THE RELATION BETWEEN ORIENTING TO EYE GAZE AND SOCIAL GAZE FOLLOWING IN CHILDREN WITH AUTISM

by

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ABSTRACT

Previous research indicates that adolescents with autism, unlike their typically developing peers, do not automatically orient their attention in response to directional gaze cues. The present study investigated relations between orienting responses to gaze direction on a computer-based attention task and performance on tasks that required the ability to understand or act on the social meaning of directional gaze in a lab setting. Results confirmed that children with high functioning autism (HFA) show less reflexive orienting in response to eye-gaze cues and also extend this finding to a younger sample (mean mental age = 131 months). Although individuals varied with regard to the degree to which they reflexively oriented to eye-gaze direction, for children with autism, volitional orienting to eyes was associated with delayed social gaze following. Findings suggest that computer based assessments of social attention may be useful indices of the real world social attention in children with autism.

Keywords: Autism; Social Attention; Visual Orienting; Eye Gaze

Subject Terms: Autism; Cognitive Psychology; Social Perception; Other minds (Theory of Knowledge)

DEDICATION

This thesis is dedicated to my parents, Norah Curtis and Dr. Peter Rombough, who have fostered a love of learning and zest for life in all of their children. Their unwavering love and support means more to me than I can express.

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INTRODUCTION

Sophisticated non-verbal communication evolved in response to a selective push towards cooperative group living. Visual signals promoting communication between conspecifics, such as signals that provided information regarding another's focus of attention, were particularly important and enabled our ancestors to co-exist harmoniously (Emery, 2000). Today, the ability to interpret visual attentional signals remains a pre-requisite for successful navigation of the social world. This is because the focus of attention provides valuable clues that allow observers to infer the volitional and referential mental states of others. Thus, attention-followers are better able to predict and anticipate another's behaviour. Attention followers are also able to locate, with increased ease, potential rewards or threats in the environment (Fox, 2005). Eye gaze-direction is one of a few visual cues, along with body posture, pointing, and head direction that can indicate the focus of an observer's attention and conveys key social information, such as status and personal interest (Ristic et al., 2005). The social importance of gaze-following is underscored by morphological changes within our species that facilitate the ease with which one may follow gaze. For example, the white sclera is enlarged in the human eye compared to other primates, causing the dark iris to be visually salient (Emery, 2000; Argyle & Cook, 1976). Cross-species studies have documented gaze following behaviour in many social animals such as dogs (Call, 2004), non-human primates (Tomasello, Call, & Hare, 1998), and dolphins (Tschudin, Call, Dunbar, Harris, & van der Elst, 2001) emphasizing the broad social utility of this skill. In contrast with other social animals, gaze- following in humans predicates the development of sophisticated social understanding and communication (Carpendale & Lewis, 2006).

Gaze Following in Typical Development

Following eye-gaze direction is fundamental to the development of social perception. Social perception can be broadly defined as the initial stages of evaluating the social communicative intents of others (Pelphrey, Morris, & McCarthy 2004). Rudimentary gaze following behaviour occurs early in typical development and facilitates the acquisition of a variety of social perception skills. Typically developing (TD) individuals appear sensitive to directional gaze from birth (Farroni, Mansfield, & Lai, 2003; Caron, Caron, Roberts, & Brooks, 1997). By 3 months of age infants will reliably follow an adult's gaze towards close targets in the visual field but not towards moving targets (D'Entremonte, 2000). By 6 months of age, typically developing infants consistently react to shifts in gaze direction (Hood, Willen, & Driver, 1998; Symons, Hains, & Muir, 1998; D'Entremont, 2000). However, 6-month-olds do not follow gaze to interesting events occurring outside their visual field (Corkum & Moore, 1995). Eight to 12-month-old TD children spontaneously follow gaze towards static and moving objects within and outside of their visual field (Corkum & Moore, 1998; Lempers, 1979).

Once children reach a year of age, sensitivity to gaze direction allows infants to establish joint attention with their caregiver (Brooks & Meltzoff, 2002; Butterworth & Jarrett, 1991; Carpenter, Nagell, & Tomasello, 1998). Joint attention, or triadic gaze, involves following another's gaze (or other directional cues such as pointing), towards an object and then re-establishing dyadic, or mutual gaze. Joint attention is fundamental to language development because it allows children to locate the referents of utterances (Leekam, Hunnisett, & Moore, 1998; Ruffman, Garnham, & Rideout, 2001), explore the world in a guided fashion, and eventually understand that others possess minds (Carpendale & Lewis, 2006). By 2 years of age, most typically developing children are using triadic gaze following for word learning (Poulin-Dubois & Forbes, 2002).

Between 2 and 3 years of age, children begin to use eye-gaze direction to make inferences about mental states such as desire and contemplation (Lee, Eskritt, Symons, & Muir, 1998; Baron-Cohen, Campbell, Karmiloff-Smith, & Grant, 1995). Four and 5-year-old children are able to use eye gaze frequency and duration to make sophisticated inferences about another person's mental state (Baron-Cohen et al., 1995). For example, by 4 years of age, children begin to understand that eyes can inform them about a liar's true intentions (Freire, Eskritt, & Lee, 2004). Sensitivity to the social meaning of gaze-direction continues to develop into adulthood (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Baron-Cohen, Wheelwright, & Jolliffe, 1997) and is a strong predictor of adult social competence (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Adults are able to use gaze direction to infer complex mental states such as: contemplation, reference, knowledge, desire, belief, guilt, and submission (Lee et al., 1998).

Gaze Following in Children with Autism

Autism is a pervasive developmental disorder characterized by difficulties in reciprocal social interaction, communication, and the presence of odd repetitive or restrictive behaviours (DSM-IV; American Psychiatric Association, 2000). One of the earliest detectable signs of autism and most commonly reported symptom is lack of eye contact and gaze following (e.g. Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Baron-Cohen et al., 1995; Ruffman et al., 2001; Leekam, López, & Moore, 2000; Baron-Cohen et al., 1996; Baird, Charman, & Baron-Cohen, 2000; Leekam et al., 2000). Children with autism routinely fail to use eye gaze to establish joint attention and to understand the mental states of others (Pelphrey, Morris, & McCarthy, 2004). Early gaze-following difficulty is thought to hinder learning about the social world and ultimately adversely affects the child's social development (Dawson, Meltsoff, Osterling, 1998; Baron-Cohen et al., 1995). For example, Behrman, Thomas, and Humphreys (2006) suggest that a lack of gaze following in autism results in a failure to develop the behavioural and neural mechanisms required for face processing expertise. Improved understanding of gaze following difficulties in children with autism may advance early identification and treatment of the disorder.

Theorists have presented motivational (Leekam et al., 1997), social-cognitive (Baron-Cohen, Leslie & Frith, 1985; Baron-Cohen, 1994), and affective (Hobson, 1993; Kasari, Sigman, & Mundy, 1990) explanations for deficient gaze following in autism. This study focused on how basic cognitive abnormalities may account for later social deficits. There is evidence that perceptual and attentional problems play a significant role in higher order social problems in autism (Behrmann, Thomas & Humphreys, 2006). In particular, abnormalities in social attention may be associated with deficits in gaze-following. Attention researchers have recently suggested that typical gaze following behaviour is mediated by attentional systems devoted to the rapid processing of social stimuli (Friesen & Kingstone, 1998). TD adults and children as young as 10 months reflexively shift their visual attention in response to others' gaze direction (e.g. Macrae, et al., 2002; Friesen & Kingstone, 1998; Driver et al., 1999; Langton & Bruce, 1999; Kingstone, Friesen, & Gazzaniga, 2000; Corkum & Moore, 1995). Two recent studies have used computer-based cueing paradigms to examine attention shifting in response to directional gaze cues in individuals with autism. Findings indicated that, unlike TD individuals, young children and adolescents with autism did not reflexively shift their visual attention in response to gaze direction cues (Johnson et al., 2005; Ristic et al., 2005). Rather, individuals with autism shifted their attention in an intentional, not reflexive, manner. Further, participants with autism only shifted their attention to follow gaze direction when they were explicitly instructed to attend to eyes and in response to increased contingency between the cue and the target. These findings suggest that individuals with autism may learn to orient to gaze in a unique fashion. Eye gaze orienting may not be reflexive in individuals with autism to the same extent as it is in TD individuals.

Computer Based Measurement of Attention to Eye Gaze

The majority of studies examining visual social attention in humans have employed a modified Posner (1980) spatial cueing paradigm to measure orienting to gaze. Typical Posner paradigms are computer-based and involve detection of a target or discrimination between multiple targets located in the visual field. Subjects are instructed to fix their attention upon a central point and to respond when they see the target. The target is typically preceded by a cue that is either valid (correctly indicates the target location), invalid (incorrectly indicates the target location), or neutral (gives no indication of target location). Shorter reaction times (RTs) to targets in validly cued locations versus invalidity cued locations indicate that participants have shifted their attention to the cued location. The time interval between the cue and the target can be varied in order to obtain a temporal profile of the attentional effect (Posner, 1980). This cue-to-target delay is referred to as the stimulus onset asynchrony (SOA). Reflexive or automatic orienting of attention is often measured at shorter (100ms to approximately 300 ms) SOAs (Muller & Rabbitt, 1989). Reflexive orienting occurs quickly, is not sustained, and does not contribute to cognitive load (Jonides, 1981). In contrast, volitional orienting is effortful and engaged later and, therefore, is typically measured at longer (>600 ms) SOAs (e.g. Ristic, Friesen, & Kingstone, 2002). Exogenous stimulus cues are typically abrupt luminance transients in the periphery (e.g. flash cues) that elicit reflexive orienting. Central informational cues (e.g. arrows) are not traditionally associated with reflexive orienting (Jonides, 1981). However, centrally presented gaze cues (i.e. a face with averted eyes) may represent a different type of central informational cue. Results from spatial cueing tasks reveal that centrally presented gaze cues are associated with faster reaction times (RTs) for valid versus invalid trials at shorter SOAs (100 to 300ms) (e.g. Friesen, Moore, & Kingstone, 2005; Friesen, Ristic, & Kingstone, 2004; Friesen & Kingstone, 2003a; Friesen & Kingstone, 2003b; Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). These findings suggest that gaze cues elicit reflexive orienting of attention in TD individuals.

Orienting Attention to Eye Gaze in Autism

Spatial cueing tasks were recently used to examine orienting of attention to gaze cues in individuals with autism (Rustic et al. 2005). Adolescents with autism were instructed to fixate their gaze upon a centrally presented schematic face with no pupils in the eyes. The pupils then appeared to look either to the right or left side of the screen. After an SOA delay of variable length (i.e. 105ms, 300ms, 600ms, or 1005ms), a target appeared on either the right or left side of the screen. Participants were instructed to press the spacebar when they detected this target. There were two conditions within the experiment that varied between participants; predictive gaze and non-predictive gaze. Participants in the predictive gaze condition were encouraged to pay attention to the eyes because eye gaze was informative as to the location of the target 80% of the time. Thus, targets appeared in the cued location for 80% of the trials. Participants in the non-predictive gaze condition were instructed to ignore the eyes because gaze direction was not generally informative as to the location of the target. Targets appeared in the randomly cued locations for 50% of the trials. Ristic and colleagues' (2005) findings indicated that unlike TD individuals, adolescents with autism did not reflexively orient their attention to gaze in the non-predictive gaze condition. However, when instructed to attend to gaze cues, participants were able to orient their attention to gaze in a volitional manner.

Implications of Attention Findings

Attention orienting findings may be relevant to understanding the lack of spontaneous social gaze following observed among children with autism in their daily activities. Basic attentional processing differences between children with autism and their TD peers may be related to social gaze following deficits in specific ways. For example, lack of reflexive orienting to gaze may be associated with diminished social use of gaze. Within the context of a social task wherein many stimuli compete for attention, gaze cues may not be salient enough to automatically draw the attention of children with autism. Thus, gaze following within a social setting may occur less spontaneously and with decreased frequency in persons with autism. Alternatively voluntary orienting of attention in response to gaze cues may be involved in the social gaze following behaviour of children with autism.

There is evidence that different mechanisms underlie reflexive and volitional orienting (Posner, Cohen, & Rafal, 1982; Robinson & Peterson, 1986; Wurtz, 1985). Volitional orienting is governed by controlled processing (Brodeur & Enns, 1997; Shiffrin & Schnieder, 1977) and requires cognitive resources whereas reflexive orienting occurs automatically and does not contribute to cognitive load (Jonides, 1981). Reflexive and volitional orienting are used together to facilitate visual exploration. For instance, Enns and Brodeur (1989) found that some participants supplemented reflexive orienting with voluntary orienting in order to take advantage of the predictability of flash cues. Children with autism who orient to gaze cues in a primarily volitional manner may fail to follow eyes in social situations when their attentional resources are taxed. Currently, it is unknown whether the orienting differences found in performance on spatial cueing tasks predict clinically relevant behavioural differences between children with autism and their TD peers. Laboratory findings from computer based attention paradigms may be specific to the contrived environment in which they are generated (Smilek et al., 2006). Alternatively, computer based orienting performance may reflect an underlying problem in understanding or using gaze following in social tasks.

Hypotheses

The goal of the present study was to explore the relation between children with autism's ability to orient their attention to directional gaze cues during a spatial cueing task and their ability to understand and use gaze cues in social contexts. First, children's tendencies to orient to gaze in a volitional (as opposed to reflexive) manner were assessed based upon their performance on a spatial-cueing-task. Next, children's tendency to spontaneously follow gaze and head turning during a social interactive game in the laboratory was assessed using a scenario similar to that used by Leekam et al., (1997). Leekam et al., (1997) positioned the experimenter across from the participants and the experimenter then turned their head and eyes towards a sticker on the wall directly to the right, left and behind the participant. The experimenter first engaged the participant in a social interaction, than spontaneously averted their gaze. Interactions were video-taped. Participant's received a score of 1 when they followed the experimenter's gaze and a score of 0 when they failed to follow gaze.

Children's ability to understand that gaze direction can be informative of the mental states of others was assessed with Baron-Cohen's (1995) 'sweets task'. Baron-

Cohen and colleagues (1995) tested four-year old children with autism for their ability to infer mental states from averted gaze. Participants were shown a schematic face (Charlie) with averted gaze and required to answer questions about Charlie's intentions, desires, and referents. Finally, the ability to accurately follow line of sight was assessed using computer software designed by Tanaka & Low (2001) to ensure that potential difficulties with spatial perception of gaze did not confound results. Participants were required to follow the gaze of a centrally presented face and identify the "looked at" object from an array. Correlations between performance indices in each of the tasks were examined in order to determine whether performance on the spatial cueing task was related to performance on the social gaze tasks.

It was hypothesized, based on previous research (Ristic et al., 2005; Johnson et al., 2005), that children with autism would demonstrate a lack of reflexive orienting in response to gaze cues on the spatial cueing task. Specifically, cue validity was not expected to affect reaction times when children with autism were instructed to ignore the eyes and gaze cues were non-predictive. The performance of children with autism on the social-gaze-following task was expected to be impaired relative to that of the TD children. Similarly, it was predicted that the performance of children with autism would be poor relative to that of the TD comparisons on the social understanding of gaze task. Significant positive correlations were anticipated between orienting performance on the spatial cueing task and understanding or acting on gaze direction in the interactive tasks. It was hypothesized that a positive correlation would be found between performance on the spatial cueing task and spontaneous social gaze following in children with autism. It was also hypothesized that a positive correlation would be found between performance on the spatial cueing task and social understanding of gaze in children with autism. In children with autism, lack of reflexive orienting was expected to be associated with impoverished social use and understanding of gaze. Similarly, increased volitional orienting to gaze was expected to be associated with poor social use and understanding of gaze because it would be associated with decreased reflexive orienting. Based upon previous findings (Leekam et al., 1997), ability to follow line of sight was expected to be comparable in the group of children with autism and the matched group of TD children. Finally, it was hypothesized that line of sight following ability would be un-related to other gaze measures in all participants.

METHOD

Participants

Twenty-eight participants with autism between the ages of 7 and 14 yrs (mean ± SD= 130 months ± 27) were recruited from the Lower Mainland and Kamloops areas of British Columbia. In order to confirm the child's clinical diagnosis, all parents of participants with autism were administered an Autism Diagnostic Interview - Revised (Couteur, Lord, & Rutter, 2003) by the experimenter who was trained in administration at a two-day ADI-R workshop sponsored by the BC government. The ADI-R consists of 93 items that ask about early development in a number of domains including: reciprocal social interaction, communication, and restricted interests. Scores from the interview were entered into a Diagnostic Algorithm to determine whether individuals met the cut-off for a diagnosis of autism. Two children did not meet the diagnostic criteria for autism and were excluded from the analysis after they had completed the experimental protocol. An additional child with autism was excluded from the final analysis because he did not attend to the spatial cueing task. High functioning autism (HFA) was defined as a diagnosis of autism in conjunction with a non-verbal or verbal IQ in the average or above average range. Non-verbal mental age was measured using the Raven's Coloured Progressive Matrices (Raven, 1962). The Peabody Picture Vocabulary Test - Third Edition (PPVT-III) (Dunn & Dunn, 1997) was used to assess participants' verbal mental age. All the children diagnosed with autism met the criterion for HFA based upon their mental ages.

Twenty-five TD participants between the ages of 4 and 14 years (mean ± SD= 177 months ± 30.74) were recruited from communities surrounding Brandon, MB and in

Qualicum, B.C. The mean chronological age (CA), non-verbal mental age (MA), and verbal MA in months for all participants are listed in Table 1.

Table 1: Mean chronological ages (CA) and mental ages (MA) (± standard deviations) for children with autism and typically developing (TD) participants.

	N	CA	Non-Verbal MA in months	Verbal MA in months
Autism group	25	132 (± 27)	131 (± 35)	151 (± 70)
TD group	25	117 (± 31)	134 (± 34)	156 (± 51)

Chronological, non-verbal and verbal MAs were not significantly different between groups. Mean verbal MA was significantly higher than mean CA in the TD comparison group, $t(24)$= -6.23, p < .001) and the autism group $t(24)$= -1.51, p = .14. Non-verbal MA was not significantly different from CA for the autism group $t(24)$ =.16, p =.87. However, non-verbal MA was significantly higher than CA in the TD comparison group $t(24)$ = -3.38, p <.001.

Individuals from the autism and TD groups were matched based upon their non-verbal mental ages. Non-verbal MA was selected as a basis for matching because experimental tasks were primarily non-verbal in nature and the groups did not differ significantly on nonverbal, $t(48)$ = -.30, p = .75, and verbal MA, $t(48)$ = -.27, p = .78. Each child with autism was matched to a TD child who was close in non-verbal mental age (all individuals matched within 12 months of each other). The mean non-verbal age difference between participants with autism and their matched TD comparison was 6 months (SD = 3 months).

There were significantly more males than females in the autism group, $t(48) = -3.28$, $p = <.001$. Twelve percent of participants were female in the autism group compared to 52% of participants in the comparison group. These numbers are roughly consistent with a 4:1 male to female sex ratio in autism (Steffenburg & Gillberg, 1989). Females with autism tend to be lower functioning than males with autism (Zahn-Waxler, Crick, & Shirtcliff, 2006). This may have also contributed to the under representation of females in the autism sample since participants with autism were required to be high functioning.

Experimental Tasks

Task 1. Orienting of Attention in Response to Gaze Direction

The extent to which participants reflexively oriented their attention in response to eye gaze-direction was measured using a procedure similar to that utilized by Ristic et al. (2005). This involved a target detection task where centrally presented schematic faces with eyes acted as cues for target detection. Participants in this study were younger than those in Ristic et al.,'s (2005) study and participated in both experimental conditions. Participants first completed a non-predictive condition where, overall, gaze did not consistently indicate target location. Participants were instructed to ignore the eyes in this condition. Participants then completed a predictive condition where gaze frequently indicated target location and they were instructed to attend to the eyes. Results from the orienting task were later used to derive a measure of the extent to which individuals orient reflexively in response to gaze.

Apparatus

Stimuli were presented using a portable personal computer (Dell Inspiron 1100) with a 17-inch colour monitor. The refresh rate for this computer is 60 hertz. E-Prime (version 1.1) software was used for task programming, data collection, storage and part of the data analysis. Participants were seated directly in front of and approximately 50 cm away from the screen and used keyboard presses to make responses.

Stimuli

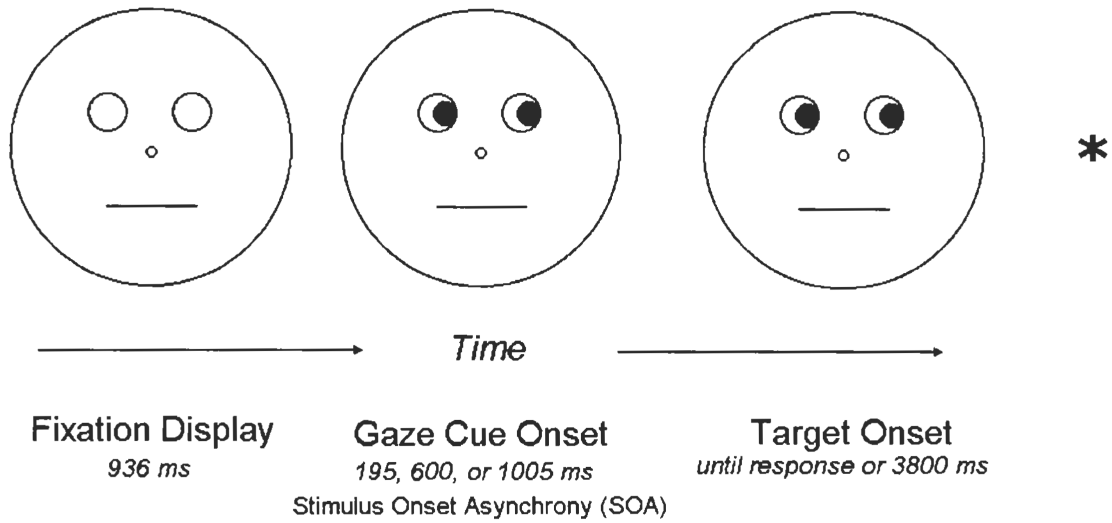
All experimental stimuli consisted of black line drawings on a white background (Fig. 1). A circle, with a diameter of 14.03 ° (visual angles) represented the outline of the face. A small circle located in the centre of the monitor, with a subtended diameter of 0.6°, represented the nose and also served as the fixation point in the experiment. The nose was located in the centre of the 17-inch (43.18 cm) monitor, 13.5 cm from the top and bottom of the screen edge and 17 cm from the right and left of the screen edge. The face outline contained two small circles for eyes which subtended 2.06 ° in diameter. Black circles with subtended diameters of 1.37 ° represented pupils and appeared in the centre of the eyes. A line subtending 4.57 ° in length was centred below the nose and represented the mouth. Targets were black asterisks measuring 2.06 ° in width and height that appeared 12.40° to the direct left or right of the central fixation point (the nose).

Design and Procedure

There were two experimental conditions treated as a within subject variables; a non-predictive gaze condition and a predictive gaze condition. All participants completed both experimental conditions within the same 1 to 2 hour experimental session. The non-predictive gaze condition was always completed before the predictive condition so that participants would not have to "unlearn" instructions to attend to eyes.

A trial began with the appearance of a face with blank eyes for 963 ms (Fig. 1). Participants were instructed to fixate their attention on the nose. The pupils then appeared looking to the right or left for an SOA (or cue duration) of 195 ms, 600 ms, or 1005 ms. SOAs of 195 ms, 600 ms, and 1005 ms were selected in order to track the time course of reflexive to volitional orienting. Within the experiment, SOAs occurred with equal probability within trials. After the cue-to-target (SOA) delay, the target appeared on the right or left side of the screen until the participant made a response by pressing the space bar or until 3,800 ms had elapsed. There was an 808 ms interval between trials. On valid trials, pupils accurately indicated the location of the target (e.g. pupils "looked" right and target appears on the right). On invalid trials, targets appeared in the location opposite of that indicated by the pupils (e.g. pupils "looked" left and the target appeared on the right). Eight percent of experimental trials were catch trials which were designed to ensure that participants were attending to the task. During catch trials, no target appeared following the gaze cue. All participants completed two blocks of 42 trials in each experimental condition. Valid and invalid trials were intermixed within each block. In the non-predictive condition, 50% of non-catch trials were valid and 50% were invalid. Targets appeared on the side indicated by the position of the eyes on half of the trials (valid) and on the side opposite of that indicated by the eyes on half of the trials (invalid). In the predictive condition, 80% of non-catch trials were valid and 20% were invalid. Target detection reaction time (RT) was measured as the time elapsed between the appearance of the target and the pressing of the spacebar by participants.

Figure 1: Stimulus display sequence for the orienting to gaze direction task.



At the beginning of each session, participants completed the non-predictive gaze condition. In this condition, gaze was not predictive of target location and participants were told “Be careful, the eyes will try to trick you. They will not always tell you where the star is going to appear. Do not pay attention to the eyes.” Participants were then informed of the sequence of events and instructed to press the space bar as quickly as possible once they saw the target. Additionally, participants were warned that there would be trials in which no target would appear (i.e. catch trials) that were designed to ensure that they were accurately attending to the task. Trial type (i.e. valid, invalid, or catch) varied randomly at the above specified frequencies. Participants were instructed not to move their eyes while completing trials and were reminded of this by an experimenter who sat beside them during the task. Eye-movements were not measured. However, Friesen, Ristic, & Kingstone (2004) established that when participants are told not to move their eyes, they refrain from doing so. Additionally, eye movements cannot occur within 200ms, ensuring that the shift in attention is purely covert at the shortest

SOA (Akhtar & Enns, 1989). Therefore, it is assumed that eye-movements were not involved in producing cueing effects and that orienting was covert in nature.

At the end of the 1 to 2 hour experimental session, participants completed the predictive gaze condition. In this condition, on average, gaze was spatially predictive of target location and participants were told, "The eyes will be very helpful this time. They will almost always tell you where the star will come. So pay good attention to the eyes, they will give you hints."

Reflexive and Volitional Cue Effects

An individualized measure of reflexive orienting to gaze was calculated using RTs from the computer task in order to test the hypothesis that orienting was related to social gaze following. Reflexive orienting was defined as the cue validity effect in the non-predictive condition where:

Reflexive cue effect = mean RT invalid trials at 195 ms SOA

– mean RT valid trials at 195 ms SOA

Difference scores between valid and invalid trial means at the 195ms SOA in the non-predictive condition were calculated because participants were instructed to ignore gaze in this condition and difference scores reflected the extent to which participants unintentionally oriented to gaze.

A volitional cue effect reflects the extent that target detection was facilitated when participants were instructed to attend to the eyes and when gaze was predictive. Voluntary orienting was defined as the reflexive cue effect subtracted from the cue validity effect in the predictive condition where:

Volitional cue effect = (mean RT invalid trials at 195 ms SOA– mean RT valid trials at

195 ms SOA) – Reflexive cue effect

A higher score would indicate that an individual displayed a higher degree of volitional orienting to gaze cues. Lower scores suggest that a participant responded to gaze cues in a less volitional manner. However, the scaling is likely interval and there is no true zero point that represents a complete lack of volitional orienting.

Task 2. Social Gaze Following

Leekam et al.'s (1997) gaze monitoring task was modified to assess the degree to which individual participants spontaneously followed averted gaze and head turning in a contrived social context. Specifically, the same procedure and number of trials used by Leekam and colleagues were administered but scoring was changed in order to obtain a continuous measure of social gaze following.

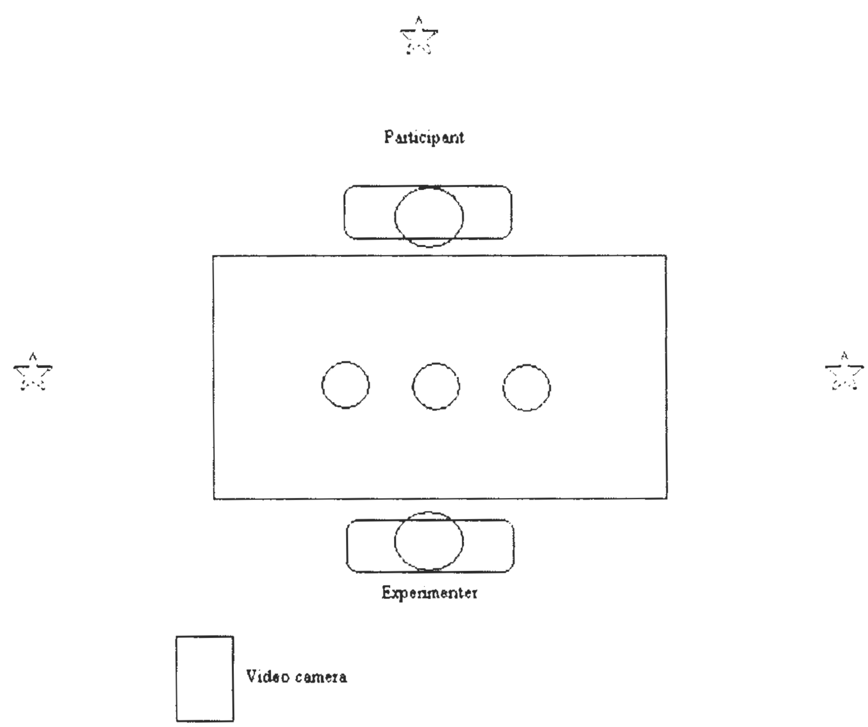
Materials

The experimenter sat at a table across from the participant. A video camera was positioned to capture the participants' faces and the back of the experimenter's head. Three gold stars were placed on the wall at the experimenter's eye level and directly to the right, left and behind the participant. Three identical opaque cups with a small Winnie-the-Pooh toy were used for the "cup game" and were placed in a line directly in front of the examiner and the participant.

Design and Procedure

A gaze following task was administered in the laboratory and videotaped for later coding. The experimenter engaged the child in a semi-structured game (the "cup game") which consisted of hiding a small toy under one of three identical cups. The experimenter repositioned the cups on the table and asked the child to pick the cup under which they felt the toy was situated. During any point in this game, when the experimenter received the child's eye-contact, she immediately moved her head and looked at a target (star sticker) either to the left or the right (at 90° from her midline), or behind the child, and fixated upon the target for 20 seconds. During these 20 seconds the experimenter maintained a facial expression as if to indicate that she had seen something of interest. If the child obviously oriented their attention in the direction of the experimenter's gaze, the experimenter resumed the cup game, otherwise, the experimenter maintained their gaze for 20 seconds. As in the Leekam et al., (1997) experiment, each child participated in one trial at each location (left, right, and behind) for a total of 3 trials. Gaze direction was counterbalanced between participants. Half of the participants were administered trials in a right, behind, left order and the other half in a left, behind, right order. Figure 2 shows a schematic depiction of Task 2.

Figure 2: Schematic of lab set up during the Social Gaze Following Task.



Scoring

Orienting to head turn and gaze direction was scored in seconds elapsed between head turning on the part of the experimenter and gaze following on the part of the participant. Participant gaze following was indicated by head turning or averted eyes in the direction of experimenter gaze. Video-tapes were viewed and scored with a stopwatch by two raters who were blind to the children's diagnosis. In order to obtain a continuous measure of gaze following, Leekam et al.'s, (1997) pass / fail scoring was modified. Specifically, participants received scores on each trial ranging from 0 to 20. Failure to follow gaze received a score of 20. A score of 1.23, for example, would indicate that the participant had followed the experimenter's averted gaze within 1.23 seconds. Each participant completed 3 trials for a total possible score of 60. Lower scores on this measure indicate a shorter latency to orient in response to head and gaze direction.

Task 3. Inferring Social Meaning from Directional Gaze

A variation of Baron-Cohen's (1995) "sweets task" was utilized to measure the extent to which participants were able to use gaze for social understanding. Specifically, children's use of eye-gaze to infer mental states such as desire, intention, and reference was assessed.

Materials

Five laminated white cards with colourful photos in each corner were presented to the participants. One card had photos of 4 common chocolate bars with one in each corner of the card, one had 4 cartoon dogs, two had 4 nonsensical shapes and a final card had 4 boxes of different sizes. Eight transparencies were used to present gaze and arrow cues. Four transparencies had a schematic face with eyes that gazed diagonally at one of the corners and four had an arrow pointing either horizontally or vertically towards one of the four corners. For each trial, gaze and arrow transparencies were placed overtop of each other and then on top of a photo card. See Figure 3 for an illustration of stimuli used in this task.

Design and Procedure

Three conditions that measured use of gaze to infer desire, intention, and reference were administered to all participants. Additionally, all participants completed a control condition that assessed their ability to understand task instructions and respond appropriately.

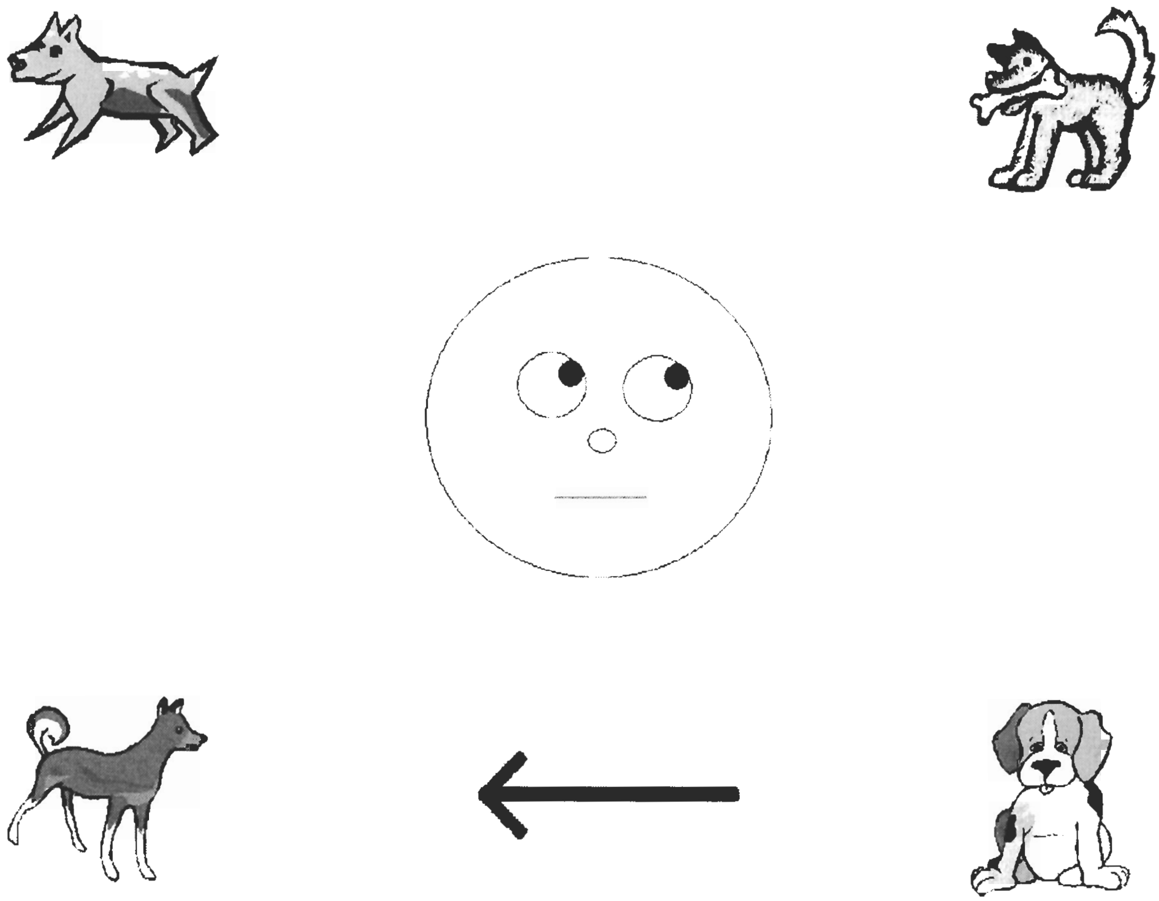
The first condition measured desire and utilized the card with photos of chocolate bars and the card with the photographs of dogs. Children were asked, "Which one is your favourite?" and responded by either pointing to or naming their favourite chocolate bar or dog. The experimenter then showed the child one of the face transparencies and said, "This is my friend Bob" and pointed to the schematic face with averted eyes. One face and one arrow transparency were then placed over the photo card, ensuring that neither the eyes nor the arrow pointed to the child's favourite item or at the same photo. The arrow served as an alternative to the social gaze cue. See Figure 3 for an illustration of how arrows and gaze cues were placed relative to each other. Eye gaze and arrow direction were varied by the experimenter so that they did not indicate the same spatial areas on two subsequent trials. Beginning with the chocolate bar card, the experimenter asked, "Bob wants one of these chocolate bars. Which one does Bob want?" With the dog card, the experimenter said, "Bob is a lucky boy. He gets to go to the pet store and pick out a new pet. He wants one of these puppies. Which one does he want?" Participant selections were noted and scored.

The next intention condition also utilized the chocolate and dog cards. Trials commenced with the experimenter query, "Which one would you take?" Face and arrow transparencies were then laid over the card so that neither cue indicated the participant's choice and the arrow and gaze pointed towards different photos. The participant was told: "Here is Bob again. He is going to take a chocolate bar. Which one is he going to take?" or, "Here is Bob again. He is going to pick a puppy. Which one is he going to take?" Participant selections were noted.

The cards with nonsensical shapes were used in the third condition to assess use of gaze to infer reference. The experimenter showed the child a card and stated "One of these is a *beb* [an arbitrarily selected nonsense word]. Which one is the *beb*?" If, as was often the case, the child did not spontaneously pick a shape, they were encouraged to guess. The experimenter then placed transparencies over the shape card and stated, "Bob says, '*There's* the *beb*!' Which one does Bob say is the *beb*?" Participant's responses were noted and scored. The trial was repeated using the other shape card with the non-sense word "*reth*".

The control condition employed the card with the four boxes of differing size. A face and an arrow transparency were placed over top of the card and children were asked "which box is the smallest?" If children indicated the smallest box, regardless of where Bob's eyes were looking, they were deemed to understand the questioning and passed the control task.

Figure 3: Example of stimuli used to evaluate social understanding of gaze in Task 3.



Scoring

Participants received a total score out of 6 for the entire task. For each trial (two trials in the desire condition, two trials in the intention condition, and two trials in the reference condition), participants received a score of either 1 or 0. Scores of 1 denote that the child correctly selected the photo indicated by gaze direction. Scores of 0 indicate that the child did not select the photo indicated by gaze direction. Scores of 0 were further coded to track error types. Specifically, 0's followed by A: denoted arrow following, E: denoted egocentric responding (the child chose his or her favourite item), or

R: denoted random incorrect responding. Children either passed or failed the control task. One child with autism failed the task and was not included in the final analyses. The probability of passing all trials in a condition due to chance alone was small (0.06). The probability of passing all six trials by chance alone is very small (i.e. 0.0002). Therefore, higher scores on this task were interpreted as reflecting the extent to which participants were able to infer mental states from eye-gaze direction cues. For example, a score of 6 indicates that a child used the direct of the eyes to make their photo selection on all trials; it was assumed that they were able to use gaze to infer social meaning. A score of 0 (A) indicates that a child selected the photo indicated by the arrow on all trials.

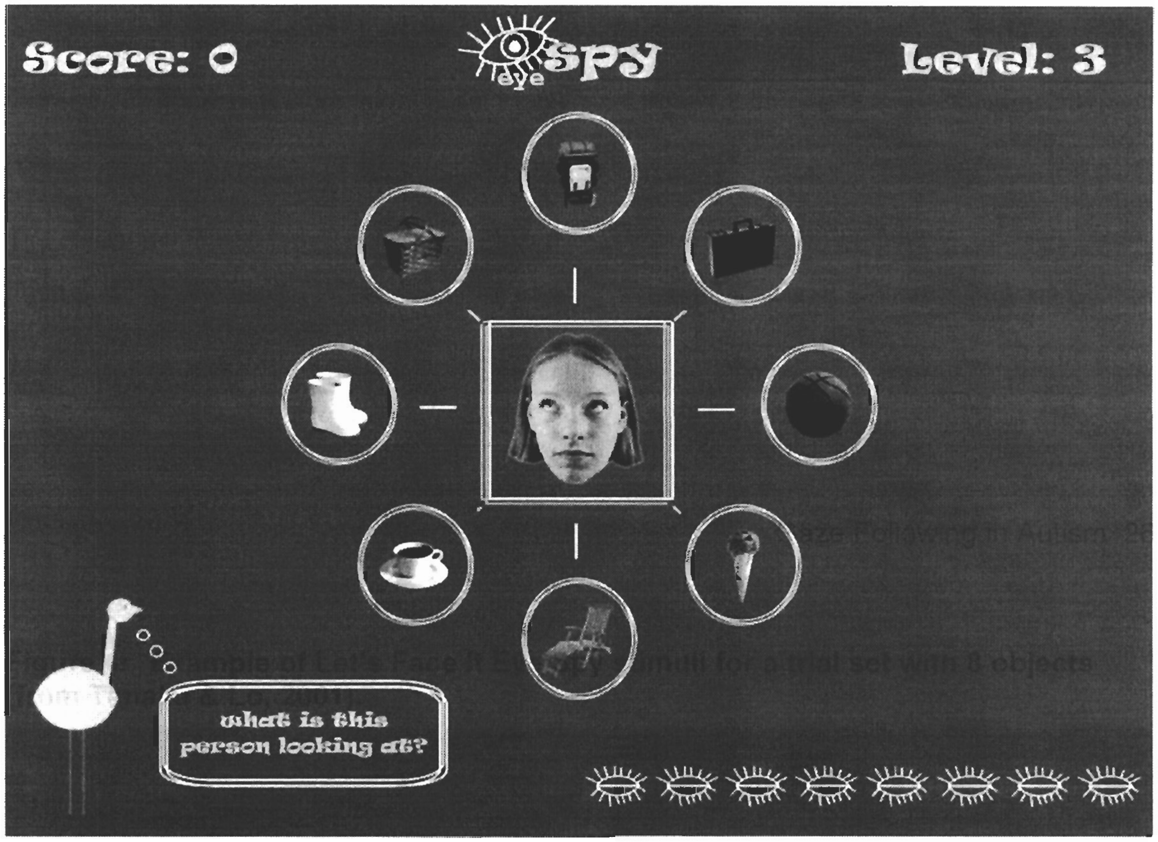
Task 4. Following Line of Sight

Line of sight following refers to the ability to visually track and accurately report what another person is looking at. This skill involves spatial tracking of gaze in a "geometric" sense and does not require a social understanding of eye gaze. In contrast, spontaneous gaze following involves monitoring another's attention and requires more social reasoning (Leekam, 1997). To ensure that predicted findings of lack of social gaze following and reflexive orienting to gaze in individuals with autism were not due to spatial perception difficulties, line of sight following ability was measured using a task from the Let's Face It (LFI) computer program (Tanaka & Lo, 2001;http://web.uvic.ca/~jtanaka/). Participants were presented with a centrally located photorealistic face and asked to identify the "gazed at" object from an assortment of household objects.

Materials and Procedure

Stimuli were presented on a portable PC system with a 17-inch touch screen monitor. The screen displayed a centrally located photorealistic face with averted eyes that "looked" to the right or left at one of two household objects (e.g. dog dish, basketball, ice cream cone). Participants received the prompt, "what is this person looking at?" and were required to click the mouse icon on the object of their choice. Two four-year old children in the comparison group had difficulty manipulating the mouse and pointed to the object of their choice on the touch screen. When a child selected a gazed-at object (i.e. made a correct response), this object disappeared from the screen and the next trial commenced. If the child made an incorrect selection, the selected object would not disappear from the screen. Furthermore, if a child made an incorrect selection and had made previous correct selections, for each incorrect response, one object that had disappeared would re-appear on the screen until all the original objects were displayed. All participants completed 6 sets of trials. The first set had two objects to select from, the second set had four objects and the final set had eight objects (eight trials). In the first 3 sets of trials (including 2, 4, and 8 objects), the central face maintained static gaze upon an object until the participant made a selection. In the final 3 sets of trials, the identity of the photo realistic face and the direction of gaze changed approximately every 3 seconds. Therefore, for the final 3 sets of trials (which included 2, 4, and 8 objects respectively) participants had to make object selection decisions in a time-limited fashion. Following line of sight had to be performed within a 3 second interval. See Figure 4 for an example of visual stimuli in LFI task.

Figure 4: Example of Let's Face It Eye Spy stimuli for a trial set with 8 objects (from Tanaka & Lo, 2001).



Scoring

Overall percent accuracy for each trial set was calculated by LFI software (Tanaka & Lo, 2001) and was used to derive a mean percentage accuracy score for each participant.

RESULTS

Task 1. Orienting of Attention in Response to Eye-Gaze

Prior to statistical analyses, anticipations (RTs<100 ms) and timed-out trials (RTs<1000 ms) were classified as errors and excluded from analyses (e.g. Freisen, Ristic, & Kingstone, 2004). These outlying points comprised 2.9% of experimental trials. Catch trials were also excluded from the final analyses. False alarms on catch trials (key presses on trials where no target was present) occurred at a low frequency of trials (4.6%). This suggests that most participants were completing the spatial cueing task appropriately. One participant with autism responded on 100% of the catch trials and was excluded from the final analysis. Means, standard deviations, and error rates for RTs for each trial type (invalid and valid) at each SOA (195 ms, 600 ms, and 1005 ms) for each experimental condition (non-predictive gaze and predictive gaze) were calculated for the autism and comparison groups. Due to few trials in some conditions (especially invalid trials in the predictive condition), there were 2 empty data cells in the autism group which were filled using the average mean for that cell.

Four 2 x 3 Repeated Measures ANOVAs of mean RT performance were conducted for each group (autism and comparison) in each experimental condition (non-predictive gaze and predictive gaze) with trial validity (valid and invalid) and SOA (195ms, 600ms, and 1005ms) as within subject variables. Family-wise error rate corrections (i.e. alpha corrections to account for multiple tests) were not conducted as each experimental condition for each group was conceived of as a separate “family”. The mean RTs and standard errors (SE) for the non-predictive condition are shown in Table 2. The mean RTs and SE for the predictive condition are shown in Table 3.

Table 2: Mean Reaction Times (RT) and Standard Errors (SE) in milliseconds for the autism and Typically Developing (TD) group in the Non-Predictive condition.

	195 ms SOA		600 ms SOA		1005 ms SOA	
	invalid	valid	invalid	valid	invalid	Valid
Autism						
M	466	460	415	407	434	420
SE	24	23	22	21	23	21
TD						
M	498	478	458	436	453	446
SE	24	24	29	28	28	27

Table 3: Mean Reaction Times (RT) and Standard Errors (SE) in milliseconds for the autism and Typically Developing (TD) group in the Predictive condition.

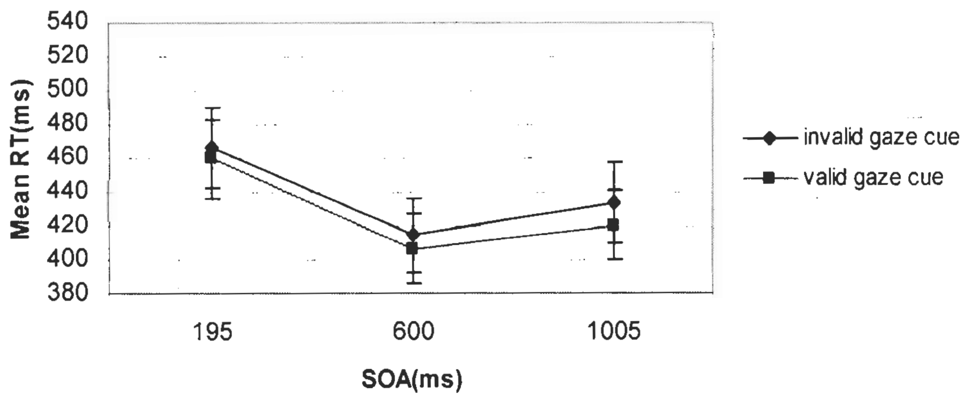
	195 ms SOA		600 ms SOA		1005 ms SOA	
	invalid	valid	invalid	valid	invalid	valid
Autism						
M	506	446	416	422	450	421
SE	31	21	14	22	27	21
TD						
M	488	455	447	406	431	413
SE	18	15	19	15	20	14

For the autism group in the non-predictive condition, a significant main effect was found for SOA, $F\,(3, 48) = 36.78$, $p < .001$ but not for gaze cue validity, $F(1, 24) = 2.83$, $p = .10$. There was no significant interaction between SOA and cue validity $F(2, 48) = .18$, $p = .83$. RTs decreased as SOA increased, a standard finding on spatial cueing tasks (Mowrer, 1940). In general, children with autism did not respond faster on valid gaze cue trials over invalid gaze cue trials in the non-predictive condition (Fig. 5A). A planned post-hoc comparison confirmed that the difference between mean RTs on valid and invalid trials at the 195 ms SOA in the non-predictive condition did not reach significance for children with autism, $t(24) = .69$, $p = .50$.

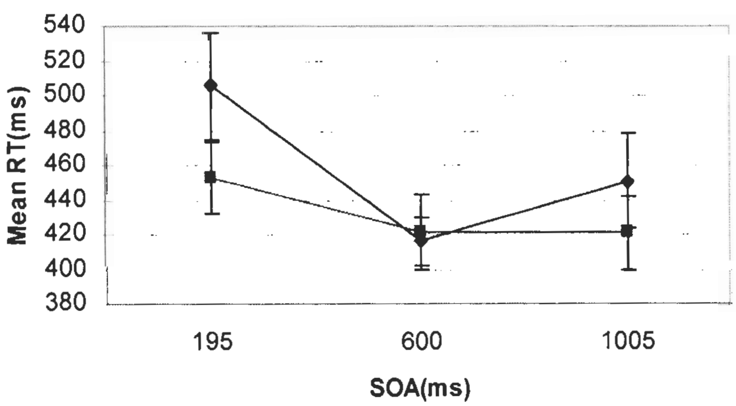
The performance of children with autism in the predictive gaze condition differed from their performance in the non-predictive condition (Fig. 5B). In the predictive condition, main effects were found for both SOA, $F\,(2, 48) = 12.78$, $p < .001$, and gaze validity, $F\,(1, 24) = 8.90$, $p < .001$ for the autism group. There was no significant interaction between SOA and validity, $F\,(2, 48) = 2.80$, $p = .07$. The main effect of gaze validity suggests, that the group of participants with autism responded faster to valid versus invalid trials in the predictive condition. At the shortest SOA, the effect of cue validity on mean response time is apparent. A planned post-hoc mean comparison confirmed significant differences between invalid and valid trial means at the 195 ms SOA $t(24) = 2.931$, $p = .007$. Children with autism responded faster to validly cued trials versus invalidly cued trials when a 195 ms cue-to-target time delay is present, gaze cues were generally predictive of target location, and participants were instructed to attend to the eye cues. However, the performance of children with autism in the non-predictive condition (Fig. 5A) indicates that they did not respond faster to valid gaze trials at the shortest SOA when gaze was not predictive of target location and when instructed to ignore the eye cues.

Figure 5: Mean Reaction Times (RT) with standard error bars for valid and invalid trials as a function of Stimulus Onset Asynchrony (SOA) for the High Functioning Autism (HFA) group in the Non-predictive and Predictive Gaze conditions.

High Functioning Autism
A: Non-predictive Gaze



B: Predictive Gaze

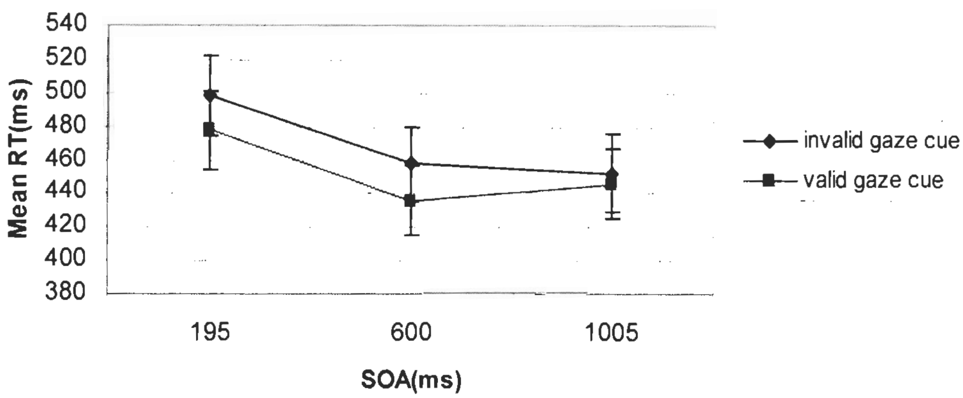


The comparison group's performance in the non-predictive condition indicates that despite instructions to ignore the eye cues, TD children responded faster to valid versus invalid trials at shorter SOAs (Fig. 6A). For the comparison group, main effects for SOA, $F\,(2, 48) = 22.37$, $p < .001$, and cue validity were significant, $F\,(1, 24) = 9.39$, $p < .01$. There was no significant interaction between SOA and validity, $F\,(2, 48) = 1.47$, $p = .24$. Planned post-hoc comparisons confirmed significant differences between invalid and valid trial means at the 195 ms SOA in the non-predictive condition for the TD group, $t(24) = 2.26$, $p = .03$. TD participants oriented attention reflexively in response to gaze cues.

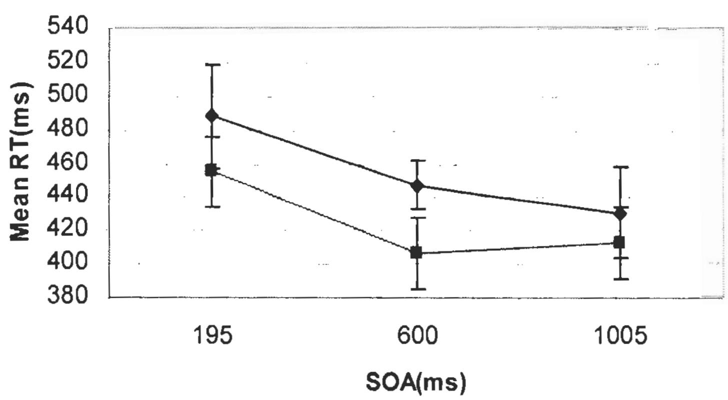
Performance for the TD group in the predictive condition indicates that, as expected, the participants responded faster to valid over invalid cue trials (Fig. 6B). There was a significant main effect for SOA, $F\,(2, 48) = 15.72$, $p < .001$ and gaze cue validity, $F\,(1, 24) = 15.43$, $p < .001$. There was no significant interaction between SOA and gaze validity, $F\,(2, 48) = .93$, $p = .39$. A planned post-hoc mean comparison (paired samples *t*-test) revealed significant differences between invalid and valid trial means at the 195 ms SOA , $t(24) = 3.05$, $p < .01$.

Figure 6: Mean Reaction Times (RT) with standard error bars for valid and invalid trials as a function of Stimulus Onset Asynchrony (SOA) for the Typically Developing (TD) comparison group in the Non-predictive and Predictive Gaze conditions.

Typically Developing
A: Non-predictive Gaze



B: Predictive Gaze

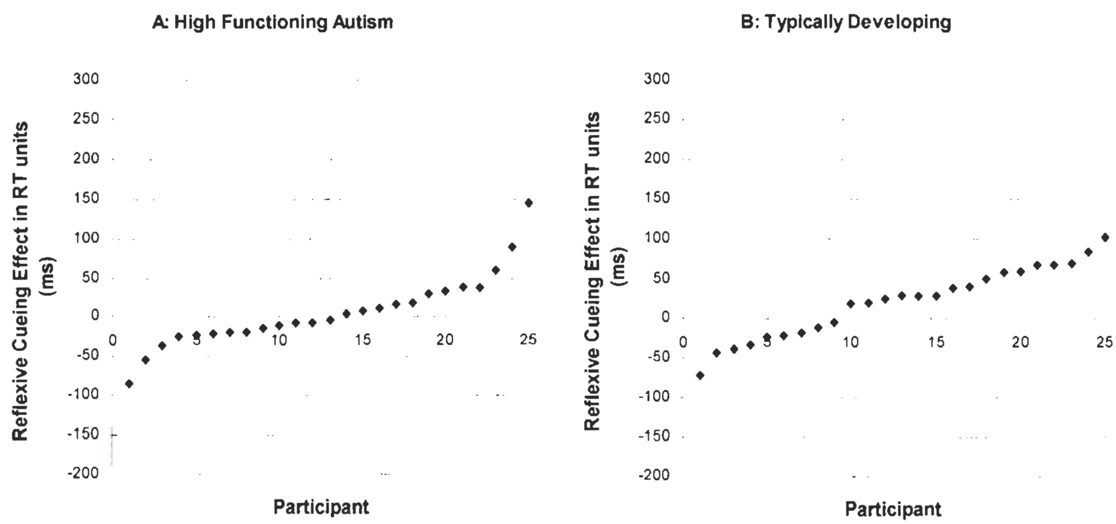


A 2 x 3 x 2 Repeated Measures ANOVA for the autism group with experimental condition, SOA, and gaze cue validity as within subject variables confirmed the presence of a significant experimental condition x cue validity interaction *F* (2, 24) = 4.60, *p* =.04. When children with autism were instructed to ignore the eyes in the non-predictive condition, there was no effect for cue validity whereas in the predictive condition an effect of cue validity was found. This suggests that, in contrast with TD children who reflexively shifted their attention in response to the gaze cue, children with autism ignored the gaze cue when they did not receive explicit instructions to attend to the eyes.

Individualized Orienting Scores

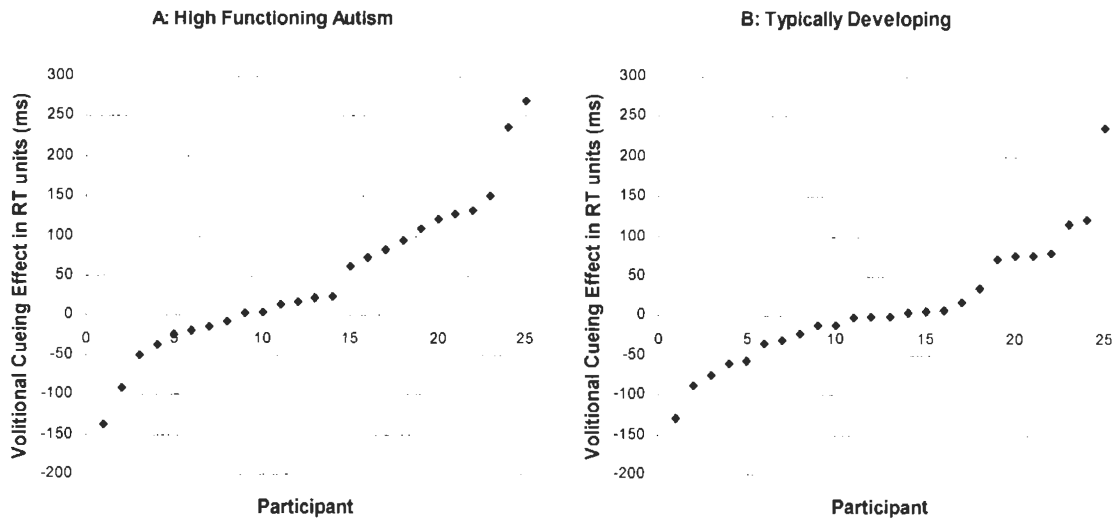
Reflexive cue effects were calculated for individual participants based upon performance in the non-predictive condition. Higher scores indicate a greater degree of reflexive orienting while lower scores indicate less reflexive orienting to gaze cues. The resulting scores in RT units for the autism group ranged from -84 ms to 144 ms (larger scores indicating more reflexive attending to eyes) and had a mean of 6 ms (SD = 46 ms). Scores for the TD comparison group ranged from -71 ms to 102 ms and had a mean of 20 ms (SD = 45 ms). An independent samples t-test revealed no significant mean difference between scores for the autism group and the TD group, $t(48) = -1.08$, $p=.28$. Figure 7 depicts scatter plots of reflexive cue effect scores for individuals with autism and TD participants.

Figure 7: Reflexive Cue Effect Scores for Individual Participants.



Volitional cue effects were calculated for individual participants. Resulting scores reflect an individual's tendency to orient to gaze in a volitional rather than reflexive manner, high scores indicating more volitional orienting. Resulting scores for individuals in the autism group ranged from -137 ms to 269 ms and had a mean of 46 ms (SD = 95 ms). Scores for individuals in the TD comparison group ranged from -130 ms to 235 ms and had a mean of 13 ms (SD = 77 ms). A mean comparison (independent samples *t*-test) of volitional orienting scores for the autism and comparison groups indicated that there were no significant group differences in tendency to orient volitionally to gaze, $t(48) = 1.37$, $p = .17$. Figure 8 depicts scatter plots of individual scores on the measure of volitional orienting for the autism and comparison group.

Figure 8: Volitional Cue Effect Scores for Individual Participants.



Task 2. Social Gaze Following

Because of the continuous nature of the data, an interclass correlation coefficient (ICC) was calculated using 80% of the video data to assess inter-rater reliability of videotape coding. Guidelines suggest that when the reliability coefficient is between .75 and 1.00, the level of clinical significance is excellent (e.g. Cicchetti & Sparrow, 1981; Fleiss, 1981). Inter-rater reliability in calculating orienting scores from the videotapes was high (*ICC* = 0.974). Trials with discrepant scores between raters comprised 10.98 % of the data and were examined by a third independent rater who was not involved in other aspects of the study. In all 17 cases of discrepancy, one rater had missed an early display of gaze following on the part of the participant while the other rater had accurately detected early gaze following. Scores for the rater who made the least errors were entered into the final analysis.

A mean comparison was conducted in order to test the hypothesis that children with autism would have absent or slower social gaze following responses. Final "social orienting" scores (out of at total of 60) were entered into a Pearson correlation matrix with scores from other tasks in order to examine potential relations between orienting responses and social gaze following.

Contrary to predictions, an independent samples t-test revealed no significant mean group differences in social gaze following scores $t(48) = .33$, $p = .74$. Mean time elapsed before gaze following occurred (over three trials) was 23.6 seconds (SD = 15.5 seconds) for the autism group and 22.07 seconds (SD = 16.7 seconds) for the comparison group. A repeated measures ANOVA was conducted in order to investigate whether the direction of the experimenter's gaze affected mean differences. A main effect for direction of gaze was found $F(2, 96) = 9.36$, $p < .001$. No main effect for group was found. There was no interaction between experimenter's gaze direction and group $F(2, 96) = .62$, $p = .54$. Post hoc tests revealed that participants took longer to follow gaze directed behind them than gaze directed to the right $t(49) = 4.09$, $p < .001$, or the left $t(49) = -3.23$, $p < .01$.

Table 4: Mean orienting times and Standard Deviations (SD) in seconds for children with autism and Typically Developing (TD) children in the Social Gaze Following Task.

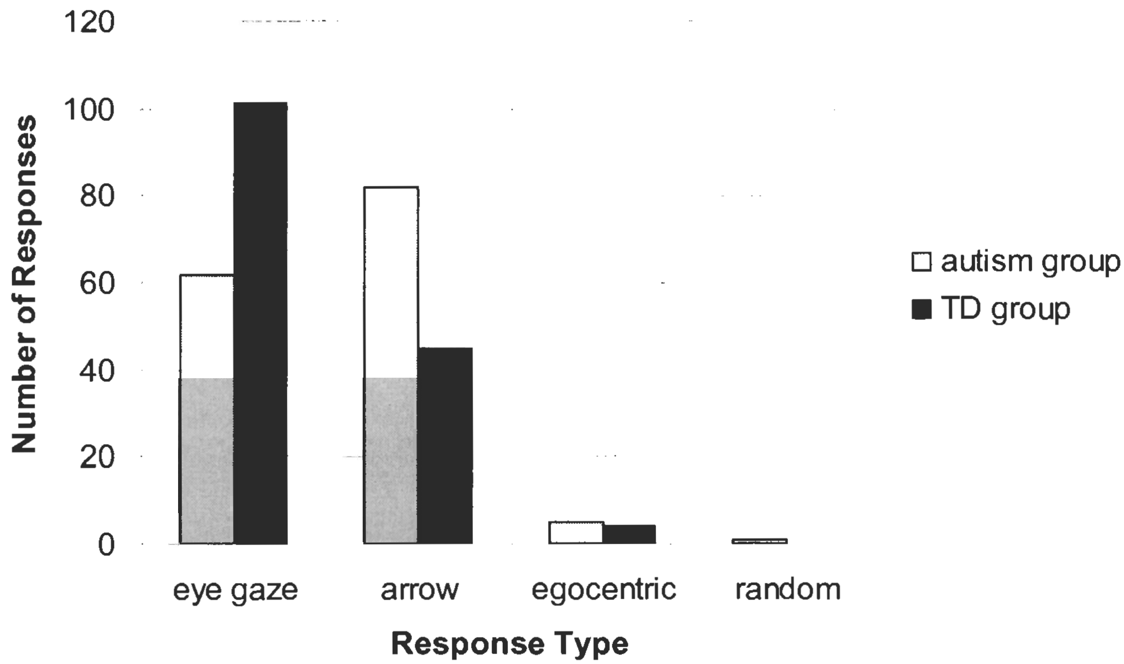
	Experimenter's Gaze Direction		
	Left	**Behind**	**Right**
Autism			
Mean	7.27	10.16	6.17
SD	7.13	8.37	6.34
TD			
Mean	5.48	11.05	5.54
SD	6.42	8.29	6.76

Leekam and colleagues' (1997) pass or fail scoring criteria was used to search for group differences in performance on the social gaze following task. A child was scored as passing a trial if they followed the experimenter's head and gaze direction within the six second duration of the trial. Participants were then scored as passing the task if they monitored gaze on at least two of the three trials (see Scaif & Bruner,1975; Morisette, Ricard, & Decarie, 1995; Moore & Corkum, 1994). This scoring criteria was applied to the present data. Results from an independent samples t-test revealed no group differences on the social gaze following task, $t(48)$ -.62, p = .54. Participants with autism were not less likely to fail at following gaze than TD participants.

Task 3. Inferring Social Meaning from Directional Gaze

Mean comparisons of response types between groups were examined using independent samples *t* -tests. For the autism group, the mean score on the inferring social meaning task was 2.48 (SD = 2.96) compared to TD comparison's mean score of 4.04 (*SD* = 2.59). Children with autism selected items indicated by eye gaze cues less frequently than their TD counter-parts, $t(48) = -1.98$, p = 0.053. Children with autism were more likely than TD children to select items indicated by arrow cues, $t(48) = 1.94$, p = .058. Figure 9 depicts frequencies of response types for the autism and comparison groups. Each group gave a total of 150 responses.

Figure 9: Frequencies of Response Types for Participants in the Autism and TD group in the Inferring Social Meaning from Directional Gaze Task.



In order to justify the consolidation of the three conditions into a unitary score, potential responding differences between conditions were examined. A between subjects repeated measures ANOVA revealed that there was no significant main effect for condition, $F(2, 96) = .594$, $p = .496$. The *p* value was adjusted using the Greenhouse-Geisser technique in order to account for violation of the sphericity assumption. Additionally, Pearson's correlation coefficients reveal a significant and high level of positive correlation between conditions for all participants (see Table 5). A significant between subjects main effect for group was found, suggesting that children with autism performed significantly worse than TD children in all conditions, $F(1, 48) = 3.93$, $p = .053$. A medium effect size confirms that the marginal significance of this effect reflects real group differences, $d = -.56$.

Table 5: Correlation matrix of scores for all participants (high functioning autism and typically developing) in the three conditions of the Inferring Social Meaning from Directional Gaze Task.

	1	2	3
1. Desire condition	--	*r* = .89** *p* = .000	*r* = .88** *p* = .000
2. Intention condition		--	*r* = .97** *p* = .000
3. Reference condition			--

** $p < .001$ (2-tailed)

Task 4. Following Line of Sight

In accordance with the prediction that line of sight following abilities would be intact in children with autism, no significant mean differences in overall line of sight following accuracy were found between groups $t(48) = -1.84$, $p = .07$. Overall accuracy scores for the autism group ranged from 76% to 100% with a mean of 92% (*SD* = 6.5%). For the TD group, overall accuracy scores ranged from 77% to 100% with a mean of 95% (SD = 4.9%). Mean performance accuracy on the line of sight following task for each trial by group are listed in Table 6. A between group repeated measures ANOVA was conducted in order to examine whether number of choice items or movement of the gaze cue affected line of sight following performance of children with autism. A significant main effect for group was found, indicating that children with autism performed differently than TD children on this task $F(1, 48) = 6.61$, $p < .01$. An interaction between group and number of objects suggests that the performance of children with autism significantly decreased as the number of objects increased relative to TD comparisons $F(2, 96) = 3.99$, $p = .03$. A 2 x 3 within subjects ANOVA for the autism group with cue movement and number of objects present on the screen as factors revealed a significant main effect for object $F(2, 48) = 29.64$, $p <= .001$ but not for movement, $F(1, 24) = .023$, $p = .881$. An interaction between movement and number of object approached significance $F(2, 48) = 3.01$, $p = .059$. Post hoc mean comparisons revealed that the accuracy of the group of children with autism was significantly lower than that of the TD comparisons when eight objects with a stationary gaze cue were presented $t(48) = -2.36$, $p = .02$, and when eight objects with a moving gaze cue were presented, $t(48) = -2.07$, $p = .04$. The significance finding disappeared with a Bonferroni correction.

Table 6: Mean percentage accuracy and Standard Error (SE) for participants with Autism and Typically Developing (TD) controls on the Line of Sight Task.

	Stationary Cue			Moving Cue		
	2 objects	4 objects	8 objects	2 objects	4 objects	8 objects
Autism						
Mean %	98.7	98.6	73.7	98.7	93.2	80.0
SE %	1.3	0.9	3.9	1.3	4.8	4.0
TD						
Mean %	100	98.4	84.1	98.7	99.0	89.4
SE %	0	1.1	2.0	1.3	1.0	2.6

Correlations between Scores on the Various Tasks

It was hypothesized that orienting as measured on the spatial cueing task would be related to social gaze following. Volitional orienting was positively correlated with social gaze following in the autism group ($r = .41$, $p = .04$). Based on guidelines proposed by Cohen (1988), the correlation is moderate in magnitude. This finding indicates that children with autism who had higher volitional orienting scores were likely to take longer to follow the experimenter's gaze. There was no significant correlation between volitional orienting and social gaze following in the TD comparison group ($r = .31$, $p = .12$).

The correlation between the reflexive cue effect and the volitional cue effect was not significant in the autism group (*r* = -.35, *p* = .086). In the comparison group, the correlation between tendency to reflexively orient to gaze and tendency to volitionally orient to gaze was large and negative (*r* = -.732, *p* < .001). This may indicate that for TD participants, reflexive and volitional orienting to gaze are related.

Contrary to the hypothesis that orienting to gaze would be related to the children with autism's social use of gaze, neither reflexive orienting (*r* = .285, *p* = 168) nor volitional orienting (*r* = -.294, *p* = .153) correlated significantly with the ability to infer social meaning from eye-gaze in the autism group. In accordance with predictions, line of sight following ability was not significantly correlated with any other gaze measure in the autism group. Tables 7 and 8 depict correlation matrices for all measures for each group.

Table 7: Correlation matrix of all measures for the autism group.

	Non-Verbal Ability	**Reflexive Cue Effect**	**Volitional Cue Effect**	**Social Gaze Following**	**Inferring Social Meaning from Gaze**	**Ability to Follow Line of Sight**
Non-Verbal Ability	--	*r* = -.23 *p* = .28	*r* = -.10 *p*= .62	*r* =.18 *p* = .38	*r* = .21 *p* = .33	*r* = .26 *p* = .21
Reflexive Cue Effect		--	*r* = -.35 *p* = .09	*r* = -.30 *p* = .16	*r* = .29 *p* = .17	*r* = .15 *p* = .47
Volitional Cue Effect			--	*r* = .41* *p* = .04	*r* = -.29 *p* = .15	*r* = -.16 *p* = .44
Social Gaze Following				--	*r* = -.37 *p* = .07	*r* = -.07 *p* = .74
Inferring Social Meaning from Gaze					--	*r* = .18 *p* = .38
Ability to Follow Line of Sight						--

* $p < 0.05$ level (2-tailed)

Table 8: Correlation matrix of all measures for the TD comparison group.

	Non-Verbal Ability	Reflexive Cue Effect	Volitional Cue Effect	Social Gaze Following	Inferring Social Meaning from Gaze	Ability to Follow Line of Sight
Non-Verbal Ability	--	*r* = .01 *p* = .98	*r* = .03 *p* = .99	*r* = .36 *p* = .07	*r* = .13 *p* = .54	*r* = .57** *p* = .00
Reflexive Cue Effect		--	*r* = -.73** *p* = .00	*r* = .03 *p* = .90	*r* = -.11 *p* = .59	*r* = -.26 *p* = .21
Volitional Cue Effect			--	*r* = -.02 *p* = .93	*r* = .32 *p* = .12	*r* = -.09 *p* = .55
Social Gaze Following				--	*r* = .13 *p* = .54	*r* = .09 *p* = .66
Inferring Social Meaning from Gaze					--	*r* = .13 *p* = .53
Ability to Follow Line of Sight						--

** $p < .01$ (2-tailed)

DISCUSSION

Orienting of Attention in Response to Eye-Gaze

Results from the spatial cueing task support previous findings that individuals with autism show a lack of automaticity in orienting to gaze cues (Ristic et al., 2005; Johnson et al., 2005). Unlike their mental age matched TD peers, children with autism did not demonstrate a reflexive orienting of attention response to gaze cues. In particular, in the non-predictive condition at the 195ms SOA, children with autism were not faster at responding to validly cued targets over invalidly cued targets. The validity of gaze cues did not appear to impact their performance, suggesting that children with autism ignored gaze cues in the non-predictive condition. In contrast, children in the TD group were unable to ignore gaze cues even when cue did not aid task performance and when explicitly instructed to ignore the eyes. At the 195ms SOA in the non-predictive condition, responses on valid trials were significantly faster than responses on invalid trials for the comparison group. In short, TD children exhibited a reflexive orienting response to gaze cues while children with autism did not. The performance of children with autism in the predictive condition suggested that they oriented quickly in response to gaze. However, orienting occurred when explicit instructions to attend to eyes were given and when gaze cues had a high probability of being valid. Therefore, orienting to gaze in this condition was deliberate or volitional.

Conflicting reports of reflexive orienting triggered by gaze cues in children with autism are found in the experimental literature. While two recent papers have documented absent reflexive orienting to gaze cues in individuals with autism (Ristic et al., 2005; Johnson et al., 2005), several authors have reported intact reflexive orienting to gaze cues (Senju, Tojo, Dairoku, & Hasagawa, 2004; Vlamings, Stauder, van Son, & Mottron, 2005; Chawarska, Klin, & Volkmar, 2003; Kylliäinen & Hietanen, 2004). Chawarska, Klin, & Volkmar (2003) studied overt orienting triggered by moving gaze cues in 2-year-old children with autism. They found that children with autism automatically shifted their eyes in the direction of another's gaze. However, movement alone has been demonstrated to trigger reflexive orienting (Farroni, Johnson, Brockbank & Simion, 2000), confounding Chawarska and colleagues' results. Similarly, in the Vlamings, Stauder, van Son, & Mottron (2005) study, gaze cues appeared to move. Kylliäinen & Hietanen (2004) and Senju et al. (2004) accounted for a potential movement confound and presented static gaze cues to school-aged children. Both research groups found that participants with autism reflexively shifted their covert visual attention in response to gaze cues. However, Senju et al. (2004) reported that, unlike TD participants, children with autism shifted attention equivalently regardless of whether the directional cue was gaze or an arrow. Senju and his colleagues concluded that children with autism fail to demonstrate preferential sensitivity to social cues such as gaze.

The present study differs from the Kylliäinen and Hietanen (2004) and Senju et al. (2004) studies in two important ways. First, previous studies did not have a predictive condition. Therefore, researchers were not able to compare orienting responses between a reflexive and voluntary orienting condition. Second, in most previous studies, the gaze cues consisted of photo-realistic faces that disappeared when the target appeared. The target and gaze cue were not presented simultaneously in order to eliminate attentional demands associated with disengagement from a central stimulus which is a reported area of difficulty for children with autism (Pascualvaca, Fantie, Papageorgiou, & Mirsky, 1998; Wainright-Sharp & Bryson, 1993). In the present study, the gaze cue remained present on the screen when the target appeared. Children with autism in the present study were not significantly slower to detect the target in either the non-predictive or predictive condition. It is therefore unlikely that children with autism had difficulty disengaging from the gaze cue. Thus, the present study offers another piece of compelling evidence that suggests that children with autism do not reflexively shift attention in response to gaze cues. Another possibility for the discrepant findings is that participant characteristics differed between research groups. For example, Senju et al. (2004) did not pair children with autism with mental age matched TD comparisons. Closer examination of participant characteristics and identification of possible subgroups may be fruitful in future studies.

Social Gaze Following

Findings of diminished sensitivity to gaze at a basic attentional level are congruent with reports of children with autism's difficulty using another's gaze to spontaneously search for important environmental stimuli during social interactions. Lack of reflexive orienting to gaze would likely impact the social development of children with autism. For example, lower frequency of looking at eyes may result in limited opportunities to acquire knowledge about the predictive value and social meaning of gaze (Klin et al., 2002). The present study examined whether poor reflexive orienting to gaze in children with autism was associated with poor social understanding and use of gaze cues. The findings indicated that, contrary to predictions, diminished reflexive orienting to gaze was not associated with delayed gaze following in children with autism. Although children with autism as a group demonstrated a lack of reflexive orienting to gaze, this difference was not evident when their individualized reflexive cueing scores were compared with those of TD children. It is unclear why reflexive orienting to gaze was not associated with social gaze following in children with autism. It may be that these two skill sets are unrelated. Alternatively, it is possible that our measures did not adequately capture reflexive orienting and/or social gaze following behaviours. There was considerable variation in reflexive orienting scores. However, the overall pattern of scores is similar to Ristic et al.'s (2005) findings. Further, a moderate correlation between children with autism's volitional cueing scores and spontaneous social gaze following was found. This correlation suggests that the spatial cueing task may have been an effective measure of orienting behaviour. Specifically, children with autism who had higher volitional orienting scores took longer to follow the experimenter's gaze. The association between children with autism's elevated volitional cueing scores and delayed or absent spontaneous social gaze following suggests that basic orienting mechanisms may be associated with spontaneous social gaze monitoring even in late childhood.

Children with autism were not delayed in their spontaneous social gaze following relative to their MA matched TD peers. This finding was unexpected considering the previous research that found deficits in spontaneous social gaze monitoring in individuals with autism (e.g. Dawson, Meltsoff, & Osterling, 1998; Leekam et al., 2000). A qualitative examination of videotaped interactions provided some clarification of the unexpected findings. Videotapes and anecdotal evidence from experimenters revealed that TD children were frequently suspicious of the experimenter's head-turning, and suspected that the experimenter was trying to "trick them" by switching the cups as they looked away. Some TD children reported consciously resisting following gaze and head direction. Many TD children asked the experimenter, "What were you looking at?" once the task was over. These children were aware of the experimenter's head and eye movements but suppressed gaze-following in order to succeed at the 'cup-game'. Leekam and colleagues (1997) noted a similar finding with TD children and suggested that the tendency to spontaneously monitor gaze may become socially inhibited as children grow older. In contrast with TD children, participants with autism were frequently unaware that the experimenter had averted her attention until many seconds had elapsed. Experimenters commented that they did not feel awkward when they "stared" at the wall when working with the children with autism because these children were not attending to them. It is therefore possible that the social gaze following task may not have been a good measure of spontaneous gaze following for TD comparisons. This would explain the finding of an association between orienting and spontaneous social gaze following for the autism group but not for the TD group.

Results from the social gaze following task indicated that participants in both experimental groups were slower to follow experimenter gaze when it was directed behind them. The ability to follow gaze outside of one's visual field is a skill that develops in early childhood. Infants are able to monitor gaze to their right and left but have difficulty following gaze to locations behind them (Butterworth & Cochran, 1980; Butterworth & Jarrett, 1991). Leekam and colleagues (1997) found that developmentally delayed children in their sample did not demonstrate difficulty following gaze to a behind location. However, TD comparisons were less likely to follow gaze directed behind them. Leekam et al., (1997) postulated that social inhibition may have caused TD children to constrain their gross motor movements and refrain from glancing behind. In the present study, both TD controls and children with autism were less likely to follow gaze directed behind them. It is possible that two distinct mechanisms underlie behaviour in each group. Children with autism may have been delayed in following gaze because they were unaware or uninterested. In contrast, TD children may not have followed gaze to a behind location they were socially inhibited.

Inferring Social Meaning from Directional Gaze

Since consistent monitoring of gaze promotes learning that gaze can be informative of another's mental state (Lee, Eskritt, Symons, & Muir, 1998; Baron-Cohen, Campbell, Karmiloff-Smith, & Grant, 1995), it was postulated that lack of reflexive orienting to gaze and / or spontaneous social gaze following in children with autism would be associated with diminished social understanding of gaze. Results did not support this hypothesis. No significant correlations between individual performance on the computer task or and the social understanding of gaze task were found. However, findings indicated that children with autism were impaired in their ability to infer social meaning from gaze. Compared with TD children, participants with autism were less likely to follow eyes when questioned about a cartoon character's desires, intentions, and references. In contrast, children with autism were most likely to follow an arrow when inferring mental state. These findings suggest that children with autism did not understand that eyes can be used to infer social meaning to the same extent as TD children, demonstrating a lack of social understanding of gaze. Unlike TD children, participants with autism did not interpret averted gaze as an ostensive act that signalled a mental state. Children with autism appeared to find the arrow more salient than the eye-gaze cue. Preferences for non-social stimuli have been well documented in the literature and may represent a pervasive bias for individuals with autism (Klin, Jones, & Schultz, 2005).

It remains unclear why no correlation was found between impaired ability to understand the social meaning of gaze and orienting findings or spontaneous gaze monitoring. Methods of assessing either skill set may have been flawed. Alternatively, skill sets required for task completion are likely diverse. The ontogeny of social understanding of gaze is a complex process reliant upon perceptual, attentional, social, and cognitive factors (Charwarska, Klin, & Volkmarm 2003). Mentalistic gaze following, therefore, may not correlate with other simpler gaze following tasks such as spontaneous gaze monitoring or orienting to gaze. Klin et al. (2002) found that the amount of time individuals with autism spent focusing on eyes was unrelated to other measures of social competence. Klin and colleagues concluded that attending to eyes does not result in improved understanding of social situations for individuals with autism. This interpretation may explain the lack of correlation between orienting, gaze monitoring, and social understanding of gaze in the present study.

Following Line of Sight

Previous findings indicate that children with autism have intact geometric sight tracking abilities (Leekam et al., 1997). Initial findings from the present study suggest that children with autism performed equivalently to TD comparisons, implying that impaired spatial perception of gaze likely did not impair performance on other gaze tasks. However, further analyses revealed that children with autism were less accurate at following line of sight when there were multiple distracting objects on the screen. A non-significant trend suggested that, additionally, children with autism may have difficulty following line of sight when gaze cues are presented for only three seconds amongst eight objects on the screen. Children with autism's difficulty following line of sight as task demands increase (i.e. time constraints and numerous potential targets are introduced) may relate to their lack of reflexive orienting to gaze. Since effortful re-direction of attention requires cognitive resources (Jonides, 1981), increased task demands that deplete attentional resources will likely lead to reduced response accuracy. Because TD children appear to process gaze direction effortlessly, increased task demands should not impair performance. In short, time limited gaze or number of objects in the visual field may differentially affect the performance of children with autism because these children are less inclined to automaticly orient to the gaze-at location (Schuller & Rossion, 2001). Clinical observations are consistent with this interpretation. For instance, children with autism in educational settings have a decreased ability to focus on socially meaningful stimuli when in object-rich environments (Olley & Reeve, 1997).

Correlations between Scores on the Various Tasks

There were no significant correlations between performances on the various tasks for the TD children. This was contrary to expectations. The social orienting task was likely an ineffective measure for this group, perhaps reflecting levels of social inhibition rather than spontaneous gaze monitoring. It is possible that tested skills sets may have been related early in typical development but were no longer associated in our older sample thereby limiting the ability to detect correlations. For instance, typically developing children make less eye contact as they age (Arnold, Semple, & Beale, 2000), implying that diminished social referencing and gaze following is likely not associated with social impairment in older children.

Limitations

A number of methodological problems limit the interpretability of findings from the present study. In the spatial cueing task, a small number of data points were used to derive individual means. Specifically, individual means for valid and invalid trials at the 195 SOA in the non-predictive condition were based upon fourteen data points. Individual means at the 195 SOA in the predictive condition were based upon six data points for invalid trials and twenty-two data points for valid trials. Low numbers of trials may have caused unstable individual means that were subject to undue influence by performance on a given trial. The large range of reflexive and volitional cueing scores may reflect this instability, perhaps affecting the interpretability of individual scores. Generally, however, the spatial cueing task appears to have accurately captured orienting behaviour. The overall pattern of means for each group resembles findings from previous orienting studies (e.g. Ristic et al., 2005; Ristic, Friesen, & Kingstone, 2002). Additionally, standard error rates for group means do not appear to differ dramatically from those reported in other orienting studies conducted on children with autism (e.g. Kylliäinen & Hietanen 2004; Senju, Tojo, Diaroku, & Hasegawa, 2004; Vlamings, Stauder, van Son & Mottron, 2005). However, individualized orienting scores remain subject to scrutiny. Trial numbers for the present study were based upon Ristic, Friesen, & Kingstone's (2002) work with children and were selected because they were deemed developmentally appropriate. When working with developmentally delayed child populations, participant's limited ability to sustain attention unfortunately prohibits administration of a great number of trials. In future studies where participant characteristics prohibit administration of more trials, efforts should be made to ensure that participants are accurately completing the task. For instance, use of eye-tracking equipment would provide a means of ensuring that participants are attending to all trials.

The social gaze following task is subject to similar methodological criticisms. Mean scores were based upon performance over three trials. Leekam et al.'s (1997) original pass/fail scoring was modified in order to derive a continuous score which reflected tendency to spontaneously follow gaze. However, the manner in which continuous scores were derived introduced the possibility that a single trial would greatly influence an overall orienting score. Experimenter gaze was maintained for twenty seconds and failure to follow gaze on a trial was scored with a twenty. The twenty second time limit was arbitrary but meant that failure to follow gaze on one trial could result in a high overall score. Leekam et al., (1997) noted that even TD children do not spontaneously monitor gaze on every occasion. Therefore, normal variation in gaze following behaviour may have caused scores to be artificially high, limiting their overall interpretability. Indeed, the social gaze following task failed to differentiate between TD comparisons and participants with autism. In future studies, a greater number of trials and gaze cues of decreased duration should be used to measure social gaze-following. The validity of the social gaze following task is also questionable. As previously noted, social inhibition may have confounded results, especially for the TD children. Additionally, experimenters turned their heads as they averted their eyes, causing our measure to reflect more than gaze following alone.

Implications and Future Directions

The findings confirm a lack of reflexive orienting to schematic gaze cues in children with high functioning autism (HFA). For children with HFA, greater volitional cueing effects were associated with reduced or delayed spontaneous gaze monitoring. The association was robust despite high variation due to measurement issues. This finding has two major implications. The first is that atypical orienting of attention in autism may contribute to a core symptom of the disorder (i.e. reduced spontaneous gaze following). Emerging studies link basic cognitive differences with deficits in complex social behaviour in autism (e.g. Klin et al., 2002). Rudimentary attentional differences may be key to understanding how children with autism often fail to acquire fundamental skills that may derail early social development. The second major implication from the current study is that performance on computer based attention tasks can be used to assess attentional abnormalities in response to eye-gaze cues in children with autism. Orienting to gaze may predict level of social impairment in children with autism. The degree to which orienting to gaze is reflexive appears to vary between individuals. In future, orienting responses may be used to predict spontaneous social gaze following on an idiographic basis and identify targets for individually tailored intervention programs that would promote gaze following.

Findings of the current study suggest that children with autism have difficulty using directional gaze to understand mental states in a relatively simple, non-timed task. This finding underscores the significance of children with autism's impairment in understanding the social meaning of eyes. Reflexive or volitional attending to eyes was not associated with improved social understanding for individuals with autism. Eyes may simply be uninformative for older children with autism, regardless of their attentional pull. For adults with autism, social competence appears to be enhanced by attention to mouths instead of eyes (Klin et al., 2002), suggesting that individuals with the disorder develop alternative social strategies.

Unexpectedly, findings indicated that children with autism may have difficulty accurately following line of sight when task demands increase to resemble more naturalistic social situations. Gaze following in children with autism may be more susceptible to disruption from task demands; a possibility that should be explored in future studies.

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