Reflexive orienting in response to eye gaze and an arrow in children with and without autism

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Background: This study investigated whether another person's social attention, specifically the direction of their eye gaze, and a non-social directional cue, an arrow, triggered reflexive orienting in children with and without autism in an experimental situation. **Methods:** Children with autism and typically developed children participated in one of two experiments. Both experiments involved the localization of a target that appeared to the left or right of the fixation point. Before the target appeared, the participant's attention was cued to the left or right by either an arrow or the direction of eye gaze on a computerized face. **Results:** Children with autism were slower to respond, which suggests a slight difference in the general cognitive ability of the groups. In Experiment 1, although the participants were instructed to disregard the cue and the target was correctly cued in only 50% of the trials, both groups of children responded significantly faster to cued targets than to uncued targets, regardless of the cue. In Experiment 2, children were instructed to attend to the direction opposite that of the cues and the target was correctly cued in only 20% of the trials. Typically developed children located targets cued by eye gaze more quickly, while the arrow cue did not trigger such reflexive orienting in these children. However, both social and non-social cues shifted attention to the cued location in children with autism. **Conclusion:** These results indicate that eye gaze attracted attention more effectively than the arrow in typically developed children, while children with autism shifted their attention equally in response to eye gaze and arrow direction, failing to show preferential sensitivity to the social cue. Difficulty in shifting controlled attention to the instructed side was also found in children with autism. **Keywords:** Autism, eye gaze, joint attention, reflexive orienting, arrow.

The morphology of the human eye is unique among primates (Kobayashi & Kohshima, 1997, 2001). The sclera is more widely exposed and is much paler in color than the iris and skin, which makes it easier to discern where the eyes are looking. This unique characteristic can be considered an adaptation that facilitates a higher level of effective communication using gaze signals. The direction of another person's eye gaze can reveal their current attention, thereby indicating potential resources (e.g., food) or danger (e.g., a predator). Moreover, the ability to attend to the same target as others is crucial in social communication, because it enables us to share the same topic. Therefore, it is reasonable to assume that humans evolved the tendency to attend to other people's eye region and gaze direction, and that this tendency has been shaped by natural selection in our evolutionary history.

Studies in cognitive neuroscience have provided evidence that supports the evolutionary perspective described above. Specifically, eye gaze is processed in specific brain regions. Brain imaging studies have revealed that the perception of eye gaze activates the superior temporal sulcus (STS) (Puce, Allison, Bentin, Gore, & McCarthy, 1998; Hoffman & Haxby, 2000) and amygdala (Kawashima et al., 1999). Furthermore, Broks et al. (1998) reported that lesions of the amygdala impair the ability to discriminate eye direction. Considering these findings, Baron-Cohen

(1995) recently proposed that the STS and amygdala constitute a modular 'eye direction detector' (EDD), which is an element of Baron-Cohen's mind-reading system. According to this model, development of the EDD precedes the development of joint visual attention or the 'shared attention mechanism' (SAM). The definition of 'joint visual attention' follows Butterworth and Jarrett (1991) as 'adjusting one's own attention based on change in another's focus of attention' or, more simply, 'looking where someone else is looking'. In conjunction with the EDD, the SAM was thought to generate a 'triadic representation' and to enable the development of joint attention behaviors, such as gaze-following and protodeclarative pointing. Importantly, the attentional mechanisms in this model, such as orienting to gaze direction, were included in the functions of the SAM, not in the EDD.

Considering the evolutionary importance and neural modularity of these functions, it is not surprising that the ability to attend to the eye region appears very early in life. In typical development, even neonates spend more time looking at faces with open eyes than at faces with closed eyes (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000). By four months of age, infants can discriminate the direction of eye gaze (Vecera & Johnson, 1995). These results suggest that the EDD begins to function very early in life, at least by the

age of six months. By contrast, the SAM seems to emerge in later development. Four- to five-month-old infants rapidly saccade in the direction of the eye gaze of a photograph of a face (Hood, Willen, & Driver, 1998; Farroni, Johnson, Brockbank, & Simion, 2000). Beginning at about six months of age, infants look in the direction that other people's eyes and heads are directed to (Scaife & Bruner, 1975; Butterworth & Jarrett, 1991). However, infants cannot reliably follow other people's eye gaze alone until 18 months of age, regardless of whether their gaze is accompanied by a head turn (Butterworth & Jarrett, 1991; Corkum & Moore, 1995; Moore & Corkum, 1998).

This skill-development outline does not necessarily apply to children with developmental disorders, such as autism. Autism involves abnormalities in social and communication development in the presence of repetitive behavior and limited imagination (American Psychiatric Association, 1994). One of the early symptoms of autism is difficulty in joint visual attention behavior (Loveland & Landry, 1986; Mundy, Sigman, Ungerer, & Sherman, 1986; Landry & Loveland, 1988; Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997; Leekam, López, & Moore, 2000). This impairment cannot be attributed to difficulties with basic gaze perception, because children with autism can accurately discriminate gaze direction (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; Leekam et al., 1997).

Several theories have been proposed to explain the dissociation between joint visual attention and gaze perception. From the cognitive point of view (e.g., Baron-Cohen, 1995), the deficit in joint visual attention observed in children with autism is regarded as a manifestation of the failure to establish triadic representations. According to this hypothesis, joint visual attention is a developmental precursor to acquiring the 'theory-of-mind mechanism' (ToMM), which allows an individual to infer the full range of mental states from behavior. Although children with autism can detect that another person's eyes are directed towards something, they have an impaired SAM. The SAM is necessary for the formation of triadic representations, such as 'A sees B see C'. In fact, at early ages, the development of joint attention ability predicts the subsequent development of the ToMM (Charman et al., 2000).

Joint visual attention deficits in children with autism can also be caused by attentional difficulties. Using computer-based experiments, many researchers have reported that people with autism have difficulty in disengaging or shifting attention (Casey, Gordon, Mannheim, & Rumsey, 1993; Wainwright-Sharp & Bryson, 1993; Wainwright & Bryson, 1996; Townsend, Harris, & Courchesne, 1996; Pascualvaca, Fantie, Papageorgiou, & Mirsky, 1998; Townsend et al., 1999). In a more natural setting, Dawson, Meltzoff, Osterling, Rinaldi, and Brown (1998) found that children with autism are less likely to orient to social stimuli. The reason that children with autism fail to develop joint visual attention behavior might be that they have difficulty in shifting their attention in the direction of another person's eye gaze. However, other studies have claimed that the attentional deficits of people with autism are limited to the endogenous components, which are thought to be controlled by internal, volitional, or central executive mechanisms (Posner, 1980). Therefore, the exogenous components, which are thought to be activated reflexively by external stimuli (Posner, 1980), remain intact (Minshew, Luna, & Sweeney, 1999; Goldstein, Johnson, & Minshew, 2001). Currently, the extent of the attentional difficulties in autism is still controversial.

Recently, the attentional mechanism process corresponding to joint visual attention ability, or reflexive orienting towards the direction of other's eye gaze, was directly assessed using a traditional cueing paradigm (Posner, 1980). In cueing paradigms, participants are asked to detect visual targets, which may appear on either side of a visual fixation point. Before the target appears, a stimulus cues the participant to one side or the other. If a response is made towards the side of an uninformative cue, such as a flash in the peripheral visual area, then the cue is considered to have triggered exogenous, automatic attention. Exogenous attention is usually fast, but short-lived. When the eye direction of a computerized face is used as a cueing stimulus, adults (Driver et al., 1999; Friesen & Kingstone, 1998; Hietanen, 1999; Ogawa, 2002; Senju & Hasegawa, 2001; Yoshikawa & Sato, 2000) and 4- to 5-month-old infants (Hood et al., 1998) shifted their attention in the direction of the face's eye gaze, even when it was uninformative. These findings strongly suggest that, in the typically developed population, the perceived eye direction can trigger a reflexive shift in attention towards the direction of another's gaze. However, it is also reported that infants at this age shift their attention in the direction of eye gaze only when the gaze is accompanied by movement of the pupils (Farroni et al., 2000). In light of the results of these cueing tasks, Driver et al. (1999) argued that the SAM meets the traditional criterion for modularity (Fodor, 1983), because it seems to operate in an obligatory manner. However, Perner (1991) and Tomasello (1995) have pointed out that if children spontaneously follow another person's gaze, they do not necessarily understand the other person's attention, or share attention with others. In other words, children might look mechanically in the direction of another's gaze without recognizing the internal mechanism of the other's attention.

By contrast, several researches have found that an uninformative central cue other than eye gaze, such as an arrow, can also trigger reflexive orienting (Eimer, 1997; Hommel, Pratt, Colzato, & Godijn, 2001; Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). At first sight, these findings seem to suggest

that reflexive orienting to the direction of another's eye gaze might be a mere response to the directional central cue, and not a modular function of SAM. However, a series of studies by Kingstone and his colleagues with a split brain patient found that reflexive orienting to eye gaze was lateralized to the right hemisphere (Kingstone, Friesen, & Gazzaniga, 2000), while no such cortical lateralization was found in response to an arrow cue (Ristic et al., 2002). Their findings strongly suggest that although both eye gaze and the arrow trigger reflexive orienting, different cognitive or neural mechanisms may engage in these two tasks in the typically developed population.

To date, three independent studies have investigated whether an uninformative social cue, such as another's eye or head direction, triggers reflexive orienting of individuals with autism. Swettenham, Milne, Plaisted, Campbell, and Coleman (2000) found that high-functioning children with autism were not cued by a face profile, while moving eyes in a full face facilitated their response (see also Swettenham, Condie, Campbell, Milne, & Coleman, 2003). Since movement itself is reported to trigger orienting (Farroni et al., 2000), it is difficult to judge whether eye direction or eye movement served as the cue in their experiment. Neely (2001) conducted a series of experiments with a group of high-functioning adults with and without autism, and found that both groups shifted their spatial attention in the direction of a static eye gaze, but not in the direction of the face. Okada et al. (2002) replicated part of these findings: they found reflexive orienting to the direction of eye gaze in three low-functioning individuals with autism. To our knowledge, however, no previous experiments have used a central arrow to examine reflexive orienting in children with autism. Moreover, it is still unknown whether individuals with autism process eye direction in a special manner, like the typically developed population does.

We adopted a computerized cueing method for the experiments reported here. The computer presented a face gazing or an arrow pointing to the left or right. The aims of these experiments were threefold. First, we examined whether previous findings of reflexive orienting to the direction of eye gaze are replicated in our participants with autism. Second, we also examined whether the central arrow triggered reflexive orienting in high-functioning children with autism, as it does in typically developed children (Ristic et al., 2002) and adults (Eimer, 1997; Hommel et al., 2001; Ristic et al., 2002; Tipples, 2002). Since reflexive, automatic orienting to non-social cues is reportedly intact in individuals with autism (Minshew, Goldstein, & Siegel, 1997; Minshew et al., 1999; Leekam et al., 2000; Neely, 2001), it is likely that the arrow cue also triggers reflexive orienting in children with autism. Finally, we tried to determine the conditions under which the responses to the social (eye gaze) and non-social (arrow) cues diverge.

Assuming that these two orienting mechanisms are really dissociated from each other, as suggested by Kingstone et al. (2000) and Ristic et al. (2002), it is quite possible that the responses to the eyes and arrow differ under some conditions. Moreover, it is also possible that the performance of individuals with and without autism differ at that point, if individuals with autism use a different mechanism from individuals without autism when processing eye direction. The experimental design was almost the same as that used by Driver et al. (1999); in our task, however, the central face or arrow disappeared at the same time as the target stimulus appeared. The purpose of this modification was to eliminate the attentional demand of disengaging from the central face, because children with autism are reported to have difficulty disengaging their attention (Casey et al., 1993; Pascualvaca et al., 1998).

Experiment 1

In this experiment, we investigated whether children with and without autism shift their spatial attention in the direction of perceived eye gaze or an arrow. The eye-gaze cues in each trial consisted of a photograph of a face that was displayed on a computer screen. The eyes in the photograph were directed to the left or the right, and a target then appeared on the left or right side. In the same manner as the eye-gaze cue, arrow cues were presented centrally, and pointed to the left or right, followed by a target that appeared on the left or right. Children had to judge the location of the target as soon as possible. The targets appeared on the side to which the cue was directed in only 50% of the trials, which rendered the cue direction completely uninformative. Therefore, if the participants preferentially localized targets to the cued side rather than to the opposite side, their response might be regarded as exogenous or automatic orienting that was induced by the perceived cue direction. The experimental design and procedures, including the way to make facial stimuli, stimulus onset asynchrony (SOA), and feedback, were similar to Driver et al. (1999, Experiment 2), but differed in four points: (1) A central arrow, in addition to the central face with averted gaze, was used to cue to the target direction. (2) The central cue was removed when the target appeared, in order to minimize its attentional demand. (3) The task was localization rather than discrimination of the target, in order to reduce the task difficulty. (4) To examine the cueing effects with a longer SOA, an SOA of 1,000 msec was added.

Methods

Participants. Eleven children with autism (8 males and 3 females; mean age, 10.11 years; range, 9.7–12.6 years) and 14 age-matched typically developed children (6 males and 8 females; mean age, 11.1 years;

range, 10.0–12.2 years) participated in this experiment. All of the children attended a primary school for both children with autism and typically developed children. All of the children with autism met the DSM-IV criteria for autistic disorder (American Psychiatric Association, 1994), and had been diagnosed with autistic disorder by at least one child psychiatrist when they entered the school. Although no indices of the children's general intelligence were available, they were reported by their teachers to be within the normal range of academic achievement. For each child, the experiments were conducted individually in a quiet room at the school.

Apparatus. The experiment was run using SuperLab software on a SONY PCG-885 with a 12.1-inch LCD monitor. The participants were seated approximately 60 cm from the monitor. The children's reaction times (RT) and accuracy were measured from their keyboard responses.

Stimuli. A central cross that was subtended by 1° was used as the fixation point. The target stimuli consisted of an asterisk that was subtended by 1° and positioned 10° to the left or right of the fixation point.

The eye-gaze cues were digitized images of a female face. The same basic image was used to produce both the left- and right-gazing faces by using mirror images of the eye region. Another face with closed eyes, which was superimposed on the basic face (the eyes-closed face), was used as a pre-cueing stimulus. The images of the faces were presented in black and white, and measured 5° wide and 7° high (Figure 1, left side). The arrow cues were gray arrows that pointed to the left or right. The arrows measured 7.5° wide and 3.5° high. A gray square that was 7.5° wide and 1.5° high was used as a pre-cueing stimulus (Figure 1, right side).

Design. The experiment consisted of the gaze-cue session and the arrow-cue session. Each session was composed of 136 trials, with eight practice trials and two blocks of 64 test trials. All the children participated in both tests, and the order of presentation of the two sessions was counterbalanced across children. There were three within-participant factors: cue type (eye gaze or arrow), cue validity (valid or invalid), and cue-target stimulus onset asynchrony (SOA; 100, 300, 700, or 1,000 msec). Both types of cue validity and all SOA durations were presented randomly and equally within each block and, as mentioned above, one of the cue types was used in each session.

Procedure. Participants were instructed to note the location of the target stimuli as soon as possible; they were told to press the 'Z' key when the target appeared on the left, or the '/' key when the target appeared on the right. It was strongly emphasized to the participants that the directions of both the gaze and the arrow were completely irrelevant to the target position and must be disregarded.

The same sequence was used for each trial. At the beginning of the trial, a fixation cross was presented at the center of the screen for 675 msec. The pre-cueing stimulus (the eyes-closed face or a square, depending on the session) then appeared at the center of the screen for 900 msec, and was replaced by a cueing stimulus (a gazing face or an arrow). After the SOA, the cue disappeared, and a target was presented on the left or right side of the screen. The target remained on the screen until the participant responded (see Figure 1 for an example). After the participant responded, a feedback symbol was displayed for 500 msec ('O' for a correct response and 'X' for an incorrect response), and then the next trial started. If the participants became too tired to continue, they were allowed to ask the experimenter sitting next to them for a short break between trials. In all the experiments reported in this article, however, no children became 'too tired' or asked for a break.
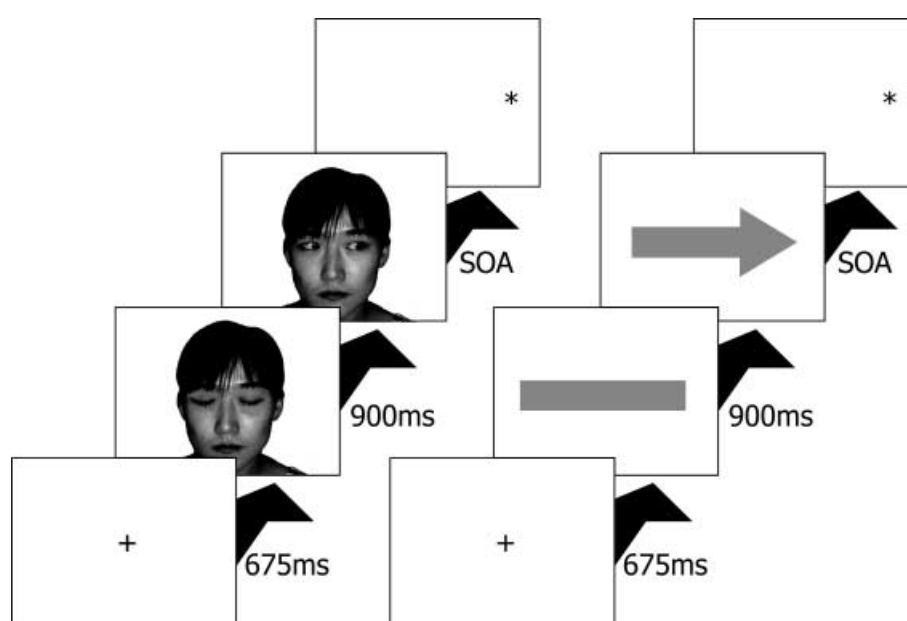

Figure 1 Examples of the trial sequence in a valid trial. Left side: gaze-cue test. Right side: arrow-cue test. SOA: stimulus onset asynchrony

Results

Reaction times less than 100 msec or greater than 3,000 msec were excluded from the analysis, which eliminated less than 1% of all the trials. The mean RTs and percentage of errors are shown in Table 1.

RT data were logarithmically transformed and analyzed by a six-way analysis of variance (ANOVA) with participant group (autism or typical development), participant factor (individual differences), SOA (100, 300, 700, or 1,000 msec), cue validity (valid or invalid), cue type (eye gaze or arrow), and block (one or two). In this and all the following analyses, participant factor and blocks were regarded as nuisance factors in order to control the variance explained by these factors. These factors will not be mentioned again because they did not interact with other factors and did not seem to influence the main findings reported in this article. The RTs of the children with autism were significantly slower than those of the control children (main effect of group: $F[1, 6447] = 1162.12$, $p < .0001$). There was a main effect of SOA ($F[3, 6447] = 89.08$, $p < .001$); targets that appeared after a long SOA were located faster than targets that appeared after a short SOA. The main effects of cue validity ($F[1, 6447] = 27.58$, $p < .001$) and cue type ($F[1, 6447] = 18.97$, $p < .001$) were also significant, which means that there was a faster response to the cue side, and in the eye-gaze session. The main effect of block was also significant ($F[1, 6447] = 7.20$, $p < .01$). Since response times were faster in later blocks, this suggests a training effect. There was also a significant main effect of participant factor ($F[23, 6447] = 175.55$, $p < .001$),

which suggests that there were individual differences, or that some children responded faster than others. The interaction between group and cue validity was significant ($F[1, 6447] = 8.77$, $p < .01$), because the effect of cue validity was greater in children with autism. The interactions between cue validity and SOA ($F[3, 6447] = 6.59$, $p < .01$) and between group and cue type ($F[1, 6447] = 14.46$, $p < .01$) were also significant. The three-way interaction between group, cue type, and SOA was significant ($F[3, 6447] = 2.98$, $p < .05$). Simple effect analyses found that the children with autism were slower in the arrow-cue condition than in the gaze-cue condition for all cue-to-target SOAs (all Fs > 5.25, all ps < .05), but that the simple main effect of cue type was not significant in typically developed children, except for the 700-msec SOA ($F[1, 6447] = 16.59$, $p < .01$). Another significant three-way interaction was also found between cue type, cue validity, and SOA ($F[3, 6447] = 2.85$, $p < .05$). This interaction suggests a different time course for the cue validity effect between gaze cue and arrow cue, which is discussed below. No other interaction approached significance.

To examine the time course of the cue validity effect in each SOA, the simple effects were calculated at each individual SOA for each cue type and participant group. In children with autism, responses to the eye-gaze side were significantly faster at an SOA of 300 and 700 msec (300-msec SOA: $F[1, 6447] = 7.58$, $p < .01$; 700-msec SOA: $F[1, 6447] = 5.09$, $p < .05$). At the other SOAs, the cue validity effects were not significant (100-msec SOA: $F[1, 6447] = 3.73$, not significant [n.s.]; 1,000-msec SOA:

Table 1 Reaction times (msec), standard errors, and error rates (%) for Experiment 1

	100-msec SOA		300-msec SOA		700-msec SOA		1,000-msec SOA	
	Valid	Invalid	Valid	Invalid	Valid	Invalid	Valid	Invalid
Gaze-cue test								
Autism								
M	551.6	582.9	524.4**	544.5	495.9*	521.1	521.4	527.1
SE	15.0	20.1	14.8	14.6	12.6	14.6	21.1	16.7
%E	1.7	1.7	1.7	1.1	1.1	1.1	.6	.6
Typical								
M	466.0	463.4	435.0**	465.5	403.4	415.1	427.5	416.9
SE	8.9	8.0	9.2	10.7	7.2	9.6	8.4	9.0
%E	1.3	1.3	.4	1.3	2.9	.8	.4	1.3
Arrow-cue test								
Autism								
M	585.7**	669.0	530.3**	589.3	519.2	543.5	542.9	577.7
SE	16.5	22.7	14.0	17.1	15.2	19.0	15.5	21.9
%E	1.1	.6	.6	.0	.6	.0	.6	.6
Typical								
M	462.1**	480.7	438.4**	456.2	423.8	423.0	422.8	411.4
SE	12.1	7.9	10.4	10.2	8.5	8.0	8.8	8.5
%E	.9	2.6	.4	1.3	.4	.9	1.7	.9

Note: Error rates represent the percentage of test trials excluded because of anticipation, pressing the wrong key, or that were timed out. SOA: stimulus onset asynchrony.
**$p < .01$; *$p < .05$.

F[1, 6447] = 2.57, n.s.). Targets on the side indicated by the arrow were located faster with the 100- and 300-msec SOAs (100-msec SOA: F[1, 6447] = 48.81, $p < .01$; 300-msec SOA: F[1, 6447] = 32.39, $p < .01$), but no significant differences were observed at the 700- and 1,000-msec SOAs (700-msec SOA: F[1, 6447] = 2.23, n.s.; 1,000-msec SOA: F[1, 6447] = 3.15, n.s.). In typically developed children, eye gaze significantly facilitated responses at the 300-msec SOA (F[1, 6447] = 15.69, $p < .01$). At other SOAs, the cue validity effect did not reach significance (100-msec SOA: F[1, 6447] = .00, n.s.; 700-msec SOA: F[1, 6447] = 1.20, n.s.; 1,000-msec SOA: F[1, 6447] = 2.84, n.s.). The results for the arrow cue were the same as those of children with autism (100-msec SOA: F[1, 6447] = 12.33, $p < .01$; 300-msec SOA: F[1, 6447] = 6.76, $p < .01$; 700-msec SOA: F[1, 6447] = .02, n.s.; 1,000-msec SOA: F[1, 6447] = 3.15, n.s.).

The percentages of errors were also analyzed by six-way ANOVA, with participant group (autism or typical development), participant factors (individual differences), SOA (100, 300, 700, or 1,000 msec), cue validity (valid or invalid), cue type (eye gaze or arrow), and block (one or two). Participant factors and block were regarded as nuisance factors. There were no significant main effects or interaction (all Fs < 2.5, and all ps > .1).

Discussion

Children both with and without autism located targets that appeared on the cued side faster than targets that appeared on the opposite (uncued) side, regardless of whether the cue was eye gaze or an arrow. These results with children with autism replicated previous findings, which have shown that uninformative eye direction triggers reflexive orienting in individuals with autism (Neely, 2001; Okada et al., 2002; Swettenham et al., 2000). An uninformative arrow also shifted reflexive attention towards the corresponding direction in children with autism. The latter finding has never been reported before, as far as we know.

Furthermore, this validity effect was short-lived. In response to the gaze cue, it occurred only at the 300-msec SOA in both groups of children. These results replicate those of Driver et al. (1999), who also reported a significant effect of eye gaze at a 300-msec SOA in adult participants. In children with autism, the gaze cue also elicited a significant cueing effect at a 700-msec SOA. Note that the onset of the attention shift with the 300-msec SOA was slower than in more common exogenous orienting tasks, such as orienting to a peripheral pre-cue (e.g., Posner, 1980), where the onset of the attention shift is at around 100 msec. Although this cueing effect of later onset is thought to result from children shifting their strategic or volitional attention, our data failed to support this explanation; previous studies predicted

that the facilitative effect should increase with SOA (e.g., Jonides, 1981), which was not the case with our data. In addition, Driver et al. (1999) proposed that this difference occurs because it takes longer to encode the direction of gaze than to encode the location of the peripheral pre-cue. This possibility was further examined in Experiment 2 (below). In all, the results suggest that, although the children were carefully instructed to disregard the eye direction, children with autism shifted their spatial attention in the direction of eye gaze, which was independent of target appearance. In this sense, children with autism, at least in the age range studied, are able to automatically follow another person's eye gaze at the perceptual-attentional level. Similarly, in the arrow-cue condition, an uninformative arrow triggered reflexive orienting only at 100 and 300 msec, which is concordant with previous findings that found the cueing effect at short cue-to-target SOA, such as 100 and 300 msec (Tipples, 2002), 195 msec (Eimer, 1997), and 200 msec (Ristic et al., 2002), suggesting that both groups of children automatically shifted their spatial attention in the direction indicated by the arrow. Moreover, in both groups of children, the arrow cue had a greater cueing effect than the gaze cue. This might result from the relative salience of an arrow compared to eye gaze, but further research is needed to address this issue.

Although the performances of children with and without autism did not differ in most of the aspects discussed above, there were three major differences between the groups. First of all, the children with autism had slower overall response times. This characteristic might be due to their inability to easily disengage attention (e.g., Casey et al., 1993), their psychomotor difficulty (Hughes, 1996; Minshew et al., 1997), or the fact that there might be a slight between-group difference in their general cognitive ability, although all the children with autism were reported to be high functioning. Second, the overall cueing effects were greater in children with autism than in typically developed children. This might result from difficulty in strategic or endogenous attention in autism, which made it difficult to detect the target appearing on the unattended side. In line with this interpretation, Minshew et al. (1997) reported difficulty in antisaccade, a voluntary saccade to the uncued side, in individuals with autism. Finally, children with autism were slower to respond to the targets presented after an arrow than were those that followed a central face with eye gaze. By contrast, the performance of typically developed children was virtually the same regardless of cue type, especially at shorter cue-to-target SOAs, when the cueing effect was significant. It is probably because the stronger contrast of the arrow cue versus that of a photographed face might make it more difficult to disengage from an arrow than from a face in children with autism, who have difficulty in disengaging

attention. However, we cannot come to any firm conclusions from these data alone. Further research is necessary.

Experiment 2

Experiment 2 examined whether the facilitative effect of an eye gaze or an arrow was really mediated by an automatic process under more stringent conditions. Similar to the design of Driver et al. (1999), the targets in this experiment appeared on the side opposite to that indicated by the eye gaze or arrow in 80% of trials, instead of in 50% as in Experiment 1. Moreover, all the children were explicitly informed of this, and were instructed to attend to the side where the target was most likely to appear. However, if the eye gaze or arrow really triggers exogenous or automatic attention, and the children cannot strategically suppress this automatic orienting, then we would expect the predominance of responses to be to the side indicated by the uninformative eye gaze or arrow. This predominance was found in a previous study of eye gaze (Driver et al., 1999), and the same effect was predicted to emerge if both groups of children possessed a functioning mechanism to exogenously orient to eye direction.

Methods

Participants. The participants consisted of 26 children with autism (23 males and 3 females; mean age, 9.6 years; range, 7.6–12.3 years), and 38 age-matched typically developed children (25 males and 13 females; mean age, 9.6 years; range, 7.7–12.5 years). All the children attended the same primary school as in Experiment 1. All the children with autism met the DSM-IV criteria for autistic disorder (American Psychiatric Association, 1994), and had been diagnosed with autistic disorder by at least one child psychiatrist when they entered the school. For each child, the experiments were conducted individually in a quiet room at the school. None of these children had participated in the previous experiment.

Apparatus and stimuli. The stimuli were presented on a NEC PC-LC800 with a 14.1-inch LCD monitor. Otherwise, the materials were identical to those used in Experiment 1.

Design and procedure. As in Experiment 1, this experiment consisted of a gaze-cue session and an arrow-cue session. Each session consisted of 128 trials, with eight practice trials and four blocks of 30 test trials. All the children took part in both sessions, and the order of presentation of the two sessions was counterbalanced across children. There were three within-participant factors: cue type (eye gaze or arrow), cue validity (valid or invalid), and SOA (100, 300, or 700 msec). To reduce the total number of trials and lessen the demands on the children, the 1,000-msec SOA condition was removed from Experiment 2. In this experiment, however, trials in which targets appeared on the side opposite that indicated by the eye gaze or arrow occurred four times more often than in trials in which the targets appeared on the same side as that indicated by the eye-gaze or arrow. Therefore, invalid trials are referred to as 'expected' trials, and valid trials are referred to as 'unexpected' trials. The procedure was identical to that used in Experiment 1, except the children were told that the targets would appear more frequently on the side opposite that indicated by the eye gaze or arrow. As in Experiment 1, the experimental design and procedures were similar to Driver et al. (1999, Experiment 3), except (1) an arrow cue was added; (2) the central cue was removed when the target appeared; and (3) the task was localization rather than discrimination of the target.

Results

Reaction times less than 100 msec or greater than 3,000 msec were excluded from the analysis, which eliminated 2.4% of all trials. The mean RTs and error rates are shown in Table 2.

The RT data were logarithmically transformed and analyzed by six-way ANOVA with participant group (autism or typical development), participant factor (individual differences), SOA (100, 300, or 700 msec), cue expectancy (expected [invalid] or unexpected [valid]), cue type (eye gaze or arrow), and block (one, two, three, or four). Participant factors and block were considered nuisance factors. The RTs of children with autism were significantly slower than those of typically developed children (main effect of group; $F[1, 14439] = 9901.48$, $p < .0001$). Unlike Experiment 1, the main effect of cue expectancy was not significant ($F[1, 14439] = .26$, n.s.). This seemed to be because there are two factors competing for attention: reflexive orienting in the direction of the eye gaze or pointing arrow, and strategic or controlled attention to the opposite direction. These had different effects in each group and in each condition. A significant main effect of SOA was found ($F[2, 14439] = 295.63$, $p < .0001$), and the main effect of cue type was also significant ($F[2, 14439] = 40.76$, $p < .001$), which means that the RTs were shorter for longer SOAs and the arrow-cue session. The main effects of block and participant were also significant (block: $F[3, 14439] = 10.5$, $p < .0001$; participant: $F[62, 14439] = 102.73$, $p < .0001$), which suggests that there were training effects and individual differences, respectively. SOA had significant interactions with participant group ($F[2, 14439] = 16.94$, $p < .001$), cue expectancy ($F[2, 14439] = 18.42$, $p < .001$), and cue type ($F[2, 14439] = 3.61$, $p < .05$). These significant interactions suggest that the effects of SOA were greater in typically developed children than in children with autism, in the arrow-cue condition versus the gaze-cue condition, and on the expected side versus the unexpected side. The three-way interaction between participant group, cue validity, and cue type was also significant ($F[1, 14439] = 8.30$, $p < .01$). The

Table 2 Reaction times (msec), standard errors, and error rates (%) for Experiment 2

	100-msec SOA		300-msec SOA		700-msec SOA	
	Unexpected (Valid)	Expected (Invalid)	Unexpected (Valid)	Expected (Invalid)	Unexpected (Valid)	Expected (Invalid)
Gaze-cue test						
Autism						
M	914.2**	1000.8	939.7	926.8	917.1	914.4
SE	34.5	18.9	36.4	17.1	36.6	18.2
%E	3.6	3.3	3.6	4.3	3.6	3.8
Typical						
M	546.9*	574.2	513.9	528.8	501.7**	475.5
SE	12.9	8.3	12.6	7.6	14.0	7.0
%E	5.0	1.8	1.3	1.9	2.6	1.2
Arrow-cue test						
Autism						
M	932.7**	993.5	848.6*	908.5	834.3	872.2
SE	38.8	20.2	33.3	18.3	31.9	18.9
%E	4.7	3.5	1.5	3.0	4.0	2.8
Typical						
M	558.5	553.1	512.4**	494.3	506.0**	460.1
SE	15.9	6.6	11.9	6.4	15.5	7.1
%E	5.6	2.5	2.6	1.8	3.6	.9

Note: Error rates represent the percentage of test trials excluded because of anticipation, pressing the wrong key, or that were timed out. SOA: stimulus onset asynchrony.
**$p < .01$; *$p < .05$.

simple interaction tests found that the cueing effect was greater in the arrow-cue condition than in the gaze-cue condition ($F[1, 14439] = 4.07$, $p < .05$, for children with autism; $F[1, 14439] = 45.98$, $p < .01$, for typically developed children), but it was the direction of the cueing effect that differentiated children with and without autism. In children with autism, both the arrow ($F[1, 14439] = 19.38$, $p < .01$) and gaze ($F[1, 14439] = 7.58$, $p < .01$) cues elicited orienting to the unexpected side, and this effect was greater in the arrow-cue condition than in the gaze-cue condition. By contrast, in typically developed children, the simple main effect of cue expectancy was significant in the arrow-cue condition ($F[1, 14439] = 54.41$, $p < .01$), but not in the gaze-cue condition ($F[1, 14439] = 3.38$, n.s.). As discussed below, this was because both reflexive and volitional orienting affected the performance in typically developed children in the gaze-cue condition, but only facilitation to the expected side was found in the arrow-cue condition. No other interactions approached significance.

As in Experiment 1, the simple main effects of cue expectancy were calculated at each individual SOA, for each participant group, and for each cue type. In the gaze-cue condition, the responses of children with autism to the unexpected (eye-gaze) side were significantly faster at the 100-msec SOA ($F[1, 14439] = 24.14$, $p < .01$). At the 300- and 700-msec SOAs, the cue direction did not cause any significant effects (300-msec SOA: $F[1, 14439] = .40$, n.s.; 700-msec SOA: $F[1, 14439] = .17$, n.s.). In the arrow condition, unexpected (indicated by the arrow) targets were located faster at the 100- and 300-msec SOAs (100-msec SOA: $F[1, 14439] = 21.21$, $p < .01$; 300-msec SOA: $F[1, 14439] = 5.66$, $p < .05$). However, there was no significant difference when the SOA was 700-msec ($F[1, 14439] = .23$, n.s.). By contrast, in the gaze-cue condition, typically developed children responded faster to targets that appeared on the unexpected (eye-gaze) side at the 100-msec SOA ($F[1, 14439] = 4.73$, $p < .05$). The RTs did not differ significantly at the 300-msec SOA ($F[1, 14439] = .49$, n.s.). At the 700-msec SOA, responses to the expected (eyes-averted) direction were significantly faster ($F[1, 14439] = 37.71$, $p < .01$), in contrast to the responses at the 100-msec SOA. The results with the arrow-cue condition were almost the opposite to those in children with autism; their responses did not change significantly with cue expectancy at the 100-msec SOA ($F[1, 14439] = .18$, n.s.), and they responded faster to the expected side (i.e., opposite to the arrow direction) at the 300- and 700-msec SOAs (300-msec SOA: $F[1, 14439] = 10.41$, $p < .01$; 700-msec SOA: $F[1, 14439] = 99.59$, $p < .01$).

The percentages of errors were also analyzed by six-way ANOVA, with participant group (autism or typical development), participant factors (individual differences), SOA (100, 300, or 700 msec), cue validity (valid or invalid), cue type (eye gaze or arrow), and block (one, two, three, or four). Participant factors and block were considered nuisance factors. There were no significant main effects or interaction in either the eye-cue or arrow-cue tests (all Fs < 2.5, and all ps > .1).

Discussion

In Experiment 2, targets appeared four times more frequently on the side opposite the cue direction. The children were reminded of this, and instructed to attend to the side opposite that indicated by the central cue. As in Experiment 1, both eye gaze and an arrow were used to cue the target. In typically developed children, there was an advantage for the eye-gaze side at 100-msec SOA, which indicated that they shifted their spatial attention exogenously or automatically to the eye-gaze side. In contrast, at the 300-msec SOA, in which eye gaze facilitated responses to the corresponding side in Experiment 1, gaze direction had no significant influence on their responses. Although it is quite difficult to determine why an SOA from 300- to 100-msec promoted this, one possible reason should be mentioned. It might result from increased attention to the eye region, because children had to attend to and extract information from, rather than just ignore, the direction of eye gaze in this experiment. Since covert attention is known to accelerate the rates of information processing (Carrasco & McElree, 2001) and facilitate sensitivity to the contrast (Cameron, Tai, & Carrasco, 2002), it is possible that covert attention to the eye region augmented the processing speed or the discrimination between the iris and sclera. In fact, when illustrations of eyes, which were more salient with high contrast, were used instead of photographs of eyes to cue the targets, a validity effect was found at shorter cue-to-target SOAs, such as 105-msec (Friesen & Kingstone, 1998; Ristic et al., 2002). Moreover, Driver et al. (1999, p. 529) also showed a slight increment in the cueing effect at 100-msec SOA, although it was not significant. Furthermore, typically developed children located targets more quickly on the expected (eye-averted) side at the 700-msec SOA. This suggests that they were trying to attend to the eyes-averted side, where targets were most likely to appear. In the arrow-cue test, however, typically developed children located targets faster on the expected side, opposite the direction indicated by the arrow. This effect was significant at longer SOAs (i.e., 300 and 700 msec), suggesting that endogenous or strategic orienting was operating in these children (Posner, 1980; Jonides, 1981; Spence & Driver, 1994). In contrast to the results of the gaze-cue experiment, this result also suggests that the central arrow did not trigger automatic orienting, which can overcome a participant's intention. By contrast, responses to the side indicated by both eye gaze and the arrow predominated in children with autism at shorter SOAs (i.e., 100 and 300 msec), which suggests exogenous or automatic attention to the side indicated by the gaze or arrow.

This result with typically developed children essentially replicated Driver et al. (1999) in that uninformative or even 'counter-informative' eye gaze triggered reflexive orienting. There was one differ-ence between their results and ours concerning the effect of SOA. In Driver et al. (1999), significant facilitation of uninformative eye gaze was found at an SOA of 300-msec, and not at 100-msec, as was found in our experiment. Needless to say, their experiments differ from ours in several aspects regarding task requirements (target discrimination vs. target localization), presentation of facial stimuli (until participants' response vs. until target appearance), and participants (adults vs. children with and without autism). Any one of these factors could cause the different effect of SOA on the cueing effect. Further research is needed to determine which factor is crucial for the discrepancy. In addition, Driver et al. (1999) also showed a non-significant increase in the validity effect to the counter-informative eye gaze at 100-msec SOA, as mentioned above. Neely (2001, Experiment 6) conducted similar experiments with high-functioning adults with, and without, autism. Although the significance of the cueing effect at shorter SOA, such as 50- or 150- msec, was not tested in her paper, the data suggest a smaller cueing effect than in Driver et al. (1999) and in our data. The apparent discrepancy between Neely (2001) and the other research is rather puzzling and needs to be reconciled in further investigations. One possibility, however, is that it stems from differences in the task requirement. Neely (2001) used a simple detection task, in contrast with the localization task used in our study and the discrimination task in Driver et al. (1999). Therefore, it is possible that counter-informative eye gaze affected the finer spatial or configurative discrimination, but had little effect on detection (e.g., Spence & Driver, 1994). Of course, this is a rather speculative interpretation, and further research is required. With a longer SOA, however, typically developed children were able to voluntarily shift their attention to the expected side, which replicated Driver et al. (1999) and Neely (2001), in that typically developed individuals can shift their attention strategically to the direction opposite the eye gaze. By contrast, typically developed children could effectively shift their attention to the instructed side in response to the arrow cue. This effect was incremented with a long SOA, which is a typical characteristic of voluntary, controlled attention (Posner, 1980; Jonides, 1981; Spence & Driver, 1994). Moreover, the validity effect was significant in the arrow-cue condition, but not in the gaze-cue condition, which seems to be due to the conflicting effect of automatic and intentional orienting in response to eye gaze. Overall, these results seem to imply that typically developed children have difficulty in inhibiting reflexive orienting to the eye-gaze side, but do not have such difficulties in inhibiting the direction of the arrow, and attend to the opposite side.

In the children with autism, however, both eye gaze and the arrow triggered reflexive orienting to the indicated direction at shorter cue-to-target SOA, in

spite of the strong instruction to attend to the opposite direction. Note that this does not necessary mean a general orienting mechanism. In fact, although children with autism showed exogenous cueing to arrows at 100- and 300- msec SOA, they only showed such cueing effect to eye gaze at 100-msec SOA, which seems to indicate that exogenous cueing effect is in part cue-dependent. One might attribute this to their difficulty in understanding instructions and performing in the same manner as in Experiment 1, but our data do not support this explanation, for the following reasons. First, in contrast to the significant cueing effect at 300- (both eye gaze and arrow) and 700- (eye gaze only) msec SOA in Experiment 1, the initial advantage to the unexpected side was reduced, or disappeared completely, at the 300-msec SOA. This extinction of the cueing effect at longer SOAs suggests the existence of controlled attention, or intention to attend to the opposite side in the children with autism. Second, in this experiment, the overall response times were longer with the gaze cue than with the arrow cue, which is contrary to the prolonged RTs in the arrow-cue condition found in Experiment 1. This might result from their relative difficulty in using eye direction information, as suggested by Neely (2001), which in turn suggests that the children with autism did try to use the eye gaze information. Instead, this result seems to stem from impairment in inhibiting predisposed attention and from strategically orienting to the opposite side (Minshew et al., 1999), which indicates a deficit in endogenous or controlled attention, while sparing exogenous or automatic attention in individuals with autism (Minshew et al., 1997, 1999; Neely, 2001). In addition, the validity effect was greater in the arrow-cue condition than in the gaze-cue condition, which indicates incremented reflexive orienting to the arrow cue versus the gaze cue, just like in Experiment 1. Therefore, children with autism, contrary to typically developed children, failed to show the relative superiority of the social cue in reflexive orienting.

Two other effects must be mentioned. First, in both groups, the RTs in response to the gaze cue were longer than to the arrow cue. This might be because extracting information about eye direction requires more time than recognizing the direction of the arrowhead. Second, as in Experiment 1, the responses of the children with autism were slower in both tests and in all conditions, and this tendency seemed greater than in Experiment 1. This might be explained by difficulty in disengaging their attention, by motor deficiencies, or by differences in their general cognitive abilities. Moreover, the discrepancy in the overall response times between the groups was even larger than in Experiment 1; the RTs in children with autism were nearly 1 second. This could be mainly due to the age difference between the participants in the two experiments. Response times become faster in the course of development (e.g.,

Hale, 1990), so it is not unnatural that the younger participants in this experiment had slower overall responses than did the children who participated in Experiment 1. Task difficulty might also be responsible for the longer response times. In this experiment, the children had to inhibit their automatic orienting to the side indicated by the eye gaze or arrow and attend to the opposite side. Such inhibitory processing is regarded as a component of executive attention, which is thought to be impaired in individuals with autism (Ozonoff, Pennington, & Rogers, 1991; Minshew et al., 1997; Liss et al., 2001) and might possibly prolong their RTs. In addition, there may be other autism-specific social or motivational problems, because the RTs of individuals with autism are sometimes twice as long as those of typically developed controls (e.g., Wainwright-Sharp & Bryson, 1993; Harris, Courchesne, Townsend, Carper, & Lord, 1999). However, these findings are preliminary and further research is required to fully address these issues.

General discussion

This study adopted a computerized cueing method to examine the orienting mechanism in children with and without autism. When the gaze cue was used, the children with and without autism were quicker in locating the target presented in the direction corresponding to eye gaze, even when the eye gaze was uninformative or counter-informative, which replicated previous findings (Neely, 2001; Okada et al., 2002; Swettenham et al., 2000). In addition to eye gaze, an uninformative central arrow also triggered reflexive orienting in children with and without autism. This result replicated Ristic et al. (2002) for typically developed children, and was the first study to show that children with autism also orient to the arrow direction reflexively. Moreover, although children with and without autism were virtually equivalent in response to uninformative social and non-social central cues (Experiment 1), two aspects of their performance in response to such 'counter-informative' cues diverged (Experiment 2). First, children with autism had difficulty in strategically attending to the side opposite the direction of eye gaze or the arrow, which indicates an impairment in controlled, endogenous attention (Minshew et al., 1997, 1999; Neely, 2001). Second, although eye-gaze cue was more effective than arrow cue in typically developed children, it was not the case in children with autism. It concurs with recent functional neuroimaging studies which have found that individuals with autism use different brain areas when processing facial identity (Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Schultz et al., 2000) or facial expression (Critchley et al., 2000) than do the typically developed population, and may suggest that eye gaze is also processed by different

neural substrates. Recently, we found that the perception of eye gaze evoked different patterns of ERP in children with and without autism (Senju, Yaguchi, Tojo, & Hasegawa, 2003, in press). This also seems to suggest that individuals with, and without, autism use different neural substrates when processing eye gaze.

The relationship between our data and joint visual attention needs to be discussed carefully because developmental changes in joint visual attention ability probably occur. For example, Leekam, Hunnisett, and Moore (1998) reported that children with autism with a high verbal mental age can reliably follow another's gaze direction when both head and eye movement were provided as cues. Their findings converge with the current results in that high-functioning children with autism around school age have the ability to spontaneously attend to the corresponding direction of another's gaze. However, the lack of the relative predominance of the cueing effect in response to eye gaze over an arrow in children with autism throws doubt on whether their joint visual attention, or social attention, is really 'social'.

Although some theories (e.g., Baron-Cohen, 1995) emphasize the awareness of others' mental states in development of joint visual attention, it is also known that joint visual attention behavior can be achieved mechanically, without awareness of another's attention (Perner, 1991; Perrett & Emery, 1994; Tomasello, 1995; Leekam et al., 1998). Moreover, Leekam et al. (2000) reported that many children with autism could be trained to orient to an experimenter's eye and head direction in an experimental situation. How do these claims match our results? One possibility is that joint visual attention might consist of several subsystems, some of which are intact in autism. For example, initiating joint visual attention, such as protodeclarative pointing, and responding to joint visual attention, or following another's gaze, were reported to associate with EEG activity in different cortical regions (Mundy, Card, & Fox, 2000). This suggests that the initiation of joint attention, such as protodeclarative pointing, can be functionally dissociated from gaze-following behavior and orienting to another's social attention. Another possibility is that, when responding to eye gaze, children with autism use an alternative or compensatory 'non-social' mechanism, such as an ability to shift their attention in the direction corresponding to an arrow, in order to compensate for such an early difficulty in their social motivational system such as the understanding of agency (e.g., Tomasello, Call, & Gluckman, 1997) or establishing interpersonal relationships (Hobson, 1993). Considering the lack of relative predominance of eye gaze in reflexive orienting, the latter interpretation seems more attractive. Needless to say, it is rather preliminary and further studies, including developmental psychology and cognitive neuroscience studies, must address this issue.

Some limitations of our study should be mentioned. First, the children who participated in this study were older than those in previous studies of joint visual attention deficit in preschool children with autism (e.g., Leekam et al., 2000). Further studies should include younger children with autism. Second, although the children's teachers reported that the participants were relatively high academic achievers, the precise general intellectual level of the children with autism who participated in this study is not known. Although one preliminary report found reflexive orienting toward another's eye direction in three low-functioning individuals with autism (Okada et al., 2002), it is worth investigating whether reflexive orienting toward an uninformative eye gaze differs according to the intellectual or developmental level of children with autism. Finally, covert attention and overt attention were not differentiated in this study. Although making this distinction was not an aim of this study, doing so will be important for investigations of attention and its underlying neural functioning.

Acknowledgements

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