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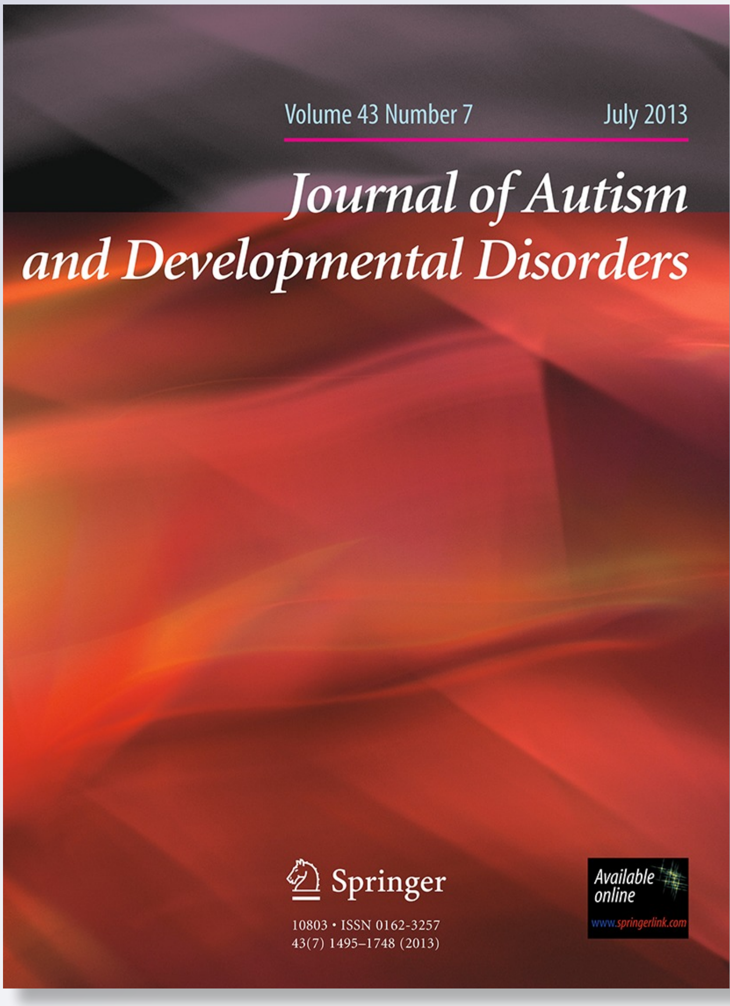

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ORIGINAL PAPER

Orienting in Response to Gaze and the Social Use of Gaze among Children with Autism Spectrum Disorder

Adrienne Rombough · Grace Iarocci

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Abstract Potential relations between gaze cueing, social use of gaze, and ability to follow line of sight were examined in children with autism and typically developing peers. Children with autism (mean age = 10 years) demonstrated intact gaze cueing. However, they preferred to follow arrows instead of eyes to infer mental state, and showed decreased accuracy in following line of sight when several visual distracters were present. Performance across tasks was not correlated for either group. Findings suggest that children with autism are less inclined to prioritize and select eyes, particularly in visually-rich environments. Gaze-following deficits may lie at the level of selective attention, rather than cueing—a possibility that can be explored with more complex and ecologically valid tasks.

Keywords Autism · Gaze-cueing · Social attention

Introduction

Difficulties with social attention may be among the earliest, most salient, and specific features of autism (Mundy 1995; Swettenham et al. 1998; Zwaigenbaum et al. 2005). Gaze-following in naturalistic situations is particularly challenging for persons with autism (e.g. Baron-Cohen et al. 1995; Dawson et al. 1998). The question arises as to whether difficulties with gaze-following reflect atypicalities in the attention orienting system that is responsible for redirecting attentional resources or whether atypicalities lie in other attentional or non-attentional domains.

The most common technique for assessing attention orienting is the spatial-cueing paradigm in which the location of a subsequent target is cued in advance (Posner 1980). Observers use symbolic (e.g. arrow) or direct cues (e.g. flash of light) to shift their attention to a location designated by the cues. As a result of the attention shift, responses are typically faster and more accurate to the targets that occur at the validly cued (expected) locations as compared to targets that occur at the invalidly cued (unexpected) locations. Spatial-cueing paradigms have been adapted to assess gaze-following. In a typical gaze cueing experiment, a trial will begin with the appearance of a face with blank or closed eyes instead of a fixation cross. The pupils then appear looking to the right or left after one of several possible delays (also called stimulus onset asynchronies: SOAs) in order to track the time course of reflexive and volitional orienting. Using this technique, eye gaze has been found to elicit automatic orienting that appears reflexive in typically developing (TD) children and adults; most people gaze-follow automatically (e.g. Driver et al. 1999; Friesen and Kingstone 1998; 2003; Friesen et al. 2005; Langton and Bruce 1999).

Posner-like gaze-cueing tasks have also been used to measure orienting in individuals with autism spectrum disorders (ASD) with the aim of identifying potential orienting disturbances associated with real-world gaze-following impairments. Findings are mixed: whereas the majority of studies have found intact gaze-cueing effects in ASD (Chawarska et al. 2003; DeJong et al. 2008; Kuhn et al. 2010; Kylliäinen and Hietanen 2004; Okada et al. 2003; Rutherford and Krysko 2008; Swettenham et al. 2003; Uono et al. 2009), a handful of studies have reported diminished gaze-cueing (Goldberg et al. 2008; Johnson

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et al. 2005, Ristic et al. 2005). Still other studies report subtle group differences that are evident under more stringent experimental conditions (counter-predictive) and when eyes are contrasted with arrow cues (Senju et al. 2004; Vlamings et al. 2005). Reduced gaze-following is also found among TD adults who rate themselves as high on autistic traits (Bayliss et al. 2005).

Other types of static gaze tasks have revealed atypicalities in important higher-order gaze-following skills in ASD. For instance, children with autism are less likely to follow gaze cues in order to infer mental states (Ames and Jarrold 2007; Baron-Cohen et al. 1997; Baron-Cohen et al. 1995; Preissler and Carey 2005). Links between gaze-cueing performance and the ability to use eye gaze information to interpret others' desire, intention and reference have yet to be explored. Evidence from typical development suggests that gaze-following within the first few months is fundamental to the later ability to understand the social meaning of gaze (see D'Entremont et al. 2007 for a developmental review). Poulin-Dubois et al. (2007) argue that an infant's understanding of gaze develops from a low-level and perceptually based system to a higher-level and inferential system. Theoretically, gaze-cueing and social inferencing from gaze are related skills. Thus, a few questions remain: (1) do orienting atypicalities underlie gaze-following deficits in ASD? (2) Is the spatial-cueing task sensitive to these deficits (see Birmingham et al. 2012)? And (3) is gaze-cueing performance related to other gaze skills in later childhood?

The current study addresses the question of whether low level attentional responses to gaze cues are related to the higher-order social use of gaze among children with ASD as measured with commonly used laboratory paradigms. We first explored inconsistencies in previous gaze-cueing findings by examining performance on a spatial cueing task. Similar to Ristic et al. (2005), we compared performance on a non-predictive gaze-cueing task (where there was no incentive to follow gaze) with performance on a predictive task (where strategic following of gaze would improve task performance). For this first task, accurate task performance required several lower level gaze skills including: selection of the cue, tracking of line of sight to the left or right, and shifting of attention. Based on previous findings, we predicted diminished gaze-cueing on the non-predictive task for children with ASD. We subsequently assessed the children's ability to understand that gaze direction can be informative of the mental states of others using a modified version of Baron-Cohen et al. (1995) 'four sweets task'. Children were shown a schematic face with averted gaze and required to answer questions about the face's desires, intentions, and referents. For this second task, accurate task performance required lower level gaze skills (selection, tracking, orienting) plus some higher level inferencing regarding mental state. Based on previous findings (Ames and Jarrold 2007; Baron-Cohen et al. 1995), we predicted that children with autism would show no preference for eyes over arrow cues to infer mental states. Finally, since these disparate gaze skills are theoretically linked in infancy, we predicted a significant positive correlation between performance on the gaze-cueing task and social use of gaze older children. We reasoned that orienting attention to gaze much like other aspects of selective attention would improve with age and would be related to the social use of gaze, in 10-years olds.

To ensure that potential difficulties with spatial perception of gaze did not confound results, we also assessed the ability to accurately follow line of sight using computer software designed by Tanaka and Lo (2001) (see Tanaka et al. 2003 for a description of the program). For this final task, accurate task performance required tracking line of sight geometrically for both static and changing gaze cues. Based upon previous findings of intact abilities (Leekam et al. 1997), we hypothesized that the ability to follow line of sight would be comparable in the group of children with autism and the matched group of TD children.

Methods

Participants

Two groups of children participated: 25 children with autism and 25 TD children. Ethical approval for this project was granted by Simon Fraser University's ethics review board. Children with ASD who were high functioning (defined as a verbal and non-verbal IQ in the average or above average range) were chosen to participate in the study. Children with ASD had a mean chronological age (CA) of 10.44 years with a maximum of 13.06 and a minimum of 6.04. Comparison children had a mean CA of 9.54 years with a maximum of 14.09 and a minimum of 4.08. Individual matching on the basis of non-verbal mental age (NVMA) within a 12 month range was used to pair each child with ASD with a TD peer. NVMA was selected as a basis for matching because experimental tasks were primarily non-verbal in nature. The groups did not differ significantly on NVMA, $U = 275.50$, exact $p = .65$ (two-tailed), or verbal mental age (VMA), $U = 275.50$, exact $p = .49$ (two-tailed). NVMA was measured using the Raven's Coloured Progressive Matrices (Raven et al. 1998a) and Raven's Standard Progressive Matrices (Raven et al. 1998b). Nonverbal mental age ranged from 5.66 to 16.50 years for the ASD group and 4.83–16.00 years for the TD group. Verbal mental age (VMA) was assessed using the Peabody Picture Vocabulary Test (PPVT-III) (Dunn and Dunn 1997) and ranged from 6.08 to

Table 1 Means and standard deviations for chronological age, verbal and nonverbal mental ages (all in years), and gender ratios for children in the ASD and typically developing groups

	Autism M (SD)	TD M (SD)	U	*p*
N	25	25		
Age (in years)	10.44 (2.22)	9.54 (2.63)		
PPVT-III[a]—Verbal Mental Age	12.88 (5.99)	12.90 (4.26)	275.50	.65
Raven's[b]—Nonverbal Mental Age	11.19 (2.86)	10.94 (34.25)	287.50	.49
Gender (male: female)	5:1	1:1		

[a] Peabody picture vocabulary test, 3rd edition

[b] Raven's coloured progressive matrices and Raven's standard progressive matrices

22.00 years for the ASD group and 6.75–22.00 years for the TD group. All children with ASD had received clinical assessments in the community in accordance with government diagnostic and funding guidelines. In order to confirm clinical diagnoses, parents of the children with ASD were administered an Autism Diagnostic Interview—Revised (Rutter et al. 2008) by the first author who was trained in research administration by developers of the tool at a 2 day training workshop. The descriptive characteristics of the ASD and TD groups are presented in Table 1.

Gaze Cueing Task

Gaze-cueing was measured in two conditions: a predictive gaze condition and a non-predictive gaze condition. In the predictive gaze condition, 80 % of trials were valid (i.e. eyes "looked" at the target) and 20 % where invalid (i.e. eyes "looked" away from target). In the non-predictive condition 50 % of trials were valid and 50 % were invalid. We presented schematic stimuli similar to that used by Ristic et al. (2002) to test gaze-cueing in children. Results from the spatial-cueing task were used to derive a measure of the extent to which individuals oriented spontaneously 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. Children 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 (see 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. 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.

Design and Procedure

All children participated in two experimental conditions: a non-predictive condition and a predictive condition. Within each experimental condition, children completed two blocks of 42 trials (for a total of 84 experimental trials). Prior to experimental trials, children completed 20 practice trials.

A trial began with the appearance of a face with blank eyes for 963 ms (see Fig. 1). Children were instructed to fixate their eyes and their attention on the nose. The pupils then appeared looking to the right or left after a cue-to-target delay or SOA of 195, 600, or 1,005 ms. These SOAs occurred with equal probability within trials and were identical to the SOAs used in a gaze cueing task administered previously to TD children (Ristic et al. 2002). The stimuli remained on the screen until 3,800 ms had elapsed or a response was made by the participant. There was an 808 ms pause 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 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 children were attending to the task. During catch trials, no target appeared following the gaze cue.

Children first completed the non-predictive gaze condition where 50 % of non-catch trials were valid and 50 % were invalid. The non-predictive gaze condition was always completed before the predictive condition so that children would not have to "unlearn" instructions to attend to the eyes. In the non-predictive condition, gaze was not informative of target location and children 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." Children 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, children were warned that there would be trials in which no target would appear (i.e. catch trials) that were designed to

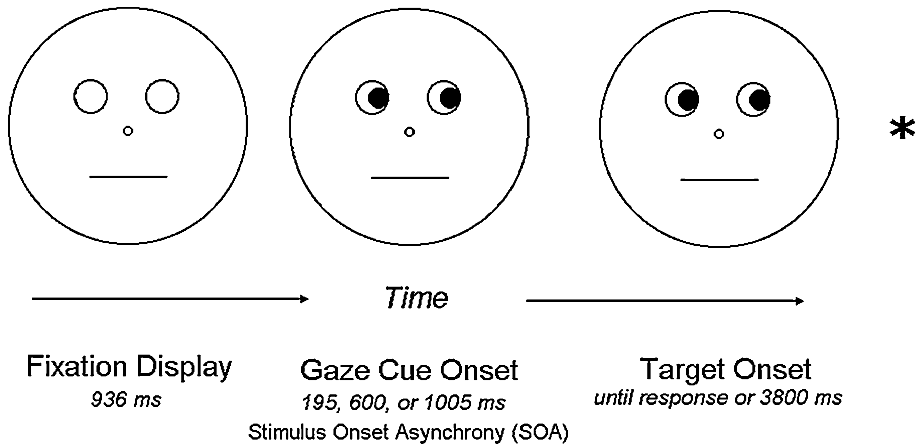

Fig. 1 Stimulus display sequence for the gaze cueing task

ensure that they were accurately attending to the task. Children 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. Target detection RT was measured as the time elapsed between the appearance of the target and the pressing of the spacebar by the children.

At the end of the 1 h experimental session (including breaks) and following the non-predictive gaze task, the social inferencing task, mental age measures, and the line-of-sight following test, children completed the predictive gaze condition. In the predictive condition gaze was, on average, spatially predictive of target location (80 % of non-catch trials were valid and 20 % were invalid). Children were told, "The eyes will be very helpful this time. They will almost always tell you where the star will be. So pay good attention to the eyes, they will give you hints."

Cueing Effect

In order to facilitate comparison of orienting performance with performance on other tasks, measures of orienting to gaze was calculated for each participant. Cueing effects were calculated for each SOA (i.e. difference scores between valid and invalid trial means at 195, 600, and 1005 ms time delays). We selected RTs from the non-predictive condition since we were interested in spontaneous orienting that was not influenced by strategy associated with cue predictability. We then standardized cueing effect score (i.e. transformed them into z scores) in order to control for any differences in basic reaction speed.

Social Inferencing Task

To assess the social use of gaze, we used a modified version of Baron-Cohen et al. (1995) "four sweets task" wherein eyes are presented along with arrows (i.e. "Experiment 3: Are eyes the natural pointer?"). This task was utilized to measure the extent to which children were able to follow eye-gaze rather than a distracter arrow in order to infer mental states such as desire, intention (named "goal" in the original sweets task), and reference. The task was modified to include additional stimuli (i.e. dogs instead of candy only), the presentation of 4 target objects (e.g. candy, dogs, nonsense symbols) instead of 2 in the reference and control conditions, and 2 trials in each condition instead of 3. These changes were made in an attempt to decrease redundancy and maintain participant interest. Further, we included a control condition that required the children to make judgments about relative size (rather than appropriate colors as in the original experiment) while ignoring directional symbols. This modification was made in order to simplify the presentation of stimuli.

Materials

Five laminated white cards with colourful photos in each corner were presented to the children. 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 unfamiliar shapes and another 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 Fig. 2 for an example 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 children. Additionally, all children completed a control condition

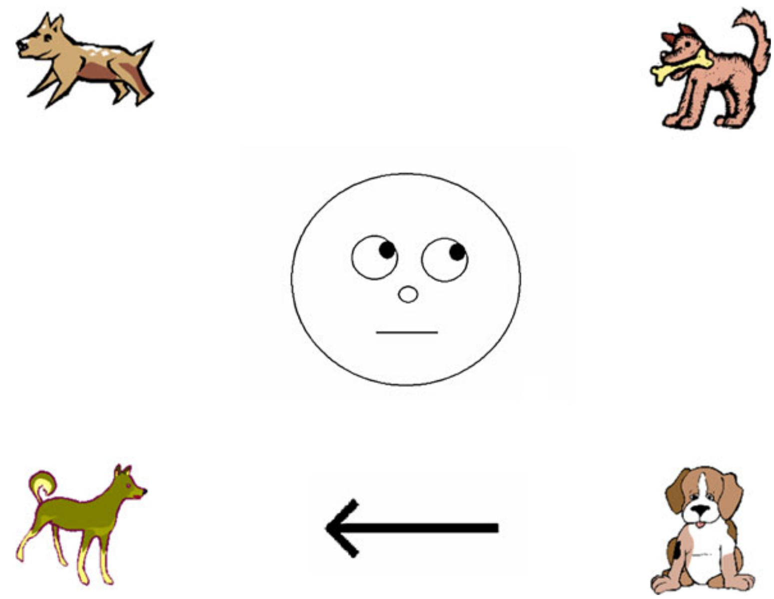

Fig. 2 Example of stimuli used in the social inferencing task to measure social use of gaze

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 Charlie" 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. See Fig. 2 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: "Charlie wants one of these chocolate bars. Which one does Charlie want?" With the dog card, the experimenter said: "Charlie 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 Charlie again. He is going to take a chocolate bar. Which one is he going to take?" or, "Here is Charlie again. He is going to pick a puppy. Which one is he going to take?" Participant selections were noted and scored.

The cards with unfamiliar 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 made up 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, "Charlie says, '*There's* the *beb*!' Which one does Charlie say is the *beb*?" Participant's responses were noted and scored. The trial was repeated using the other shape card with the made up 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 Charlie's eyes were looking, they were deemed to understand the questioning and passed the control task.

Scoring

Children 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), children received a score of either 1 or 0. Scores of 1 denoted that the child correctly selected the photo indicated by gaze direction. Scores of 0 denoted 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 ASD did not appear to understand 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 was small (i.e. 0.0002). Therefore, higher scores on this task were interpreted as reflecting the extent to which children were able to infer mental states from eye-gaze direction cues. For example, a score of 6 indicates that a child used the direction 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.

Line of Sight Following Task

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. We wanted to ensure that children did not have any difficulty with following line of sight that may interfere with their performance on other tasks. Therefore, line of sight following ability was measured using a task from the Let's Face It (LFI) computer program (Tanaka and Lo 2001) to control for potential spatial perception difficulties. Children were presented with a centrally located photorealistic face and asked to identify the "gazed at" object from an assortment of household objects (e.g. dog dish, basketball, ice cream cone).

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" at one of several household objects displayed in a circular configuration around the face. See Fig. 3 for an illustration of the stimuli used in the task. Children received the prompt, "What is this person looking at?" and were required to click the mouse icon on the object of their choice. All children were able to functionally operate the mouse with the exception of 2 young children from the comparison group who indicated their responses by pointing to a target object on a 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. All children 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 potential target objects), the central face maintained static gaze upon an object until the participant made a selection. We refer to these as *Static Gaze Cue* trials. In the final 3 sets of trials, the identity of the photorealistic face and the direction of gaze changed approximately every 3 s. We refer to these as *Changing Gaze Cue* trials. For these Changing Gaze Cue trials, children had to make object selection decisions in a time-limited fashion.

Scoring

Overall percent accuracy for each trial set was calculated by LFI software (Tanaka and Lo 2001) and was used to derive a mean percentage accuracy score for each participant. Only accuracy was reported, reaction time scores were not provided by the software.

Results

Gaze Cueing Task

Mean RTs were calculated for each participant. Prior to statistical analyses, anticipations (RTs < 100 ms) and timed-out trials (RTs > 1,000 ms) were classified as errors and excluded from analyses. These outliers comprised 2.9 % of experimental trials and were not significantly different between groups. 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 % overall) and did not differ significantly between groups, suggesting that most children 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. See Fig. 4 for a graphical representation of cueing results.

Mean RTs were analyzed using a mixed factor repeated measures ANOVA with group (TD vs. ASD) as a between subject factor and condition (predictive vs. non-predictive), cue validity (valid vs. invalid), and SOA (195 ms vs. 600 ms vs. 1,005 ms) as within subject factors. There was a significant main effect of validity $F(1, 48) = 29.15, p < .0001$, showing that overall, valid cues resulted in faster location of the target. There was also a significant main effect for SOA $F(2, 96) = 52.07$, $p < .0001$, reflecting that generally RTs decreased as SOA increased, a common finding on spatial cueing tasks. There were no significant main effects for group or for condition. A significant interaction between condition and validity was found $F(1, 48) = 5.95$, $p = .018$. This interaction indicates that overall, the participants demonstrated faster gaze-following on the predictive condition as compared to the non-predictive condition. No other significant interactions were found. Notably, there was no significant interaction between

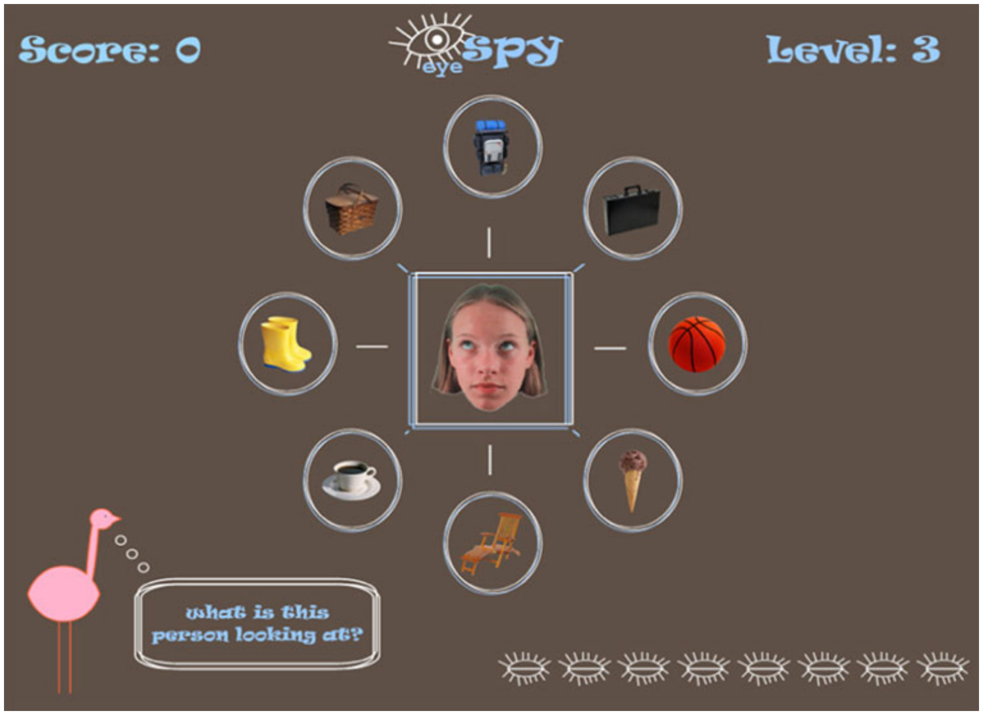

Fig. 3 Example of stimuli used to measure line of sight following. "Let's Face It—Eye Spy" stimuli for a trial set with 8 objects. Note. From "Let's Face It!: a treatment intervention in face processing for children with autism" (Computer Software) by J. W. Tanaka and A. Lo. Copyright 2001 by J. Tanaka, Reprinted with permission

validity and group $F(1, 48) = .663$, $p = .420$ or condition, validity, and group $F(1, 48) = .021$, $p = .885$, suggesting that the children with ASD did not show diminished gaze-cueing compared to TD participants in either the predictive or the non-predictive condition.

Gender ratios were even in the TD group but there were five boys for each girl in the autism group. We explored whether gender influenced cueing task performance (Bayliss et al. 2005) by comparing the performance of the TD males to that of the TD females. No significant differences were found in gaze cueing magnitude between genders in the TD group for either the non-predictive condition, $F(1, 23) = .95$, $p = .34$, or the predictive condition, $F(1, 23) = 2.68$, $p = .12$. Thus, we collapsed the genders into one group.

Social Inferencing Task

Mean comparisons of response types between groups were examined using independent samples t -tests. For the ASD group, the mean score on the inferring social meaning task was 2.48 (SD = 2.96) and for their matched TD peers the mean score was 4.04 ($SD = 2.59$). This difference was statistically significant and children with ASD selected items indicated by eye gaze cues significantly less frequently than their TD peers, $t\ (48) = -1.98$, $p = .05$. Children with ASD followed eyes on 41 % of trials as compared to the TD children who followed eyes on 67 % of trials. Children with ASD were also significantly more likely than TD children to select items indicated by arrow cues, $t\ (48) = 1.94$, $p = .029$ (one-tailed). The ASD group followed arrows on 55 % of trials while the TD group followed arrows on 30 % of trials. Figure 5 depicts the mean percentage of response types for children in the ASD and TD groups.

Line of Sight Following Task

Mean differences in overall line of sight following accuracy between the ASD and TD groups were not significant, $t\ (48) = -1.84$, $p = .07$. Overall accuracy scores for the ASD 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 %).

A between group repeated measures ANOVA with number of target objects (2, 4, or 8) and change of the gaze cue (static, changing) as within subject factors was conducted. A significant main effect for group was found, indicating that children with ASD performed differently than TD children when the number of targets was varied $F(1, 48) = 6.61$, $p = .01$. An interaction between group and number of objects suggests that the performance of children with ASD significantly worsened as the number of

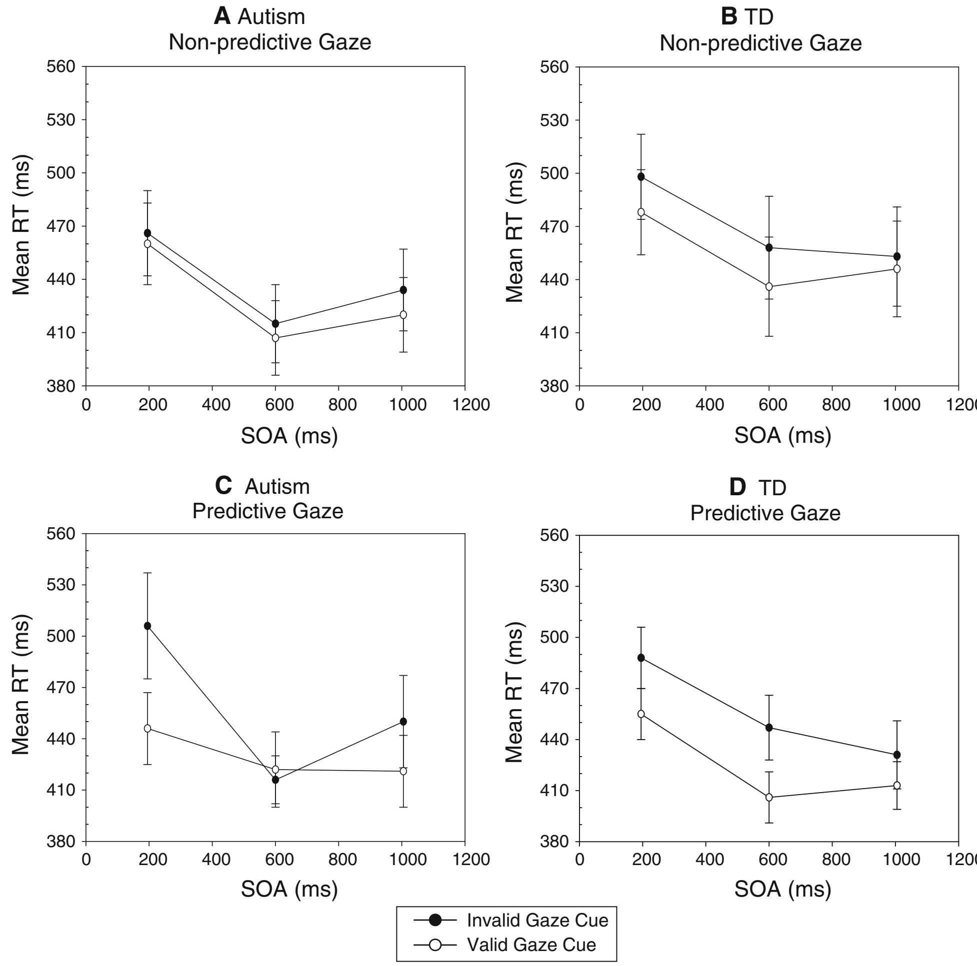

Fig. 4 Gaze cueing task results. Mean reaction times (RT) with standard *error bars* for valid and invalid trials for both groups (ASD and typically developing) in both conditions (non-predictive gaze and predictive gaze) as a function of stimulus onset asynchrony (SOA)

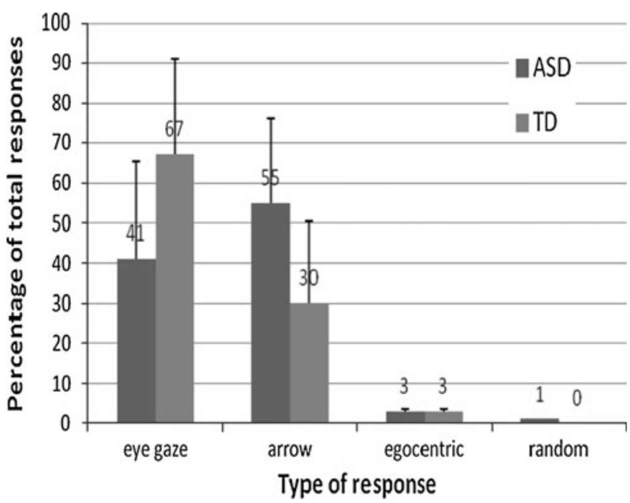

Fig. 5 Social inferencing task results. Mean percentages of responses types with standard *error bars* for children in the ASD and typically developing (TD)

target objects increased relative to their TD matched peers $F(2, 96) = 3.99$, $p = .03$. Post hoc mean comparisons revealed that the accuracy of the group of children with ASD was significantly lower than that of the TD children when eight objects and a stationary gaze cue were presented t (48) = -2.36, $p = .02$, and when eight objects and a moving gaze cue were presented, t (48) = -2.07, $p = .04$. Therefore, the performance of children with ASD compared with that of the TD children decreased when there were 8 potential target objects on screen. Table 2 depicts the mean percentage accuracy for children in each condition of the Line of Sight Following Task.

Correlations Between Scores

We hypothesized that orienting as measured on the gaze cueing task would be related to social gaze following. This hypothesis was not supported by the data. Cueing at the 195, 600, or 1,005 ms SOA was not significantly correlated with social use of gaze scores for either the ASD group or the TD group (please see Table 3). In accordance with predictions, line of sight following ability was not significantly correlated with other gaze measures for the ASD group or the TD group. There were no correlations between nonverbal mental age and any tasks. Verbal mental age was

Table 2 Mean percentage accuracy and standard error (SE) for children with ASD and matched typically developing comparisons on the line of sight task

	Static gaze cue			Changing gaze 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

Table 3 Correlation matrix of task performance for TD and ASD participants—gaze cueing scores from the non-predictive condition

	Gaze cueing (195 ms)	Gaze cueing (600 ms)	Gaze cueing (1005 ms)
TD participants			
Social inferencing	$r = -.11$	$r = .05$	$r = -.05$
	$p = .59$	$p = .81$	$p = .81$
Line of sight following	$r = .26$	$r = -.09$	$r = -.09$
	$p = .21$	$p = .64$	$p = .64$
ASD participants			
Social inferencing	$r = .28$	$r = .12$	$r = .11$
	$p = .17$	$p = .58$	$p = .58$
Line of sight following	$r = .15$	$r = .21$	$r = .21$
	$p = .47$	$p = .30$	$p = .30$

significantly correlated with performance on the LFI task $r = .48$, $p = .02$ for the TD children but not for the children with ASD.

Discussion

Twenty-five children with ASD and 25 TD mental-age matched children completed a gaze-cueing task, a task that assessed social use of gaze, and a task that assessed the ability to follow line of sight. Our aim was to examine potential relations between basic attentional orienting to gaze cues and higher order abilities to use gaze cues to infer social meaning in ASD.

Results from the gaze-cueing task are consistent with the majority of previous studies reporting intact orienting in ASD (Chawarska et al. 2003; DeJong et al. 2008; Kuhn et al. 2010; Kylliäinen and Hietanen 2004; Okada et al. 2003; Rutherford and Krysko 2008; Swettenham et al. 2003; Uono et al. 2009) yet they are inconsistent with findings of reduced orienting (Goldberg et al. 2008; Johnson et al. 2005; Ristic et al. 2005). We suspect that that methodological differences across studies (tasks employed and characteristics of the sample) may account for the mixed findings. In addition, the Posner type cueing tasks may have limited sensitivity to social orienting difficulties observed among children with ASD. Some interesting trends were present in our gaze-cueing data. Visual inspection of the predictive condition in Fig. 4 suggests that children with ASD did not follow gaze at short and long intervals but did follow gaze at medium intervals. This trend mirrors current findings from our lab where we are detecting gaze-following at medium intervals in TD individuals using more realistic visual stimuli. Unfortunately, the trend in the present study was not statistically significant. However, further investigation of sequential patterns of gaze following in ASD, perhaps using more realistic stimuli may be a fruitful avenue of further research.

Results from the social inferencing task indicated that children with ASD were more likely than their TD peers to follow arrows instead of eyes when asked about a cartoon character's mental state. It appears that children with ASD did not respond to the "social meaning" of the eyes and preferred to follow a non-social arrow cue instead. These findings are consistent with Baron-Cohen et al.'s (1995) findings of reduced eye-following and increased arrow-following in 4-year-olds with ASD. Ames and Jarrold (2007) also found reduced gaze and arrow-following to infer desire when the cues were presented separately. Finally, our findings add to evidence from word-learning experiments of reduced gaze-following to infer reference in children with ASD (Baron-Cohen et al. 1997; Preissler and Carey 2005). We did find a higher than expected rate of arrow following in TD children (M = 30 %) as compared to Baron-Cohen and colleagues findings (M = 16.6 %). There are two possible explanations: (1) arrows were interpreted as socially relevant but to a lesser degree than eyes or (2) arrows were particularly visually salient in the current task. In support of the second explanation, Pellicano and Rhodes (2003) found that TD children followed both eyes and arrows in order to infer desires and argued that this was due to the high visual saliency of arrows in their experiment. Overall, findings from the social inferencing task suggest that the children with ASD did not interpret averted gaze as an ostensive act that signals a mental state.

In terms of line-of-sight following, children with ASD performed as well as the TD children on the LFI task when two or four target objects were presented on the screen. However, group differences appeared when the task involved eight objects in the visual array. Although mean accuracy levels were high (i.e. well above chance) for both groups (ASD = 77 %, TD = 87 %), the children with

ASD were less accurate than TD children at following line of sight when there were eight potential target objects. These findings contrast with previous findings of intact line-of-sight following in ASD (Leekam et al. 1997). Potentially, less robust selective attention for faces (e.g. Dalton et al. 2005; Klin et al. 2002; Pelphrey et al. 2002; Riby and Hancock 2008; Spezio et al. 2007; Sterling et al. 2008) influenced the performance of the children with ASD on the LFI task. In particular, increased attentional demands in our task compared to that of Leekam et al. (1997) may have resulted in reduced selection of gaze in the children with ASD but not in the TD children who may select social stimuli effortlessly in visually rich environments (Birmingham and Kingstone 2009). Clinical observations also suggest that children with ASD may have a decreased ability to focus on socially meaningful stimuli when in object-rich environments (Olley and Reeve 1997).

The LFI task served as a control task to ensure that difficulties in spatial perception of gaze did not confound our results (i.e. contribute to group differences on the other two tasks). Although we did find unexpected group differences in line-of-sight following, it is unlikely that these differences affected performance on either the gaze-cueing or social inferencing task because neither task was taxing with regard to tracking targets among distracters. In the gaze cueing task, there were no distracting items on the screen. As well, the children with ASD did not differ overall in mean RTs from the TD children in the gaze cueing task. For the social inferencing task, there were only four potential targets. That being said, the findings of impairments in line-of-sight following in a complex visual array are novel and noteworthy. They indicate that differences in gaze-following in ASD may lie at the level of selection or tracking line of sight rather than orienting.

Contrary to expectations, no significant correlations were found between performance on the gaze-cueing task and performance on social inferencing for either the ASD or the TD groups. Line-of-sight following performance also did not correlate with performance on other tasks. The lack of correlation may be due to one of several possibilities: (1) higher order abilities to use gaze cues to infer social meaning are independent from orienting to gaze and tracking line of sight, or (2) these skills are correlated in the "real world" but our tasks lacked ecological validity.

With regards to the first possibility, lower order (attention orienting) and higher order (understanding mental states from gaze) eye gaze behaviours may represent developmentally proximal yet separate skill sets. Gaze following on the gaze-cueing task likely tapped into lower-level attentional biases. In contrast, a number of skill sets (e.g. perceptual, attentional, social, and cognitive) are involved in understanding the referential nature of gaze (Caron et al. 2002; Chawarska et al. 2003). Slaughter and McConnell (2003) reported no significant relations between gaze-following and other measures of joint attention in TD infants of 8–14 months of age. D'Entremont et al. (2007) also reported minimal or non-significant correlations between gaze following and joint attention in a longitudinal study of 57 infants aged 6–24 months. These authors concluded that gaze following in infancy is a separate and unrelated process from understanding the intentions of others. Similarly, Gliga et al. (2012) found intact gaze following in children with ASD but impaired use of gaze to learn new words. Possibly, the lack of correlation suggests that gaze following reflects lower-level detection and response, whereas using gaze for social learning involves higher level and coordinated reasoning.

The second possibility is that lack of correlation is due to how tasks were designed. We borrowed tasks that have been used to assess gaze-following in ASD in the past but these tasks likely lack ecological validity. Because the tasks are artificial, they likely tap into independent skills sets that would be fluidly connected in real-world social interactions. For instance, the inferencing task differs in at least three specific ways from the orienting task. First, the former task may have invoked processes of attending to, inferring, and interpreting the use of eye gaze whereas the latter hinged on reflexive and volitional processes of attending to eye gaze cues. Second, in the former task the eye gaze was 'functionally' related to the target objects in that it was a useful/adaptive means of deducing desire, inference and reference of the character (represented by the line drawing). However, in the latter, the eye gaze cue was spatially related to the target object or as a result of a probabilistic contingency and the participant had only to orient to, and detect, the target. Third, the former task was not time limited and required a verbal response whereas the latter task was time-limited and required a non-verbal visual detection response. Thus, different processes may have been tapped by each task and reflected in the task performance. Because of these considerations with artificial tasks, we are cautious in extrapolating our findings to real-world gaze-following.

What can we conclude regarding our current findings? The findings are consistent with previous research indicating that individuals with ASD demonstrate intact gaze-cueing when shown an image of a face on a blank background. We can tentatively conclude that children with autism do not have difficulty shifting their attention in response to gaze *once gaze has been selected for them.* Birmingham and Kingstone (2009) argue that the spatial-cueing paradigm pre-selects gaze-cues for viewers (by virtue of being the only stimuli on the screen) and thus the paradigm only measures one component of social attention: orienting, not selection. While children with ASD did not appear to have orienting problems, they may have had difficulties in selecting social stimuli. Our findings do support the notion of problems with selection of eyes. We found that children with ASD had difficulty selecting eye-gaze as an important social cue when there was a competing distracter (i.e. an arrow). In other words, they had trouble understanding that eyes are more socially significant than arrows and are not just directional cues. Results also indicated that children with ASD were not as good as TD children at discriminating gaze-direction in a display with eight possible targets. We theorized that impaired gaze-following within a complex display may have been driven by more effortful selection of gaze in ASD. Both findings point to difficulties with selection of gaze which dovetails with naturalistic observations that children with ASD tend to ignore or avoid looking at eyes (e.g. Osterling and Dawson 1994; Swettenham et al. 1998). Our findings also support the argument by Birmingham et al. (2012) that "the most striking aspect of a social attention abnormality in autism is not how individuals with autism process gaze cues that have already been selected for them, but rather the likelihood that they will seek out and select such information in the first place" (p. 274).

Summary

The impetus behind the current study was to investigate relationships between gaze-cueing and other gaze tasks in children with ASD. We aimed to answer the overarching question of "what are gaze-cueing tasks measuring?" Our findings are consistent with previous research and indicated that children with ASD show intact orienting on the gaze-cueing task (Chawarska et al. 2003; DeJong et al. 2008; Kuhn et al. 2010; Kylliäinen and Hietanen 2004; Okada et al. 2003; Rutherford and Krysko 2008; Swettenham et al. 2003; Uono et al. 2009) and a diminished tendency to use gaze to infer desire, intentions, and reference on the "sweets" task (Ames and Jarrold 2007; Baron-Cohen et al. 1997; Baron-Cohen et al. 1995; Preissler and Carey 2005). A novel finding was reduced ability to geometrically track line-of-sight when there were eight distracter objects. Performance was not correlated across any of the tasks. For children with ASD, gaze-following difficulties emerged only when tasks required selection of the gaze cue over a competing arrow cue or discrimination of gaze located within multiple distracter objects. These findings suggest that children with ASD may be less inclined to prioritize and select eyes as socially meaningful cues, particularly in object rich environments and when another directional cue such as an arrow is present. Because gaze-cueing paradigms "pre-select" gaze, they may not be sensitive to ASD differences in gaze-following. Most previous studies of social attention and gaze following, including the current one, have relied on well-controlled designs with simple stimuli presented within strict parameters. Future research would benefit from the inclusion of complementary sources of information from more ecologically valid designs of everyday visual scenes, in more fast paced and changing conditions with an emphasis on natural viewing preferences and self-generated attentional strategies.

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