverbal Behavior*, **5**, 155-163.
Martin, W. W., & Rovira, M. L., (1982). Response biases in eye-gaze perception. *Journal of Psychology*, **110**, 203-209.
Mason, M. F., Hood, B. M., & Macrae, C. N. (2004). Look into my eyes: gaze direction and person memory. *Memory*, **12**, 637-643.
Miller, J. (1988). A warning about median reaction time. *Journal of Experimental Psychology: Human Perception and Performance,* **14**, 539-543.
Miller, J. (1991). Reaction time analysis with outlier exclusion: bias varies with sample size. *Quarterly Journal of Experimental Psychology A,* **43**, 907-912.
Mottron, L., Dawson, M., Soulieres, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, **36**, 27-43.
Neumann, D., Spezio, M. L., Piven, J., & Adolphs, R. (2006). Looking you in the mouth: abnormal gaze in autism resulting from impaired top-down modulation of visual attention. *Social Cognitive and Affective Neuroscience*, **1**, 194-202.
Nichols, K. A., & Champness, B. G., (1971). Eye gaze and GSR. *Journal of Experimental*

Social Psychology, **7**, 623-626.
O'Riordan M, A. (2004). Superior visual search in adults with autism. *Autism,* **8**, 229-248.
O'Riordan, M., & Plaisted, K. (2001). Enhanced discrimination in autism. *Quarterly Journal of Experimental Psychology A,* **54**, 961-979.
O'Riordan, M. A., Plaisted, K. C., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology: Human Perception and Performance,* **27**, 719-730.
Osterling, J., & Dawson, G., (1994). Early recognition of children with autism - A study of 1st birthday home videotapes. *Journal of Autism and Developmental Disorders*, **24**, 247-257.
Osterling, J. A., Dawson, G., & Munson, J. A., (2002). Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development and Psychopathology*, **14**, 239-251.
Pelphrey, K. A., Sasson, N. J., Reznick, J. S., Paul, G., Goldman, B. D., & Piven, J., (2002). Visual scanning of faces in autism. *Journal of Autism and Developmental Disorders*, **32**, 249-261.
Perrett, D. I., & Emery, N. J. (1994). Understanding the intention of others from visual signals - Neurophysiological evidence. *Current Psychology of Cognition*, **13**, 683-694.
Perrett, D. I., Hietanen, J. K., Oram, M. W., & Benson, P. J. (1992). Organization and functions of cells responsive to faces in the temporal cortex. *Philosophical Transaction of Royal Society of Londondon B: Biological Sciences*, **335**, 23-30.
Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998). Enhanced visual search for a conjunctive target in autism: a research note. *Journal of Child Psychology and Psychiatry,* **39**, 777-783.
Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin,* **114**, 510-532.
Raven, J. C. (1956). *Coloured progressive matrices*. London: Lewis.
Robson, K. S. (1967). The role of eye-to-eye contact in maternal-infant attachment. *Journal of Child Psychology and Psychiatry*, **8**, 13-25.
Robson, K. S., Pedersen, F. A., & Moss, H. A., (1969). Developmental observations of dyadic gazing in relation to the fear of strangers and social approach behavior. *Child Development*, **40**, 619-627.
Rouse, H., Donnelly, N., Hadwin, J. A., & Brown, T. (2004). Do children with autism perceive second-order relational features? The case of the Thatcher illusion. *Journal of Child Psychology and Psychiatry,* **45**, 1246-1257.
Sasson, N. J. (2006). The development of face processing in autism. *Journal of Autism and Developmental Disorders*, **36**, 381-394.
Schultz, R. T. (2005). Developmental deficits in social perception in autism: the role of the amygdala and fusiform face area. *International Journal of Developmental Neuroscience*, **23**, 125-141.
Senju, A., & Hasegawa, T. (2005). Direct gaze captures visuospatial attention. *Visual Cognition,* **12**, 127-144.
Senju, A., & Hasegawa, T. (2006). Do the upright eyes have it? *Psychonomic Bulletin & Review*, **13**, 223-228.
Senju, A., Hasegawa, T., & Tojo, Y., (2005a). Does perceived direct gaze boost detection in adults and children with and without autism? The stare-in-the-crowd effect revisited. *Visual Cognition*, *12*, 1474-1496.
Senju, A., Yaguchi, K., Tojo, Y., & Hasegawa, T., (2003). Eye contact does not facilitate detection in children with autism. *Cognition*, **89**, B43-B51.

Senju, A., Tojo, Y., Yaguchi, K., & Hasegawa, T. (2005b). Deviant gaze processing in children with autism: An ERP study. *Neuropsychologia*, *43*, 1297-1306.

Seyama, J., & Nagayama, R. S. (2005). The effect of torso direction on the judgement of eye direction. *Visual Cognition*, **12**, 103-116.

Smith, A. D., Hood, B. M., & Hector, K. (2006). Eye remember you two: gaze direction modulates face recognition in a developmental study. *Developmental Science*, **9**, 465-472.

Speer, L. L., Cook, A. E., McMahon, W. M., & Clark, E. (2007). Face processing in children with autism: Effects of stimulus contents and type. *Autism*, **11**, 265-277.

Spezio, M. L., Adolphs, R., Hurley, R. S., & Piven, J. (2007). Abnormal Use of Facial Information in High-Functioning Autism. *Journal of Autism and Developmental Disorders*, **37**, 929-939.

Sugishita, M., & Yamazaki, Y. (1993*) Japanese Raven's coloured progressive matrices*. Tokyo: Nihon Bunka Kagakusya.

Teunisse, J. P., & de Gelder, B. (2003). Face processing in adolescents with autistic disorder: the inversion and composite effects. *Brain and Cognition,* **52**, 285-294.

Treisman, A., & Souther, J., (1985). Search asymmetry - A diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology - General*, **114**, 285-310.

Valentine, T. (1988). Upside-down faces - A review of the effect of inversion upon face recognition. *British Journal of Psychology*, **79**, 471-491.

van der Geest, J. N., Kemner, C., Verbaten, M. N., & van Engeland, H. (2002). Gaze behavior of children with pervasive developmental disorder toward human faces: A fixation time study. *Journal of Child Psychology and Psychiatry*, *43*, 669-678.

von Grünau, M., & Anston, C. (1995). The detection of gaze direction: a stare-in-the-crowd effect. *Perception*, **24**, 1297-1313.

Vuilleumier, P., George, N., Lister, V., Armony, J., Driver, J. (2005). Effects of perceived mutual gaze and gender on face processing and recognition memory. *Visual Cognition*, **12**, 85-101.

Werner, E., & Dawson, G. (2005). Validation of the phenomenon of autistic regression using home videotapes. *Archives of General Psychiatry*, *62*, 889-895.

Wollaston, W. H. (1824). On the apparent direction of eyes in a portrait. *Philosophical Transactions of the Royal Society of London*, **114**, 247-256.

Wolfe, J. M., (2001). Asymmetries in visual search: An introduction. *Perception & Psychophysics*, **63**, 381-389.

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology*, **81**, 141-145.