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Tracking eye movements proves informative for the study of gaze direction detection in autism

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Abstract

Considerable research effort has been dedicated to exploring how well children with autistic spectrum disorders infer eye gaze direction from the face of an actor. Here we combine task performance (accuracy to correctly label a target item) and eye movement information ('where' the participant fixates when completing the task) to understand more about the components involved in completing eye direction detection tasks. Fifteen participants with autism were significantly less accurate at interpreting eye direction and detecting a target item (array sizes 4 and 6 items) than typically developing participants of comparable nonverbal ability. Eye movement data revealed subtly different fixation patterns for participants with and without autism that might contribute to differences in overall task performance. Although the amount of time spent fixating on the target item did not differ across groups, participants with autism took significantly longer to complete several components of the task and fixate upon the regions of the picture required for task completion (e.g. face or target). The data have implications for the design of tasks for individuals with autism and provide insights into the usefulness of including measures of visual attention in understanding task performance.

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Autism is a neuro-developmental disorder characterized by qualitative impairments of social communication, accompanied by unusual repetitive or stereotyped behaviours (DSM IV, American Psychiatric Association, 1994). One of the earliest behavioural indicators of the disorder is a deficit in the development of joint visual attention; the ability to share attention with other people in a co-ordinated manner (Scaife & Bruner, 1975). Early deficits of joint attention compromise subsequent opportunities for the development of social cognition (Mundy & Burnette, 2005), plausibly contributing to the impaired social skills of individuals with autism. Clifford and Dissanayake (2008) studied home videos of infants later diagnosed with autism, identifying poor quality and timing of eye contact even during the first year of life. Similarly, 2-year–old infants with autism show less frequent joint attention behaviours (Naber et al., 2007). Thus sharing attention and being able to identify the direction of another persons' gaze, is a core problem for individuals with autism. Understanding the underlying mechanisms of such deficits can be particularly valuable in the design of training and intervention programs. The current research emphasises the value of tracking eye movements for revealing components of task performance in domains known to be of difficulty. Here we focus on fixation patterns for participants with and without autism whilst they complete a task requiring gaze direction detection; a skill that plays an important part in the development of joint attention ability and links to understanding the thoughts of others (e.g. Baron-Cohen, 1995).

For successful social communication we must infer communicative signals from the faces of people around us. Understanding that eye direction determines what someone is attending to is central to understanding visual attention. Typically developing individuals' sensitivity to where a person is looking facilitates referential communication. Typically, gaze direction detection gradually emerges during early childhood. Most 3- to 4-year-olds, but not younger children, can identify which of four widely separated objects a viewer is looking at (Masangkay et al., 1974; Doherty & Anderson, 1999). The detection of more fine-grained gaze judgements continues to develop beyond this age. For example, Leekam, Baron-Cohen, Perrett, Milders and Brown (1997) found that only 45% of 4-year-olds passed a fine-grained gaze task. Doherty, Anderson and Howieson (2004), carrying out a similar experiment with a live experimenter, found that only children aged over 6-years made consistently accurate fine-grained gaze judgements when targets were separated by 10 or 15 degrees. In typical development the evidence therefore suggests that explicit judgement of eye-direction is a skill that arises by approximately 3-years of age and continues to gradually improve in precision during early childhood.

Accurate eye gaze judgment appears particularly problematic for individuals with autism (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1993; Gepner, de Gelder, & de Schonen, 1996; Riby, Doherty-Sneddon, & Bruce, 2008b). High-functioning individuals can infer when a person is looking at them (Baron-Cohen, 1995 but see Howard et al., 2000) and identify what a person is looking at in a live situation (Baron-

Cohen, 1989) or a photograph (Leekam et al., 1997). However, this ability is predominantly restricted to individuals with an IQ over 70 (Swettenham, Condie, Campbell, Milne, & Coleman, 2003). Furthermore, even when this ability does develop, it remains severely delayed relative to participants of equivalent mental age (Leekam, Hunnisett, & Moore, 1998).

A prominent theory of gaze processing in autism is the ‘Mindblindness’ model of social cognitive development. This theory predicts that eye direction detection should be relatively ‘intact’ in autism. Baron-Cohen (1995) proposes that the basic geometric understanding of gaze direction is relatively ‘preserved’, with deficits in joint attention instead related to atypicalities of a shared attention mechanism. Evidence supporting this suggestion comes from apparent dissociations between the ability to identify where someone is looking (Leekam et al., 1997) and a lack of spontaneous gaze monitoring (e.g. Mundy, Sigman, Ungerer, & Sherman, 1986) which prevents triadic interactions.

Nevertheless, this is not the full story. Use of demanding stimuli indicates subtle deficits in eye direction detection in autism (Swettenham et al. 2001). The development of gaze direction detection and gaze perception are likely to follow atypical (and independent) pathways (Webster & Potter, 2008). This suggestion is supported by research showing more pronounced problems for younger children with the disorder, indicating an unusually protracted development (Webster & Potter, 2008). Therefore evidence concerning the eye gaze direction detection abilities of individuals with autism remains equivocal. Understanding possible mechanisms involved in the completion of gaze direction detection tasks may be particularly informative.

With an abundance of research revealing deficits in the domain of social cognition and attention in autism there have been calls for a shift away from characterising overall task performance and towards the study of the *processes* and *strategies* used to perform these tasks (Klin, Jones, Schultz, Volkmar, & Cohen 2002b; Volkmar, Lord, Bailey, Schutlz, & Klin, 2004; Boraston & Blakemore, 2007). One such method is the use of eye-tracking for identifying exactly where a person is looking during task completion. Boraston and Blakemore (2007) suggest that eye tracking is particularly useful when it is combined with tests of cognitive performance because it provides information *in addition* to a participant's overall test score. Information about which aspects of the stimuli the participant fixates upon can provide insights into the strategies they are using. Studying fixation patterns cannot indicate how the brain uses the visual information it receives, but any differences in the way individuals with and without autism attend to task stimuli are likely to indicate differences in the processes they employ. A number of theorists have argued that complex social-cognitive abilities build upon basic social–perceptual knowledge (Baron-Cohen, 1995; Hobson, 1993; Tager-Flusberg & Sullivan, 2000) and so deficits or atypicalities in attending to information are likely to have wide ranging effects on performance. It is generally reported that individuals with autism do not look at social information or faces in a typical manner (e.g. Klin et al., 2002b; Pelphrey, Sasson, Reznick, Paul, Goldman, & Piven, 2002; Dalton et al., 2005; Speer, Cook, McMahon, & Clark, 2007; Sasson et al., 2007; Riby & Hancock, 2008, 2009) and identifying how viewing patterns interact with task performance (e.g. when interpreting cues from the face region) could prove informative.

Corden, Chilvers and Skuse (2008), combining eye-tracking technology with a test of facial affect recognition, found that the extent of failure to fixate the eyes predicted the degree of impairment at recognising fearful expressions. Here tracking eye movements allowed the researchers to understand how attention affected task performance. This methodology can also identify subtle differences in performance; for example Rutherford and Towns (2008) found face scanning differences when participants with autism processed complex but not simple emotions. This strategy difference may contribute to difficulties understanding more complex mental states (Baron-Cohen, Wheelwright, & Jolliffe, 1997). The use of eye tracking is not restricted to exploring task performance during aspects of face perception and has recently been beneficial to unearthing aspects of language development for children with autism (Brock, Norbury, Einav, & Nation, in press) as well exploring the role of visual attention in action imitation for youngsters with autism (Vivanti, Nadig, Ozonoff, & Rogers, 2008). The current study extends the combined use of eye-tracking and behavioural performance to the study of gaze direction detection, a domain that is regularly implicated in explorations of autism.

We tracked the eye movements of individuals with and without autism (of comparable nonverbal ability) during a gaze direction judgment task. The hypothesis was that individuals with autism (who were not high-functioning on the spectrum) would have difficulties accurately identifying the target of the actors' gaze. Eye movement information was expected to provide additional insights into exactly where individuals with and without autism fixated during task completion.

Method

Participants

Fifteen participants with autism (13 boys) ranged from 8- to 14-years, mean 10 years 9 months. Five attended the special education unit of a mainstream secondary school and 10 attended schools for pupils with additional educational needs. All participants had been diagnosed by clinicians and satisfied the diagnostic criteria for autism according to the DSM-IV (APA, 1994). The Childhood Autism Rating Scale, completed by teachers (CARS; Schopler, Reichler, & Rocher Renner, 1988), classified 11 children with mild-moderate autism and 4 with severe autism. To comply with our inclusion criteria, all participants scored within the autistic range, with CARS scores ranging between 33-50. All participants completed a calibration phase at the beginning of the study and all were reported to have normal or corrected-to-normal vision.

Each individual with autism was matched to a typically developing child (TD) on the basis of nonverbal ability (11 males and 4 females, mean chronological age 6 years 10 months, ranging 5 years 1 month to 8 years 3 months). For typically developing participants teachers completed the Strengths and Difficulties Questionnaire (Goodman, 2001), scoring each individual on emotional symptoms, conduct, hyperactivity, peer relationships and pro-social behaviour. To comply with our inclusion criteria, all typically developing participants scored within the ‘normal’ range for the total difficulties score (scoring between 0-11). All had normal or corrected-to-normal vision and successfully completed the eye tracking calibration phase.

Ravens Coloured Progressive Matrices (Raven, Court, & Raven, 1990) scores did not differ between the typically developing group and the group with autism (max score 36; mean score for autism group 12, mean for typically developing participants 12). This measure of nonverbal ability is one of the most frequently used matching measures (Mottron, 2004) and provides a quick assessment across a wide age range.

Materials

Colour digital photographs were taken of a woman directing her gaze towards one of several targets. The target items were colourful, attractive and easily nameable for young participants (cow, duck, sheep, person, pig, car). Targets were placed on colourless transparent plastic cups to raise them to the eye level of the actor.

Targets were arranged in a straight line, as shown in Figure 1. The centre of the line was 50 cm in front of the model’s face. In the six-item array, targets were placed on either side at 10˚, 20˚ and 30˚ visual angle from the model’s midline. For the 4-item array, targets were placed at 15˚ and 30˚. These angles were chosen because gaze deviations greater than 30˚ from head direction are uncomfortable, so also unnatural, and they pose a risk of accompanying head-movements (see Doherty & Anderson, 2001).

For the 'head-and-eye' condition, photographs were taken of the model directing her head and eyes towards each item of the four- and six-item arrays. For the 'eye only' condition, the model directed her head forwards while moving her eyes towards a target. This yielded 8 photographs for the four-item array task (4 head+eyes and 4 eyes only) and 12 photographs for the six-item array task (6 head+eyes and 6 eyes only). The final colour images were standardized to 640 x 480 pixels.

The Tobii 1750 eye-tracking screen was interfaced and controlled by a Dell Latitude D820 computer for presenting stimuli and recording responses (using Tobii Studio software). The eye-tracking system is completely non-invasive, does not require restraint of participant head-movement and provides little indication that eye movements are being tracked. This system has been used extensively with these populations (see Riby & Hancock, 2008, 2009). The system was transported to the testing location of each individual, who sat approximately 50cm from the screen during testing. The system tracks both eyes, to a rated accuracy of 0.5 degrees, sampled at 50Hz. The eye tracker was calibrated for each participant using a 9 point calibration of each eye.

The Tobii system recorded gaze behaviour to pre-specified areas of interest (AOI). Each AOI was defined using the AOI Tool provided by Tobii Studio. AOIs were the following; model's face, correct side for target item, correct target item. This allowed us to examine the eye gaze behaviour of participants on each trial, alongside the accuracy information, recorded manually.

Figure 1 here

Procedure

Participants were tested individually at school. The session included other eye-tracking tasks reported elsewhere (including Riby & Hancock, in press) and the session lasted approximately 15 minutes. During the experimental task, the participant was first show an image of the target items and was asked to name them. All participants did so successfully and therefore progressed to the experimental phase. They were then told they would see pictures of a person looking at one of these items and they should tell the experimenter the name of the item being looked at. The image remained on screen until response, so the task was self-paced. With the combination of array size (4 or 6 items) and gaze type (eyes only and head+eyes), each participant completed four tasks with the order counterbalanced across participants. No feedback was provided.

Results

4-item array

We first consider the accuracy of the verbal response provided by participants. The crudest measure of gaze following is the ability to identify the correct side of the screen for the target. Analysis of variance (ANOVA) with factors Group (autism, TD) and Cue (head+eye, eyes) revealed no effect of Cue (*p*=.36): participants were not significantly aided by congruent head direction. There was a main effect of Group (F(1,28)=14.43, *p*<.01). Typically developing participants performed more accurately than those with autism (mean TD 91%, autism 74%). The interaction was not significant (*p*=.65; see Table 1 for mean accuracy across conditions and group). Nevertheless, participants with autism performed above chance (head+eye t(14)=10.02, *p*<.001; eyes alone t(14)=11.30, *p*<.001).

More precise gaze following is required to detect the target item. An ANOVA with factors Group (autism, TD) and Cue (head+eye, eyes) revealed no effect of Cue (*p*=.61) but an effect of Group (F(1,28)=26.68, *p*<.001). Participants with autism detected the precise target significantly less accurately (autism 53%, TD 74%). Again participants with autism performed above chance (head+eye t(14)=5.39, *p*<.001; eyes alone t(14)=5.17, *p*<.001). The interaction between factors was not significant (*p*=.86).

Where participants look may provide a more subtle insight into task performance than judgment accuracy. The time taken for the first face fixation did not depend on Cue (*p*=.83) but there was a significant effect of Group (F(1,28)=10.21, *p*<.01). Participants with autism were significantly slower to fixate on the actor’s face than typically developing participants (autism 1276ms, TD 471ms). The interaction between factors was not significant (*p*=.79). The duration of face gaze (after the first fixation) was affected by Cue (F(1,28)=3.43, *p*=.075) with longer face fixations during the eye only task (eyes 1469ms, eyes+head 1104ms). Participants with autism looked at the actor's face for less time than participants without autism (F(1, 8)=35.72, *p*<.001; autism 883ms, TD 1590ms). The interaction was not significant (*p*=.60).

There was no effect of Cue (*p*=.71) on the time taken to fixate the target item after a face fixation. However, there was a difference between Groups (F(1,28)=21.96, *p*<.001). Participants with autism were significantly slower than those without autism (across tasks autism 2932ms, TD 1103ms). The interaction between factors was not significant (*p*=.44).

Figure 2 here

To investigate fixation length to the target item as a factor of task accuracy gaze behaviour was combined for the eyes only and head cue tasks (see Figure 2). A 2-way mixed ANOVA with independent factors Group (Autism, TD) and Accuracy (correct, incorrect) revealed a significant effect of accuracy with longest target fixation on trials answered correctly (F(1,28)=33.58, *p*<.001; correct 714ms, incorrect 271ms). There was no significant effect of group (*p*=.74) but a significant interaction between factors (F(1,28)=26.88, *p*<.001). Participants with autism showed significantly different target fixation lengths depending on accuracy (t(14)=10.51, *p*<.001; correct 930ms, incorrect 90ms). Typically developing participants showed no significant difference depending on task accuracy (*p*=.74; correct 499ms, incorrect 453ms).

Table 1 here

6-item array

As with the 4-item array, the type of cue (head+eye, eyes) did not affect participants' ability to identify the correct side of the array (*p*=.24), but there was a main effect of group (F(1,28)=16.01, *p*<.001). Participants with autism were less accurate than those without autism (autism 72%, TD 84%). Performance of participants with autism was above chance (head+eye t(14)=21.18, *p*<.001; eyes alone t(14)=14.26, *p*<.001).

The same pattern was found for identification of the precise target: no effect of Cue (*p* = .83) a main effect of Group (autism 48%, TD 63%, F(1,28)=11.24, *p*<.01), and no significant interaction. Again, the group with autism performed above chance (head+eye t(14)=7.01, *p*<.001; eyes alone t(14)=6.92, *p*<.001).

The time to first face fixation revealed a significant effect of Cue (F(1,28)=6.01, *p*<.05; mean head+eyes 978ms, eyes alone 711ms) and a significant difference between Groups (F(1,28)=30.28, *p*<.001). Participants with autism took longer to look at the actors' face than those who were typically developing (autism 1334ms, TD 354ms). There was also a significant interaction between factors (F(1,28)=4.87, *p*<.05). Participants with autism took longer to fixate the face during the head+eye task than the eyes alone task (t(14)=.252, *p*<.05; head+eye 1588ms; eyes alone 1081ms); typically developing participants showed no difference. Participants with autism took longer to fixate the face in each task (head cue t(14)=6.93, *p*<.001; eye cue t(14)=4.00, *p*<.01).

Once fixated, the length of face gaze revealed no effect of Cue (*p*=.92) but a significant effect of Group (F(1,28)=20.02, *p*<.001). Participants with autism fixated the face for significantly less time than participants without autism (autism 916ms, TD 1464ms). There was no interaction. Having fixated the face, participants with autism were slower to fixate the target (autism 3085ms, TD 1510ms; F(1,28)=22.32, *p*<.001). There was no effect of Cue (*p*=.53) and no interaction (*p*=.70). Figure 3 suggests that differences in time to fixate the target may be due to more ‘gaze wandering’ around the image prior to target fixation for individuals with autism.

A 2-way ANOVA with factors Group (Autism, TD) and Accuracy (correct, incorrect) revealed a significant effect of accuracy on target fixation length with longest fixations for correct trials (F(1,28)=255.35, *p*<.011; correct 685ms, incorrect 125ms). There was also a significant effect of Group, with longer target fixations for individuals with autism (F(1,28)=22.17, *p*<.001; autism 535ms, TD 275ms). The interaction was not significant (*p*=.22).

Figure 3 here

Performance accuracy and level of functioning

The relationship between level of functioning on the autistic spectrum (according to scores on the CARS) and performance accuracy was investigated with a Spearman's rank correlation, although some care is required due to sample size (N=15). The take into consideration performance on all four gaze tasks (combining cue and array size) a composite score was calculated representing the participants' average performance across tasks. When exploring the relationship between level of functioning and average task performance, there was a significant negative correlation (r=-.69, *p*<.01). A significant negative correlation indicates that greater severity of autism (higher CARS score) is associated with lower performance accuracy. For participants with autism there was no significant relationship between task performance and nonverbal ability (*p*=.14) or chronological age (*p*=.28). For participants who were developing typically there was no significantly relationship between task accuracy and nonverbal ability (*p*=.19) but a significant relationship between accuracy and chronological age (r=.42, *p*<.05). Accuracy increased with age for typically developing participants.

Discussion

The method of tracking eye movements can provide a wealth of information regarding the gaze behaviour of individuals with and without autism which may be particularly informative when unearthing the source of differences in task performance. The current study emphasises that it is possible to look at very subtle aspects of task performance to unearth typicalities or atypicalities of performance for individuals with autism. The ability to appropriately direct visual attention during task completion is essential for the appropriate assessment of abilities. If individuals with autism do not direct their attention in a typical manner this could reveal the source of possible deficits as well as prove insightful for designing training programs and interventions. Previous research has emphasised that individuals with autism do not attend to socially relevant information, such as faces, in a typical manner (e.g. Klin et al., 2002b; Riby & Hancock, 2008, 2009,) and behavioural evidence has illustrated problems with using information from faces (e.g. gaze abilities; Gepner et al, 1996; Riby, Dohety-Sneddon & Bruce, 2008). The current study brings together these two streams of research to illustrate how the gaze behaviour of individuals with autism may be typical / atypical *during* task completion in a domain known to be of difficulty (e,g. Gepner et al,. 1996, Riby et al., 2008).

The basic behavioural evidence of gaze direction detection presented here corroborates previous literature showing that individuals with autism have problems detecting the target of an actor’s gaze (Swettenham et al., 2001; Webster & Potter, 2008). Individuals with autism are significantly less accurate than their typically developing counterparts (of comparable nonverbal ability) when naming not only the target item but also providing a response that corresponds to the correct side of the screen (a very crude assessment of gaze following). The evidence presented here does not support the notion that gaze direction detection is intact in autism, as proposed by the Mindblindness theory (Baron-Cohen, 1995). Interesting task accuracy reveals that participants were not affected by cues from the eye alone versus head and eyes.

The length of time spent fixating upon the target item is affected by task accuracy. Interestingly target fixation length is comparable across item array size (see Figure 2). To provide the correct response typically developing participants attend to the target item for about 500ms, where as participants with autism attend to the target for about 800ms. This corresponds with other aspects of gaze behavior illustrated in the current task that indicate a slower processing of information by participants with autism at various time points during the task. This finding is discussed later in this section, and has important implications for tasks involving the rapid presentation of targets as participants with autism may require more time to prepare a response. Language may play an important role here as it may take individuals with autism longer to prepare their correct verbal response than typically developing participants.

Task accuracy does impact upon the time spent fixating upon the target item, as illustrated in Figure 2. When the task is relatively easy (4 items) typically developing participants gaze at the target item for equal time irrespective of subsequent task accuracy. However when the task gets harder (6 items for typically developing participants) participants look at the target for less time when they respond incorrectly. Interestingly this pattern corresponds to the gaze behavior of participants with autism on both the tasks conducted here. We propose that task accuracy affects gaze behavior by reducing gaze to the correct target item. Typically developing participants may simply be over-confident in their response for the four item array task as represented by their gaze behavior. In the 6-item (but not the 4-item) task participants with autism actually gaze at the target item for longer on incorrect trials than participants developing typically. This could imply that under difficult task conditions, participants with autism are able to follow gaze cues to the target item, but are unable to provide the appropriate verbal label for task completion. Further research is required to provide insight into this proposal.

An additional factor that is implicated in the performance of participants with autism was level of functioning on the autistic spectrum; here assessed by CARS score. In the current study increased severity of autism was significantly correlated with decreased task performance. This finding replicates previous research showing that level of functioning affects a range of face perception skills, including processing eye gaze (Riby et al., 2008). Additionally level of functioning has been associated with time spent looking at faces (e.g. Klin et al., 2002b; Speer et al., 2007; Riby & Hancock, 2009) and therefore has implications for learning how to interpret information from the face region; such as subtle shifts of gaze. This finding can also accommodate the discrepancies evident in the literature that show some individuals with autism are able to complete gaze judgment tasks whilst other have severe difficulties (e.g. Baron-Cohen, 1995; Webster & Potter, 2008). Acknowledging participants characteristics is extremely important in autism research and here we emphasise that level of functioning is significantly related to the processing of gaze direction.

An important aspect of the gaze behaviour analysed here is the time taken for individuals with autism to complete each aspect of the task. The task requires participants to look at the actor’s face to detect a gaze cue, then to follow this cue to the target item. At each stage of this process the participants with autism took significantly longer than participants without autism. This has important implications for tasks that implement time restrictions or the rapid presentation of gaze cues. Figure 3 shows that for this individual with autism the number of fixations to detect the target is much higher (6th fixation is on target) than for their typically developing counterpart of comparable nonverbal ability (3rd fixation is on target). This time difference between groups may therefore represent some aspect of 'gaze wandering' prior to fixation on the target. If participants with autism had been provided with less opportunity to look at the actors' face due to time restrictions the gaze behaviour reported here may have been very different. Additionally, if the target item had only appeared on screen for a limited amount of time then participants with autism may not have had adequate opportunity to locate the item. Therefore the current study implies that the mechanisms used by individuals with autism to detect gaze cues may be activated at a much slower rate when compared to individuals without autism. Also attention mechanisms or attention capabilities are likely to play an important role in fixation patterns of this group. The results have implications for task design and emphasise the importance of measuring various aspects of gaze behaviour. It is widely reported that individuals with autism may complete cognitive / behavioural tasks in an atypical manner (e.g. processing faces featurally rather than configurally even as adults; Deruelle, Rondan, Gepner, & Tardif, 2004) and it seems sensible that such atypicalities extend to the way gaze tasks are completed. Here tracking eye movements proved particularly insightful when considering such atypicalities.

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Table 1: Accuracy (percentage correct) and Gaze Behaviour (fixation length in milliseconds) as a Function of Cue and Group Membership.

		Group	
		Autism	Typically Developing
4-item array	***Accuracy (%)***		
	Head+Eye Cue		
	Correct side	77 *(20)*	92 *(12)*
	Correct target item	55 *(21)*	75 *(16)*
	Eye Cue		
	Correct side	72 *(16)*	90 *(13)*
	Correct target item	52 *(20)*	73 *(7)*
	Gaze Behaviour (ms)		
	Head+Eye Cue		
	Time to first face fixation	1318 *(986)*	467 *(211)*
	Length of face fixation	789 *(264)*	1420 *(607)*
	Time to first target fixation[1]	3145 *(1332)*	1156 *(529)*
	Length of target fixation[2]	899 (*132)*	425 *(227)*
	Eye Cue		
	Time to first face fixation	1243 *(796)*	474 *(831)*
	Length of face fixation	977 *(542)*	1760 *(545)*
	Time to first target fixation[1]	2719 *(1211)*	1049 *(739)*
	Length of target fixation[2]	960 *(211)*	572 *(328)*
6-item array	***Accuracy (%)***		
	Head+Eye Cue		
	Correct side	71 *(10)*	89 *(10)*
	Correct target item	49 *(16)*	63 *(25)*
	Eye Cue		
	Correct side	*72 (15)*	80 *(14)*
	Correct target item	48 *(12)*	62 *(18)*
	Gaze Behaviour (ms)		
	Head+Eye Cue		
	Time to first face fixation	1588 *(796)*	368 *(273)*
	Length of face fixation	971 *(419)*	1396 *(281)*
	Time to first target fixation[1]	3201 *(1516)*	1463 (*475)*
	Length of target fixation[2]	746 (*326)*	563 *(214)*
	Eye Cue		
	Time to first face fixation	1081 *(710)*	340 *(120)*
	Length of face fixation	861 *(342)*	1532 *(732)*
	Time to first target fixation[1]	2969 *(1175)*	1557 *(606)*
	Length of target fixation[2]	921 *(287)*	432 *(271)*

1 only trials where participants made a face fixation prior to a target fixation

2 only for trials answered correctly

Figure 1: Task example, the 6-item array task with gaze cues provided by the eyes and head (target item ‘sheep’).

Figure 2: Target fixation length (ms) as a factor of task accuracy, combining cue type for each array size

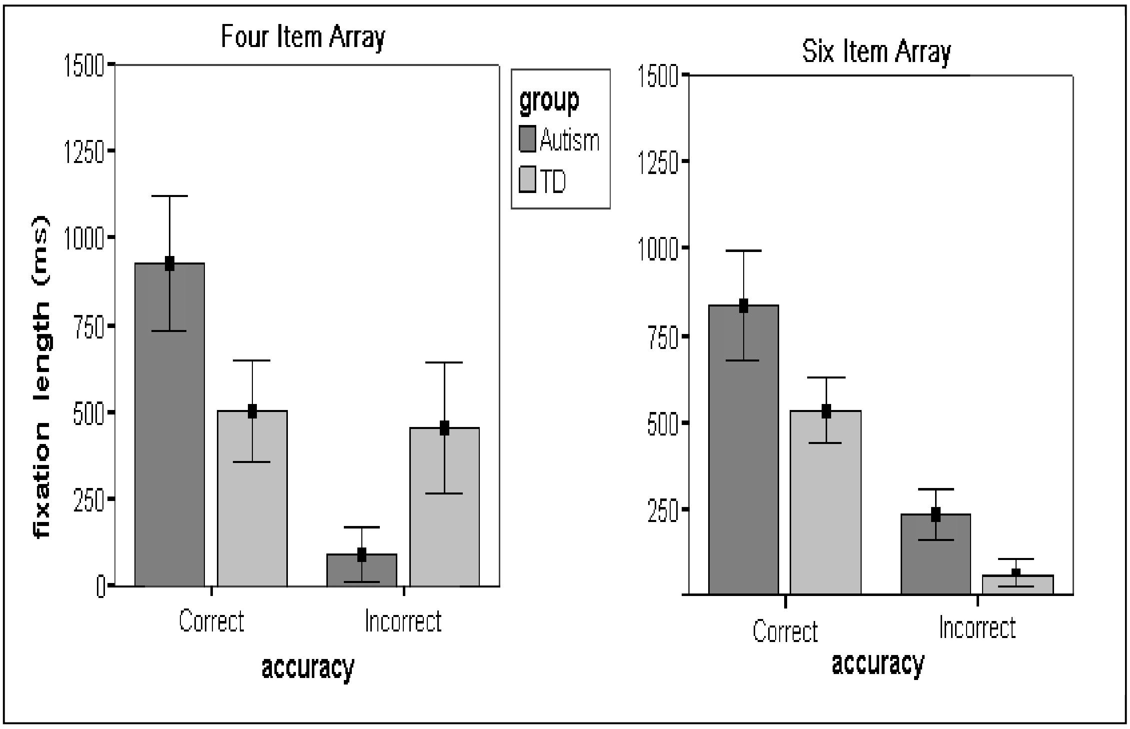

Figure 3: Examples of the ‘gaze plots’ for the 6-item array task trial depicted in Figure 1, with gaze cue provided by the head+eyes. Target item is the sheep. Images display the gaze plots of i) a participant with autism and ii) their matched comparison participant who is developing typically