

# Eye movements affirm: automatic overt gaze and arrow cueing for typical adults and adults with autism spectrum disorder

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**Abstract** People with autism spectrum disorder (ASD) show reduced interest towards social aspects of the environment and a lesser tendency to follow other people's gaze in the real world. However, most studies have shown that people with ASD do respond to eye-gaze cues in experimental paradigms, though it is possible that this behaviour is based on an atypical strategy. We tested this possibility in adults with ASD using a cueing task combined with eye-movement recording. Both eye gaze and arrow pointing distractors resulted in overt cueing effects, both in terms of increased saccadic reaction times, and in proportions of saccades executed to the cued direction instead of to the target, for both participant groups. Our results confirm previous reports that eye gaze cues as well as arrow cues result in automatic orienting of overt attention. Moreover, since there were no group differences between arrow and eye

gaze cues, we conclude that overt attentional orienting in ASD, at least in response to centrally presented schematic directional distractors, is typical.

**Keywords** Gaze following · Gaze cueing · Oculomotor inhibition · Autism · Eye movements · Social attention

## Introduction

Autism spectrum disorder (ASD) refers to a range of neuro-developmental conditions characterized by impairments in social interaction and communication, and the presence of repetitive behaviours and restricted interests (American Psychiatric Association, APA 1994). One of the earliest manifestations of autism is a deficit in joint attention behaviours with social partners, and this is thought to restrict the child's opportunities for social learning, impairing subsequent social and communication development (Baron-Cohen et al. 1996; Klin et al. 2003; Mundy 1995; Mundy and Burnette 2005). One component of joint attention is gaze following whereby the observer traces the line of sight of another person towards the object/target/person that is being looked at (Emery 2000; Frischen et al. 2007).

In typical development spontaneous gaze following behaviour develops during infancy (for reviews see Nation and Penny 2008; Senju and Johnson 2009) and it has been suggested that gaze following may be innate (Baron-Cohen 1994; Hood et al. 1998; Tantam 1992). Several behavioural studies have found spontaneous gaze following impairments in children with ASD (Leekam et al. 1998; Leekam et al. 2000) although they have an intact ability to compute gaze direction geometrically (Leekam et al. 1997). The reasons for this spontaneous gaze following impairment are far

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from clear, and several different explanations have been proposed (see Nation and Penny 2008). Individuals with ASD may fail to interpret gaze or head movement as an index of the other person's state of attention towards a particular location (Baron-Cohen 1995). This interpretation coincides with the general finding that individuals with ASD typically show deficits in their ability to read the mental states of other people (theory of mind deficits) (Baron-Cohen 2000; Baron-Cohen et al. 1996). However, gaze following does not necessarily require intact theory of mind skills. For example, gaze following is often observed in macaque monkeys, who are not thought to have representations of other people's states of mind (Deaner and Platt 2003). Others suggest that infants learn to predict where an object will appear in response to head turn which in later development results in automatic gaze following (Corkum and Moore 1998). Individuals with ASD generally pay less attention to social stimuli, and in particular may fixate less than usual on the eye-region (Dalton et al. 2005; Klin et al. 2002). On the other hand, abnormalities in gaze following could reflect more general attentional problems with disengaging attention from one stimulus and shifting it to another location (e.g. Hill 2004; Landry and Bryson 2004; Ozonoff et al. 1991).

Evidence for a gaze following deficit in ASD is based on studies involving interpersonal interaction within real-world experimental paradigms, but attentional orienting in response to gaze cues is more often investigated using a Posner type cueing task (Posner 1980). In this paradigm participants are presented with pictures of faces where the gaze is either averted to the left or the right (e.g. Friesen and Kingstone 1998). Following this shift in eye gaze, a target appears either at the gazed at (valid) location, or at the non-gazed at (invalid) location. Participants typically detect targets appearing at the valid location more rapidly than targets appearing at the invalid location, thus demonstrating that attention has been oriented towards the gazed at location. The difference in reaction time (RT) for detecting targets at valid versus invalid locations provides an index of gaze cueing (for reviews see Frischen et al. 2007; Langton et al. 2000). Importantly this gaze cueing effect occurs even when the gaze cues are non-predictive (Friesen and Kingstone 1998) or even counter predictive of the target location (Driver et al. 1999; Friesen et al. 2004), thus suggesting that this type of attentional orienting is reflexive.

Given that a lack of spontaneous gaze following is one of the hallmarks of ASD, it has been rather surprising that few studies have found abnormalities in gaze cueing in Posner-type tasks (see Nation and Penny 2008 for a review). At first sight, children with ASD seem to have comparable cueing effects for eye gaze to that of typically developing (TD) children (Kylliäinen and Hietanen 2004; Swettenham et al. 2003). Nevertheless, there is evidence of subtle atypi-

calities in the way in which children with ASD respond to gaze cues. For example, Ristic et al. (2005) found that children with ASD were more reliant than TD children on the presence of motion in the eye-gaze cue to trigger attentional shifts, when gaze-direction was not predictive of the target location. Senju et al. (2004) found that children with ASD responded reflexively to both arrow and eye-gaze cues, while TD children were able to inhibit a response to a non-predictive arrow cue. This suggests that children with ASD use the same, learnt and non-social, mechanism for responding to both social (eye-gaze) and non-social (arrow) cues. This interpretation is supported by the work of Chawarska et al. (2003) who demonstrated, by recording eye-movements during an eye-gaze cueing task, that toddlers with ASD responded more quickly to an eye-gaze cue than their TD peers. This group difference disappeared when a non-social cue was used, leading to the suggestion that the TD children were slower to respond to eye-gaze cues because of the extra time they spent processing this social stimulus.

This paper will explore responses to eye-gaze cues in adults with ASD using a novel, cueing paradigm which measures overt attention using eye-movements as well as RT. Such tasks offer a more direct way of investigating attentional abnormalities, as they are more closely related to the deviations in gaze following typically observed in ASD.

Gaze cueing in TD adults has been investigated by measuring overt attention (i.e. eye movements) (Kuhn and Benson 2007; Kuhn and Kingstone 2009; Mansfield et al. 2003; Ricciardelli et al. 2002). In one of these paradigms participants are required to fixate a central fixation point and are instructed to look at targets on either side of the screen as indicated by a colour change of the fixation point. During fixation the eye gaze of a centrally presented face shifts either to the right or the left. Participants are therefore required to saccade either in the same direction (congruent trials), or the opposite direction (incongruent trials) to which the distractor eyes are pointing. Results have shown that participants are significantly slower at initiating eye movements on incongruent than on congruent trials, even when the gaze cue is non-predictive (Kuhn and Benson 2007; Ricciardelli et al. 2002) or counter predictive (Kuhn and Kingstone 2009) of the saccade instruction. Moreover, participants typically make more errors on incongruent than on congruent trials thus demonstrating that in TD adults, gaze cues result in automatic gaze following.

Another opportunity afforded by this study is to explore the responses of adults with ASD to a different attentional cue: arrows. Initially it was thought that attentional orienting in response to gaze cues may be unique to biologically relevant stimuli (Friesen and Kingstone 1998). However, numerous recent studies have shown that symbolic cues, such as arrows, result in automatic shifts in both covert (Bonato et al. 2009; Hommel et al. 2001; Ristic and Kingstone

2006; Tipples 2002, 2008) and overt attention (Kuhn and Benson 2007; Kuhn and Kingstone 2009), thus questioning the claim that gaze cueing is unique. However, the question over whether these two types of cues result in identical attentional orienting remains controversial. For example Friesen et al. (2004) demonstrated that contrary to arrow cues, eye gaze cues resulted in reflexive attentional orienting when the cues were counter-predictive, thus proposing that gaze cueing may be more automatic than other forms of directional cueing. However, Tipples (2008) found cueing effects for both types of cues thus somewhat undermining this suggestion. Similarly Ricciardelli et al. (2002) claimed that only eye gaze, but not arrow cues would produce gaze following. Yet again, Kuhn and Benson (2007) demonstrated that both arrows and eye gaze can lead to automatic gaze following, even when the cues are counter-predictive (Kuhn and Kingstone 2009).

Neurological evidence on the other hand suggests that some differences between these two types of cues may still exist. Several neuroimaging studies have shown that arrow and eye gaze cues activate different neural networks (Hietanen et al. 2006; Tipper et al. 2008). People with ASD have established abnormalities in face-processing networks (Bird et al. 2006; Dawson et al. 2002; Grelotti et al. 2002; Humphreys et al. 2008; Sasson 2006; Schultz 2005) (though also see Jemel et al. 2006). Given the aforementioned evidence for processing of eye-gaze cues in the same way as arrows in ASD, it is possible that the successful processing of eye-gaze cues in ASD is underpinned by the networks normally used for non-facial cues such as arrows.

The aims of the current paper were twofold. The first was to determine whether high functioning adults with ASD show differences in gaze cueing compared to TD participants. This investigation employed an overt gaze cueing paradigm, in which eye-movements were recorded, which is more closely related to typical gaze following, and thus allows us to investigate the effects of gaze cues on overt rather than covert attention. Eye tracking has the additional advantage over standard covert cueing task in that it offers a rich data set. Eye tracking provides information about the timing, as well as the direction of saccades (i.e. gaze following) for saccades correctly executed toward the target, and for saccades incorrectly executed towards the target in the opposite hemifield. Moreover, by employing eye tracking techniques, rather than observations via video, we can gain finer insights into the temporal aspects of gaze following.

The second aim was to investigate whether possible abnormalities in gaze cueing are specific to gaze cues, or whether they apply to symbolic cues, such as arrows. Whilst the majority of the behavioural evidence suggests that these two cue types have identical effects, it has recently been suggested that gaze cueing is sub-served by different neural mechanisms than those governing cueing for symbolic cues. Moreover, children with ASD have been shown to have stronger attentional orienting in response to arrow cues than do their TD peers. We therefore investigated whether the attentional orienting in response to arrow cues in adults with ASD was different to that in TD adults. It was predicted that whilst TD adults should demonstrate equal cueing effects for arrow and eye gaze cues, ASD participants were expected to show stronger cueing effects for arrow than for eye gaze cues.

## Method

### Participants

There were 12 participants in each group (Table 1). Participants in the ASD group were recruited from the Southampton adult Asperger's Society, the University of Southampton and the Hampshire Autistic Society. All ASD participants had official diagnoses of ASD from UK practitioners (a psychiatrist or clinical psychologist employed by the National Health Service) working in specialized centres, as meeting DSM-IV criteria for either high-functioning autism or Asperger's syndrome (American Psychiatric Association, APA 1994).

Groups were group matched on Age, Verbal IQ, Performance IQ and Full Scale IQ, measured using the Wechsler abbreviated Scales of Intelligence (WASI) (Wechsler 1999) (all  $ps > 0.39$ ). All participants completed the 50-item Autism-Spectrum Quotient questionnaire (AQ) (Baron-Cohen et al. 2001), on which high scores imply more autism-like traits. The ASD group scored significantly higher than the TD group  $t(22) = 4.63$ ,  $p < 0.0001$ , thus confirming that the ASD group displayed disproportionately high levels of autism like traits. Baron-Cohen et al. reported that adults with Asperger's syndrome/high-functioning autism had mean AQ scores of 35.8 (SD = 6.5), which is in the region of the scores found in our ASD group. Similarly our TD participants' scores were comparable to that reported in this previous study ( $M = 16.4$ ,  $SD = 6.3$ ).

**Table 1** Average ages and test scores for the ASD and the TD groups

Group	Age		Verbal IQ		Performance IQ		Full Scale IQ		AQ	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
TD	22.4	9.7	108	14.5	107	10.9	109	12.5	15.3	6.1
ASD	26.0	10.5	109	24.9	105	17.6	108	22.9	30.6	9.7

## Procedures

The material and the procedure were based on the two previous studies (Kuhn and Benson 2007; Kuhn and Kingstone 2009). Eye movements were monitored using an Eyelink 1000 eye tracker (SR Research Ltd, Osgoode, Canada), and eye movements were recorded monocularly at 1000HZ. The experiment was run on a Dell computer and displayed on a 21in CRT Monitor (viewing distance was 57 cm). The experiment was compiled and run using Experiment Builder (SR Research Ltd, Osgoode, Canada). Each trial began with a central black fixation point ( $0.63^\circ$  in diameter) on a grey background (see Fig. 1). Participants were asked to fixate on this central spot and the experimenter pressed the space bar once the participant had achieved fixation. The Eyelink 1000 displays participants' fixation points on a separate (host) monitor that the experimenter views during the experiment. It is therefore very clear on a trial by trial basis whether the central fixation point was fixated prior to each trial being initiated by the experimenter. If it was not then the participant was recalibrated before resuming testing.

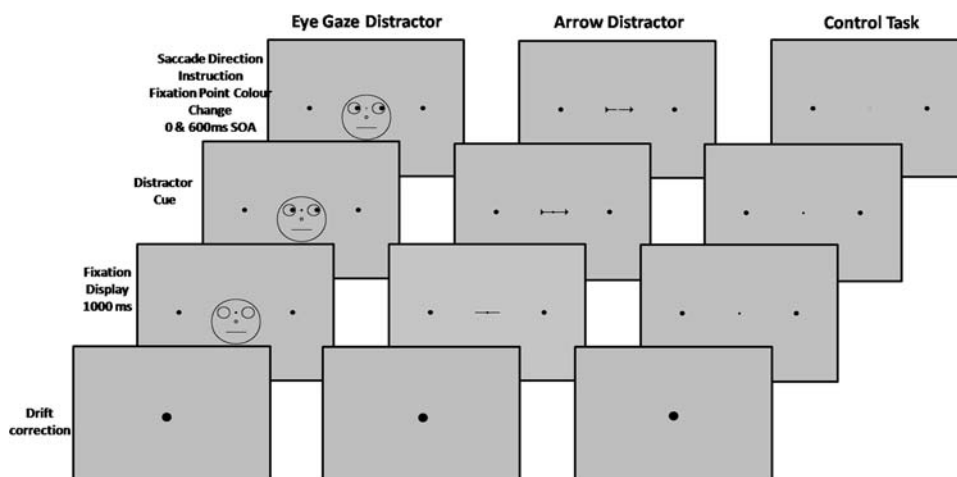
In the eye gaze condition the key press initiated the remaining trial sequence which comprised a schematic face ( $8.57^\circ$  in diameter) with two eyes ( $2.27^\circ$  in diameter) flanked by two solid black target circles ( $0.91^\circ$  in diameter,  $10^\circ$  from fixation). Between the eyes there was a small black spot that acted as a fixation point ( $0.45^\circ$  in diameter). After 1000 ms, pupils ( $0.45^\circ$  in diameter) appeared inside the eyes which were positioned so that the eyes either looked to the left or to the right. After a distractor-to-saccade-direction-cue SOA of 0 ms or 600 ms, the black fixation point turned red or green. The arrow condition was identical to the eye gaze condition with the only exception that in place of the face there was a solid black line, and rather than eye pupils appearing, arrow heads, positioned on either side of the solid black line appeared, transforming the line into a directional arrow. Both the gaze and the

arrow shifts did not induce any motion signal. Half of the participants were instructed to move their eyes to the right when the fixation point turned red and to the left when it turned green, and for the other half of the participants the colour commands were reversed. The colour change of the fixation spot therefore informed each participant as to which target they had to saccade to. Congruent trials were those where the saccade target direction and the eye gaze or arrow pointer direction were the same; incongruent trials were those in which the target and the cue direction were opposite. After 1,000 ms the display was replaced with a blank screen for 1,500 ms.

Each condition (arrow and eye gaze) contained 144 trials in total with trials equally and randomly divided between the two SOA conditions and the congruent/incongruent conditions. Halfway through each condition, participants were given a short brake. An additional control task, identical to the arrow and eye gaze task with the exception that the display did not contain any distractor cues was also included. This task contained 72 trials (half red half green) and aimed to test for general atypicalities in oculomotor control between the two participant groups. The order of these three blocks of trials was counterbalanced across participants.

Prior to each experimental block, participants performed a nine-point calibration, followed by a validation procedure. The calibration was accepted if the average error was below  $0.5^\circ$ . Participants were then asked to fixate the central fixation point at the beginning of each trial. Once the trial was initiated by the experimenter participants had to saccade to the left or the right target, as indicated by the colour switch of the fixation point, and they were told to ignore the distractor cues. Participants were instructed to move their eyes as quickly as possible to the target and to avoid making mistakes. Participants were given six practice trials prior to the experiment. Participants completed three blocks of which the running order was counterbalanced across participants. Prior to the eye-tracking component,

**Fig. 1** Shows sequence of events for each of the three conditions (*Eye-gaze Distractor*, *Arrow Distractor*, *Control Task*)



the WASI was administered and participants completed the AQ.

The study was approved by the Psychology Department's ethics committee at Southampton University and that was carried out along the principles of the Helsinki Declaration.

## Results

### Control task

The aim of the control task was to investigate whether the oculomotor behaviour of the two groups differed, independently of any distractor type effects. Eye movement onset latency was measured as time elapsing from the fixation point colour change (direction cue signal) to the initiation of the first saccade. The first saccade was defined as eye movements with velocities and accelerations exceeding  $30^\circ/\text{s}$ , and  $8,000^\circ/\text{s}^2$ . Only saccades greater than  $1^\circ$  in amplitude were analysed. All saccades that went in the intended direction, as signalled by the colour change of the central fixation spot, were defined as correct saccades. Saccades that went in the opposite direction were defined as error saccades. *T*-tests revealed no significant group differences in either response time or error-rate on the control task (all  $p > 0.1$ ). We can therefore assume that any effects found for the experimental trials do not result from differences between the participants groups in basic oculomotor control.

### Experimental conditions

Data from one of the participants in the ASD group was excluded as this participant followed the arrow cue on a

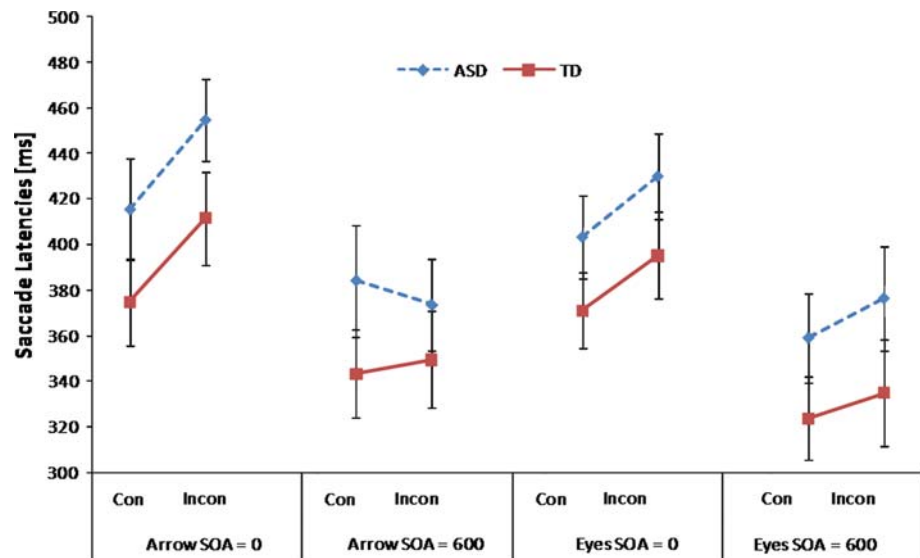
disproportionally high number of trials without correcting the saccade, suggesting that this participant failed to follow the instructions correctly. Analysis of the eye tracking data was conducted with Dataviewer (SR Research Ltd, Osgoode, Canada). Tracker loss trials, as defined by either a lack of signal, or an absence in eye movements, were excluded from analyses. Instances were very low and occurred on 0.42% (SD = 0.75) of trials.

### Saccade reaction time

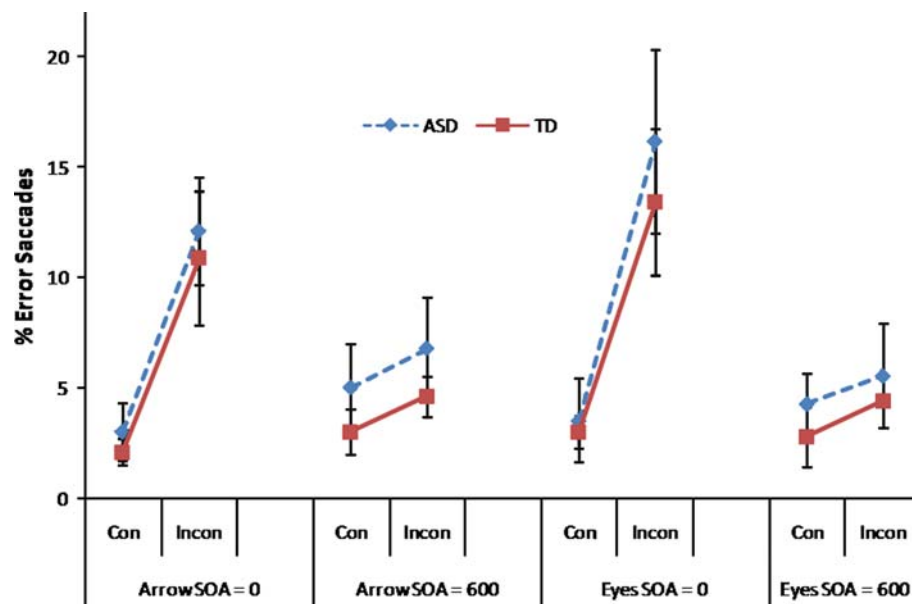
Saccadic Reaction Time (SRT) was defined as the time between the colour change of the fixation point (Saccade Direction Instruction) and the initiation of the first saccade in the correct direction. SRT's greater than 1,000 ms or smaller than 80 ms were defined as outliers and removed from further analysis ( $M = 1.14$ ,  $SD = 1.84$ ). Only saccades that were made in the correct direction were considered. Figure 2 shows the mean SRT's for both groups and each of the conditions.

SRT's were analysed using a mixed factor ANOVA with group (TD versus ASD) as between subject factor and distractor type (arrows versus eyes), congruency (congruent versus incongruent) and SOA (0 ms versus 600 ms) as within-participant factors. There was a significant main effect of congruency  $F(1,21) = 31.6$ ,  $p < 0.0001$ , showing that SRT's on congruent trials were significantly faster than on incongruent trials and thus demonstrating the typical cueing effect. There was a significant main effect of SOA  $F(1, 21) = 91.5$ ,  $p < 0.0001$  whereby SRT's at the longer SOA were significantly faster than at the shorter SOA, an effect typically found in these types of experiments. More importantly, there was a significant SOA by congruency interaction  $F(1, 21) = 37.8$ ,  $p < 0.0001$ , demonstrating that the cueing effect at the shorter SOA was stronger than at the

**Fig. 2** Saccade latencies for correct saccades for congruent (*Con*) and incongruent (*Incon*) trials, for each distractor type, SOA and group



**Fig. 3** Percentage of error saccades made on congruent (*Con*) and incongruent (*Incon*) trials, for each distractor type, SOA and group



longer SOA. Indeed matched *t*-tests show that the cueing effects for both cue types were significant at the 0 ms SOA for both the ASD and the TD groups (all  $p$ 's < 0.006), but that there were no significant differences between the congruent and the incongruent trials at the 600 ms SOA (all  $p$ 's > 0.05).

Contrary to predictions there was a significant main effect of distractor type  $F(1, 21) = 7.00$ ,  $p = 0.015$ . Overall participants responded more rapidly on eye gaze trials than on the arrow trials. There was a significant distractor type by congruency by SOA interaction  $F(1, 21) = 10.2$ ,  $p = 0.004$ . Matched sample *t*-tests showed that whilst the cueing effect for eye gaze cues is significant at the 600 ms SOA,  $t(22) = 2.57$ ,  $p = 0.019$ , this difference is not significant for the arrow cues [ $t(22) < 1$ ], which could suggest that gaze cueing effects are longer lasting than arrow cueing.

None of the other main effects or interactions reached significance (all  $p$ 's > 0.08). Of particular importance, there were no group effects, and the lack of a group by distractor type by congruency interaction,  $p = 0.34$ , illustrates that both the ASD and the TD groups were equally influenced by gaze and arrow distractors.

#### Error rates

Errors were defined as trials on which the first saccade went in the opposite direction to the task instruction. Figure 3 shows the error rates for each of the conditions. Error rates were analyzed using a mixed ANOVA with group (TD versus ASD) as between subject factor and distractor type (arrows versus eyes), congruency (congruent versus incongruent) and SOA (0 ms versus 600 ms) as within-participant factors.

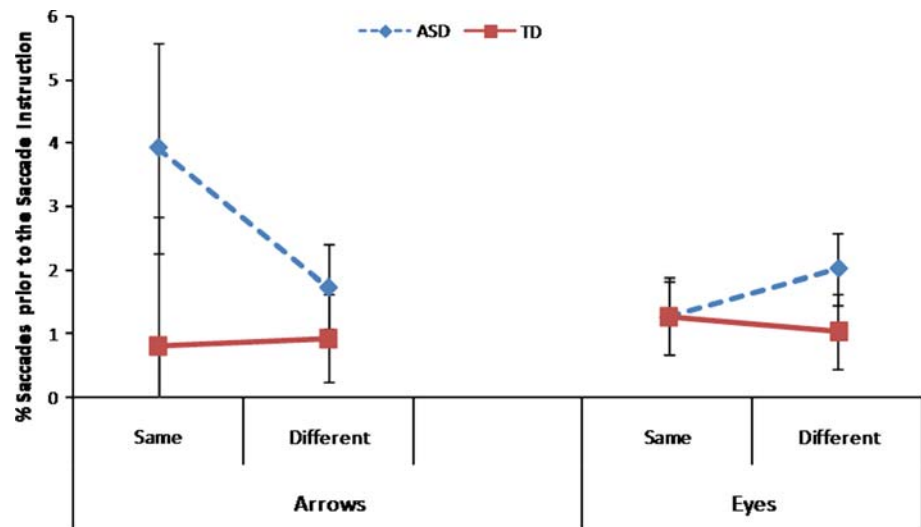
There was a significant main effect of congruency  $F(1, 21) = 38.0$ ,  $p < 0.0001$ , whereby participants made more errors on incongruent than on congruent trials. These results mirror the saccade latency SRT's, and illustrate the typical cue following effect. There was a significant main effect of SOA  $F(1, 21) = 17.2$ ,  $p < 0.0001$ , and more importantly a significant cue direction by SOA interaction  $F(1, 21) = 18.0$ ,  $p < 0.0001$ . Figure 2 illustrates that the cueing effect at the 0 ms SOA is stronger than at the longer SOA. Matched *t*-tests showed that the cueing effect was significant for both distractor types and both groups at the 0 ms SOA (all  $p$ 's < 0.023), but not at the longer SOA (all  $p$ 's > 0.17).

None of the other main effects or interactions were significant (all  $p$ 's > 0.23). Similar to the SRT data, there was no significant group by congruency by distractor type interaction,  $p = 0.78$ , thus demonstrating that the cueing effects for both distractor types did not differ significantly between the two participant groups.

#### Spontaneous gaze following

In order to investigate whether participants spontaneously followed the distractor cues we calculated the number of times participants saccaded in the direction of the distractor cue (same direction), or in the opposite direction (different direction) prior to initiating a voluntary saccade (i.e. prior to the direction cue). As the saccade direction instruction cue and the distractor cue appeared simultaneously in the 0 ms condition, data was only analyzed for the 600 ms SOA condition. We calculated the percentage of trials on which saccades were initiated in the time window between the distractor cue and the saccade direction instruction, and

**Fig. 4** Percentage of trials on which saccades were made prior to the saccade instruction. Saccades were classified according to whether they were made in the same or the opposite direction of the Distractor Cue. Only includes the 600 ms SOA condition



classified whether the saccade was in the same or the different direction (see Fig. 4) to the distractor cue.

A mixed model ANOVA with group as between-subject factor and saccade direction (Same versus Different) and distractor type (arrows versus eyes) as within subject factor found no significant main effect of saccade direction  $F(1, 21) = 2.25$ ,  $p = 0.618$ , thus demonstrating that participants did not follow the cue prior to executing their volitional saccade. None of the other main effects or interactions were significant (all  $p$ 's  $> 0.15$ ). Although it looks like the ASD participants showed a tendency to follow the arrow cue this difference was not significant [ $t(10) < 1$ ].

#### Reflexive nature of saccade

If cue following is truly reflexive we would expect saccades which were initiated in response to a distractor cue to have shorter saccade latencies than saccades initiated voluntarily (Kuhn and Benson 2007; Kuhn and Kingstone 2009; Theeuwes et al. 1999). Figure 5 shows the means of the SRT medians<sup>1</sup> for correct and incorrect saccades, on incongruent trials for both groups. As error rates on the 600 ms SOA condition were rather rare, only data from the 0 ms SOA condition were analysed. Two participants did not make any errors on congruent trials (one from each group). A mixed model ANOVA with group (ASD versus TD) as between subject factor and saccade type (correct versus error) and distractor type (arrow versus eyes) as within-participant factors found a significant main effect of saccade type  $F(1, 19) = 21.2$ ,  $p < 0.0001$  demonstrating that directional error saccades were initiated more rapidly than correctly directed saccades. Moreover, there was a significant distractor type by saccade type interaction  $F(1, 19) = 4.84$ ,

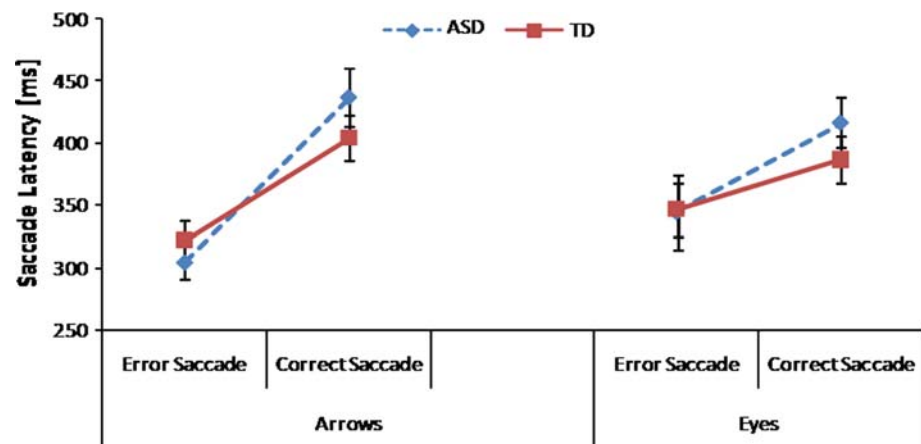
$p = 0.04$ . Contrary to previous research (Kuhn and Benson 2007) this difference in saccade latencies was greater for the arrow rather than the eye gaze distractor. However, error saccades were initiated faster than correct saccades for both the eye gaze [ $t(20) = 2.5$ ,  $p = 0.021$ ] and the arrow distractor [ $t(20) = 5.33$ ,  $p < 0.0001$ ], thus demonstrating that the difference between these two cues is magnitudinal rather than categorical. None of the other main effects of interactions were significant (all  $p$ 's  $> 0.27$ ). Importantly, there was no significant distractor type by saccade type by group interaction  $F(1, 19) = 0.14$ ,  $p = 0.71$ .

#### Correlations

Bayliss et al. (2005) found a significant negative correlation between AQ scores and gaze cueing. Importantly this correlation was not significant for arrow cueing. The authors thus claimed that AQ scores are specifically related to gaze, rather than symbolic cueing. Note that their interpretations were based on the comparison of a significant correlation with a null effect, rather than a direct comparison. We investigated this claim by correlating the difference in interference (i.e. difference between congruent and incongruent trials) between the arrow and the gaze cues with the AQ. If AQ scores are specifically related to gaze cueing we would expect to find a negative correlation between AQ scores and this difference score. In order to control for any possible speed-accuracy differences and to gain sensitivity we combined the error data with the SRT data to form efficiency scores (see Kuhn and Kingstone 2009; Townsend and Ashby 1983). Efficiency scores were calculated by dividing the mean SRT score by the proportion of correct saccades. Lower values indicate more efficient performance. For each participant we subtracted the mean efficiency score for congruent trials from incongruent trials to provide a cueing measure. We then subtracted the cueing

<sup>1</sup> As errors were only made on a relatively low number of trials medians rather than means were calculated so as to reduce the effect of outliers.

**Fig. 5** Saccade latencies for correct and error saccades made on incongruent trials for both groups (*ASD* and *TD*) and distractor types (*arrows* and *eye-gaze*)



measure for the eye gaze distractor from the arrow distractor and plotted these scores with the AQ quotients. If participants with higher AQ scores are more susceptible to arrow cues rather than eye gaze cues we would expect to find a positive correlation between these two measures. However, there was no correlation between these two measures (Pearson's  $R = .018$ ,  $p = 0.94$ ). This analysis suggests that there is no relationship between AQ scores and either type of cue distractor used in our experiment.

## Discussion

The aim of this investigation was to examine whether adults with ASD differed from TD participants in their ability to ignore centrally presented eye gaze or arrow pointing distractors, in order to saccade to a simple peripherally presented target. The use of eye-movement recordings to measure overt attention meant that this experiment had the potential to reveal subtle differences in attentional orienting in ASD, not apparent in simple RT tasks.

The findings clearly indicated that the groups performed in a similar way for both types of distractors (eye gaze and arrow). Specifically, both groups made significantly more directional saccade errors for incongruent eye gaze and arrow cues than congruent trials, and their SRT's on the congruent trials were significantly faster than incongruent trials. Thus similar cueing effects were found for both cue types and both groups, and crucially the cueing effects did not interact with group. Additionally, both cue types were shown to elicit reflexive saccades in the cued but unintended direction, for both groups. Moreover, there was no correlational relationship between AQ scores and the cueing effects for either type of distractor. Furthermore, the analyses on spontaneous orienting to cues, revealed that there were no differences between the two groups for both types of distractor.

Our data clearly demonstrate how eye gaze as well as arrow cues result in strong cueing effects for participants

with ASD and TD participants, both in terms of proportion of saccade errors and saccade latencies. Importantly, this cueing effect occurred despite the fact that both the cue identity and its direction were task-irrelevant. These results concur with a wide range of studies that demonstrate how both eye gaze as well as arrow cues result in automatic orienting of covert (Hommel et al. 2001; Ristic and Kingstone 2006; Tipples 2002, 2008) and overt attention (Kuhn and Benson 2007; Kuhn and Kingstone 2009). It has been suggested that gaze cueing is sub-served by parts of the 'social brain' (Brothers 1990) which also underpin face perception (Ristic et al. 2002), while arrow-cueing is distributed across both hemispheres (Hietanen et al. 2006; Tipper et al. 2008). Since individuals with ASD show atypical neural processing of faces in such brain regions (Schultz 2005) one might expect atypical processing of eye-gaze cues in these individuals. It was thus predicted that unlike the TD individual, the ASD group would demonstrate greater cueing for arrow than for gaze cues. However, our results clearly show that both groups responded in similar ways to the two cue types. This finding corresponds with the current contention that the atypicalities of the face-processing network in ASD have been exaggerated (Jemel et al. 2006).

Rather surprisingly, participants responded significantly faster on the eye gaze trials, than on the arrow trials, which may reflect a general alerting effect by the eyes (c.f. Kuhn and Benson 2007; Kuhn and Kingstone 2009). Previous studies have shown that when presented with faces, children with ASD were significantly faster at saccading to a peripherally presented target than TD children (Chawarska et al. 2003). Importantly, this difference only occurred when the central cue was a photo of a real face, but not for biologically irrelevant cues. The authors suggested that TD children may require more time to process the eye movement cue than the children with ASD. Our data contradict this finding and suggest that the eye movement cues required less time to be processed than the arrow cues, for both the ASD and the TD groups.



Similar to previous research (Kuhn and Kingstone 2009), the cueing effect decreased with increasing distractor-to-saccade-direction-cue SOA. Intriguingly, in terms of SRT's, our results revealed that the cueing effect for eye gaze distractors may have been longer lasting than for arrow cues. Whilst the cueing effect for arrows disappeared at the 600 ms SOA, it remained intact for the eye gaze distractor. The time course of the gaze cueing effect is rather different to that of peripheral exogenous cues, such as the onset of a new object. Whilst gaze cueing is relatively long lasting (up to 1,000 ms) (Friesen and Kingstone 1998; Frischen et al. 2007), peripheral cueing at cue-to-targets SOAs longer than 300 ms result in RT delays, an effect commonly known as *inhibition of return* (Posner and Cohen 1984). It is unclear as to why arrow and eye gaze cues should differ in their time course in this experiment, and more research would be required to investigate this rather intriguing finding.

It has been claimed that eye gaze cues shift attention more effectively than do arrow cues (Friesen et al. 2004) and that children with ASD are less able to inhibit counter-predictive arrow distractors than their TD peers (Senju et al. 2004). If cue following is reflexive, we would expect the error saccades to have shorter SRT's than the correct saccades (Kuhn and Benson 2007; Theeuwes et al. 1999). Indeed this pattern of results is what was found here for both cue types and both groups, demonstrating that there were no differences between these two cue types and that this effect did not interact with group. Once participants are planning the execution of a saccade both arrow and eye gaze cues are equally compelling at eliciting reflexive saccades, which concurs with previous results, using healthy TD participants (Kuhn and Kingstone 2009).

A further insight afforded by our data is whether distractor cues automatically initiate a gaze following response, even when the requirement is to fixate a central point. Similar to previous findings (Kuhn and Kingstone 2009) we found no evidence for this spontaneous gaze following. Eye movements during the time window between the distractor cue and saccade instruction were only elicited on a small proportion of trials. Moreover, there was no difference in the number of error saccades made in the same or the different direction to which the distractor gaze was pointing. There was therefore no evidence for spontaneous cue following for either distractor type or group. It is important to note that when participants executed a saccade, both distractor cues resulted in automatic attentional orienting in the cued direction. However, when they were required to fixate the fixation point, they were perfectly capable of ignoring the cues, and did not follow them automatically.

Finally we looked at individual differences in cue following between the two groups. Previous studies using a Posner type cueing task have found a negative correlation between the gaze cueing effect and AQ scores (only at the

700 ms SOA) (Bayliss et al. 2005). That is, individuals who scored higher on the AQ were cued less by eyes only (and not arrows) than individuals who scored lower. In the present study no such correlations were found, suggesting that AQ scores are not related to distractor differences between arrow and eye gaze cues. Several differences between our design and that used by Bayliss et al. should be highlighted. For one, Bayliss et al. used a manual RT task rather than an overt attention task. Although it is not clear why differences between these two tasks should exist, it is possible that they tap into different processes (overt versus covert attention). Another difference relates to the face cues used. Bayliss et al. used photographs of real faces rather than schematic cartoon faces. However, as both types of faces are thought to elicit identical gaze cueing effects it is not clear how the difference in stimuli could explain our findings (Hietanen and Leppanen 2003). Whilst Bayliss et al. looked at individual differences within a normal population (predominantly female), our sample included a predominantly male control group and clinical sample. Finally, as highlighted in their discussion, the analysis of the AQ scores in the Bayliss study was post hoc. Moreover, no direct comparison between the cueing effects of arrow and eye gaze cues as related to AQ scores were made. Their interpretation may therefore have been somewhat premature and more research is required to verify it.

Individuals with ASD, particularly those with normal-range IQs, may learn some of the social skills which come naturally to TD children, such as eye-gaze cueing. It is therefore possible that whilst children with ASD show abnormalities in their use of social information, by the time they reach adulthood these differences are less apparent. For example, some scene viewing studies tasks have shown that adults with ASD spend the same amount of time looking at faces as do TD adults (Fletcher-Watson et al. 2009) (c.f. Riby and Hancock 2008). However, this study also showed that TD adults but not those with ASD, are more likely to orient to social information in a scene with their first saccade, demonstrating that atypicalities in processing or orienting to social information (people) do exist in later life. Furthermore, a recent study that examined the effects of different task instruction (social versus material) for the same scene inspection (Benson et al. 2009) showed that although participants with ASD attended to social information, saccadic scanning was modulated by instruction for the TD group exclusively. Fletcher-Watson et al. also showed that under free viewing conditions the individuals with ASD were less likely to fixate objects that were looked at by the central character in a scene, thus demonstrating a reduction in spontaneous gaze following in adults. Therefore, before any firm conclusions about how gaze cueing develops in autism, more direct comparisons between adult and child populations are required.

Our simplified gaze/arrow cueing task has demonstrated that both individuals with ASD and TD people show similar levels of gaze following. An unanswered question from this study relates to whether these type of cueing tasks tap into the true nature of gaze cueing. In order to control for the salience between the arrow and the eye gaze cue we decided on using schematic rather than images of real faces. It could therefore be argued that our failure in demonstrating differences between arrows and eye gaze was due to the low ecological validity of our stimuli. However, most of the studies that have demonstrated qualitative differences between these two cue types utilized schematic rather than images of real faces [behavioural (e.g. Friesen et al. 2004) and neurological (e.g. Hietanen et al. 2006; Ristic et al. 2002)]. Moreover, studies that have directly compared the gaze cueing in real versus schematic faces have found no difference (Hietanen and Leppanen 2003), implying that schematic and real faces result in identical gaze cueing effects. The main limitations of these gaze cueing tasks, regardless of whether images or real faces or cartoon faces are used, is that the gaze cue is pre-selected (i.e. presented without background). Indeed it has been shown that under these types of conditions even non predictive tongue pointing may result in cueing effects (Downing et al. 2004). This means that findings from these types of task may be reflecting attentional cueing irrespective of social processing (Kingstone 2009; Kingstone et al. 2008). The challenge for future research should be to find tasks that investigate social attention in more naturalistic settings. One avenue that has adopted this challenge is scene viewing research (Fletcher-Watson et al. 2009). However, these studies still lack some of the sensory richness of the real world, and in particular miss out on the dynamic aspect of the world. A more ecologically valid approach would be to use dynamic scenes, which have been employed in the past with ASD groups (Klin et al. 2002; Riby et al. 2008; Rutherford and Krysko 2008; Webster and Potter 2008) as well as with TD adults (Kuhn and Land 2006; Kuhn et al. 2009; Tatler and Kuhn 2007). By using these highly naturalistic stimuli, we may be able to tap into more socially relevant processing of gaze following and thus uncover more subtle differences in gaze cueing.

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