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# Spontaneous Gaze Selection and Following During Naturalistic Social Interactions in School-Aged Children and Adolescents With Autism Spectrum Disorder

Elina Birmingham, Krista Haley Smith Johnston, and Grace Iarocci  
Simon Fraser University

Using a novel naturalistic paradigm allowing participants the freedom to spontaneously select and follow gaze cues in their environment, this study extends previous research conducted with younger children to determine whether school-age children with autism spectrum disorder (ASD,  $n = 17$ ) demonstrate abnormal gaze following relative to typically developing (TD,  $n = 15$ ) children. The participant and experimenter played a series of games, during which the experimenter pseudorandomly averted her gaze toward a social target (person) or a nonsocial target (object). A significant finding was that, relative to TD children, children with ASD were slower to follow the experimenter's gaze relative to the start of the trial (social targets  $d = -.93 [-1.70, -.16]$ , nonsocial targets  $d = -1.05 [-1.88, -.20]$ ). When we analyzed the duration of glances to the experimenter, we found that the ASD group made longer glances relative to TD children, but only in the nonsocial target condition (social targets  $d = .01 [-.68, .71]$ , nonsocial targets  $d = -.81 [-1.53, -.08]$ ). Other analyses revealed patterns of gaze selection and following that may help interpret the main findings. Despite the differences in the timing of gaze selection and following, the most common type of responder in both groups was one who followed the experimenter's gaze on over half of the trials. This pattern of results argues against a clear deficit in social attention in school-age children with ASD and underscores the importance of measuring both the timing of distinct mechanisms of social attention and the context in which these behaviors occur.

*Keywords:* autism spectrum disorder, gaze following, gaze selection, real-world, naturalistic

In novel or ambiguous situations children must look to others to guide their attention to relevant sources of information while ignoring competing input. Attending to and following others' gaze to a shared point of reference allows children to gain quick access to key sources of information for learning (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Moore & Dunham, 1995). Orienting to and following a knowledgeable other's gaze increases the likelihood that the less experienced child will share the other's point of view on novel or potentially threatening external objects or events (Racine & Carpendale, 2007; Seemann, 2011). As the coordination of this "joint attention" (Moore & Dunham, 1995) improves, children gain awareness/understanding

of themselves, their social partner and about the objects or events of interest (Bakeman & Adamson, 1984; Corkum & Moore, 1995). Indeed, previous research has demonstrated that gaze following in infancy predicts later language development (Brooks & Meltzoff, 2005) and facilitates object learning (Wu, Gopnik, Richardson, & Kirkham, 2011). Thus, when a child fails to attend to and follow the gaze of others, valuable learning opportunities may be missed, and it may be an early indicator that development is not proceeding on a typical trajectory (Mundy & Newell, 2007).

A failure to respond to the joint attention (RJA) bids of others is considered to be an early red flag for Autism Spectrum Disorder (ASD; Robins, Fein, Barton, & Green, 2001), and is a core component of the diagnostic assessment for ASD in young children (Lord et al., 2000). Furthermore, there is emerging evidence that a slow progression in the *initiation* of joint attention (e.g., pointing at objects to direct others' attention; IJA) among high-risk infant siblings of children with ASD may be a key behavioural marker of ASD within the first year of life (Szatmari et al., 2016). Thus, it is not surprising that improving joint attention has become a focal point both for research and for early interventions designed to improve social-communication in children with ASD (Kasari, Freeman, & Paparella, 2006; Rogers & Dawson, 2010; White et al., 2011). In the present study we focus specifically on understanding gaze following (RJA) in ASD, because although its importance for characterizing ASD is established for very young children (Mundy, Sullivan, & Mastergeorge, 2009), much less is known about how gaze following operates in older, school-age children with and without ASD. Below we will outline one pos-

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Elina Birmingham, Faculty of Education, Simon Fraser University; Krista Haley Smith Johnston and Grace Iarocci, Department of Psychology, Simon Fraser University.

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Correspondence concerning this article should be addressed to Elina Birmingham, Faculty of Education, Simon Fraser University, 8888 University Drive, Burnaby, BC V5A 1S6, Canada. E-mail: ebirming@sfu.ca

sible reason for this gap in the research, namely, the need for developmentally appropriate paradigms that isolate specific mechanisms of RJA within naturalistic settings.

### Measuring Gaze Following

To demonstrate ASD-related abnormalities in gaze following, naturalistic gaze following studies involve an experimenter who sits across from a child, engages the child's attention by making direct eye contact with him or her, and then looks to the left or right (typically with a head movement), focusing her gaze on a peripheral object such as a toy or picture on the wall (e.g., Butterworth & Cochran, 1980; Scaife & Bruner, 1975). Additional prompts, such as pointing and vocalizations ("Look at that!"), are used only if the child fails to follow gaze/head direction alone. This process is repeated four to eight times over the course of the session, and the measure of interest is typically the percentage of trials (or a pass/fail criterion) on which the child successfully orients attention (by looking) in the direction of the experimenter's gaze. A number of studies using this paradigm have demonstrated that preschool children with ASD are less likely to correctly follow the head turn of an adult relative to mental-age-matched typically developing (TD) children and/or developmentally delayed children (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson et al., 2004; Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997; Sigman & Ruskin, 1999; Warreyn, Roeyers, Oelbrandt, & De Groote, 2005; although see Leekam & Ramsden, 2006, who found no group differences). Young children with ASD are also less likely to follow the pointing gestures of an adult (Baron-Cohen et al., 1996; Landry & Loveland, 1988) and to follow pointing combined with looking (e.g., Dawson et al., 1998, 2004). Importantly, work by Leekam and colleagues showed that reduced gaze following in ASD could not be explained by an underlying inability to discriminate the direction of another person's gaze (Leekam et al., 1997), or to more global difficulties with disengaging and shifting attention from a central stimulus (Leekam, Lopez, & Moore, 2000). Instead, various researchers have proposed that children with ASD may be less motivated to attend to social cues (Dawson et al., 2004), lack the cognitive machinery to establish shared attention (Baron-Cohen et al., 1996), or fail to understand the social significance of observing another person orienting their attention in space (Rombough & Iarocci, 2013).

Although the available evidence points to the importance of gaze following in early development, there is still much uncertainty about whether gaze following abnormalities in ASD persist and, if so, whether they may manifest differently later in development when the role of joint attention in social interaction may be different (Mundy et al., 2009; Bean & Eigsti, 2012). Indeed, some work has demonstrated that older, relatively more able individuals with ASD show "normal" levels of gaze following. For instance, Leekam et al. (1998) has shown that school-age children with ASD (aged 8 years) with relatively higher verbal mental age (VMA >4 years) showed high rates of gaze following, whereas those children with lower VMA age (VMA <4 years) showed almost no spontaneous gaze following. The authors suggest that after a certain point in development, children with ASD may "catch up" with their neurotypical peers; and that early deficits in joint attention could reflect a developmental delay (Leekam et al., 1998). This is consistent with other research showing age-related improvements

in children's ability to follow the pointing gestures of adults (DiLavore & Lord, 1995; Mundy et al., 1994). However, the picture is far from clear, as other work has reported reduced or even absent joint attention in older school-age children with ASD (Bean & Eigsti, 2012; Leekam et al., 1997).

### Limitations of Existing Paradigms

One key limitation of existing gaze following studies that may be clouding the picture is that researchers have typically failed to distinguish between separate attentional components of gaze following. Arguably, there are at least two distinct stages in gaze following: first, we select (orient to) the eyes as a key social stimulus, and second, we follow their direction of gaze (Birmingham & Kingstone, 2009; see also Macdonald & Tatler, 2013, who find evidence for this temporal pattern in real world contexts). This distinction reflects those made in the broader attention literature, in which *selection* is defined by the process by which some items are chosen for further processing and others are ignored, and spatial orienting is the shifting of focal attention from one spatial location to another (Posner, 1980; Yantis, 1988). In most studies of gaze following, however, the experimenter circumvents the selection process by "preselecting" the gaze cue for the child, to ensure that it is attended to and processed. For instance, in naturalistic studies, the experimenter purposefully makes eye contact with the child with ASD before delivering the gaze cue (e.g., Thorup, Nyström, Gredebäck, Bölte, & Falck-Ytter, 2016); the trial typically does not continue without first establishing mutual gaze. The same feature exists for studies using the gaze cueing paradigm, an adaptation of the Posner cueing paradigm (Posner, 1980) that has been widely used to examine gaze following in more controlled settings. Here, a schematic or photographed face appears in the center of the screen, with eyes looking left or right. To give a measure of covert orienting, the participant's task is to maintain fixation at the centre of the screen and manually detect or discriminate a peripheral target as quickly as possible (e.g., Friesen & Kingstone, 1998); when researchers want to measure overt orienting, participants are asked to make a saccade from the centre of the screen to the target location (e.g., Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Again, the gaze cue is preselected for the participant, this time by placing it at the centre of the screen, where participants are instructed to attend.

Arguably, by preselecting the gaze cue for participants—whether by establishing eye contact before delivering a cue (naturalistic studies), or by presenting a face cue at the centre of an otherwise blank screen (gaze cueing studies)—researchers have created a context in which observers with ASD are processing a cue that they might normally avoid or ignore (Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002; Rutter & Schopler, 1987; Swettenham et al., 1998; Volkmar & Mayes, 1990). This could explain why, despite the field's predictions that the gaze cueing paradigm would reveal reduced, absent, or abnormal gaze following in ASD, the vast majority of studies have failed to report this finding (see Birmingham, Ristic, & Kingstone, 2012; Nation & Penny, 2008, for reviews). We suspect that the issue of preselection is particularly relevant when conducting naturalistic studies of gaze following in school-age children and adolescents, who may have caught up with their peers in terms of their ability to orient their attention in response to an already selected gaze cue

(Leekam et al., 1998). Certainly, given the large body of research suggesting that children, adolescents, and adults with ASD show reduced or slowed gaze selection when presented with images of complex social scenes (e.g., Birmingham, Cerf, & Adolphs, 2011; Dalton et al., 2005; Dawson et al., 2004; Freeth, Chapman, Ropar, & Mitchell, 2010; Kuhn, Kourkoulou, & Leekam, 2010; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Riby, Hancock, Jones, & Hanley, 2013), a question that is ripe for investigation is how gaze following unfolds when children with ASD are given the freedom to both select and follow gaze cues in natural environments.

### Present Study

We led a study of spontaneous gaze following in youth (8–16 years) with ASD and TD controls using a novel, naturalistic paradigm designed for testing both gaze selection and following. In this paradigm, children played a card or board game with an experimenter who pseudorandomly delivered task-irrelevant head turns. We purposefully delivered gaze cues while the child was looking elsewhere (down at his or her cards), so that we could capture both gaze selection and gaze following within the same task (Birmingham & Kingstone, 2009). We purposefully designed the study so that the experimenter’s averted gaze cues were unrelated to the task-at-hand (i.e., a gaze following response was not “required” as part of the interaction) so that we could measure spontaneous gaze following.

We examined both the frequency of gaze selection and gaze following in ASD and age- and IQ-matched TD controls, as well as the timing of these behaviors, analyzing high-definition video footage of the interaction. To examine the influence of context on gaze following in ASD and TD, we explored the possibility that participants with ASD and TD may differ in their likelihood, or speed, of following an adult’s gaze, particularly when that gaze is directed at a social target (another person), as opposed to a non-social target (an object).

### Method

#### Participants

We recruited 17 TD participants (13 male, four female) and 20 participants (17 male, three female) with ASD (IQ >80) between the ages of 8 and 16 years. Participants with ASD were recruited from the Simon Fraser University Autism and Developmental Disorders Lab

(ADDL) database of participants who had a diagnosis of ASD and had consented to be contacted about research participation. TD participants were recruited through this database as well as through advertisement on the ADDL website. All participants lived around Vancouver in British Columbia, Canada. Participants in both ASD and TD groups were of mixed ethnic heritage. Ethnic backgrounds represented in the TD sample include Asian (50%), European/Canadian (44%), and South American (12%). Backgrounds represented in the ASD sample include European/Canadian (60%), Asian (25%), and (15%) participants who best fit into other categories (e.g., African-Canadian, Pacific Islander, and one participant who was unidentifiable). All participants spoke fluent English. Four participants in the ASD group had a comorbid diagnosis of ADHD; one had a diagnosis of OCD; and one was reported to have both a mood and an anxiety disorder. No TD participants had any reported diagnosis. The study was conducted in accordance with the standards of the university’s Office of Research Ethics.

Three participants in the ASD group and two in the TD group were excluded from final analysis (see exclusion criteria in Data Handling section, below). Final samples were matched on both age and IQ using The Stanford Binet Intelligence Scale, Abbreviated Battery (Roid, 2003). See Table 1 for detailed participant information. For the ASD group, the revised Autism Diagnostic Interview (ADI-R; Lord et al., 1994) was administered to all participants; six by a trained researcher in the lab, and 11 by a trained clinician in the community. Since 2004, clinical diagnoses of ASD in our jurisdiction must be conducted by clinicians who are trained on the use of the ADI-R and the Autism Diagnostic Observation Schedule (ADOS-G). The clinicians must use both of these tools in their diagnostic assessment of a child suspected of having ASD in order for the family to qualify for treatment funding. Diagnostic reports were obtained to verify that the ADI-R was administered and that the child’s score exceeded the ASD cut-off. For those who had been diagnosed prior to 2004, the ADI-R was conducted by a trained clinical researcher in the lab. Participants were also administered the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005) to confirm that the ASD group met suggested cut-offs associated with autism. See Table 1 for more detailed participant information.

#### Apparatus and Materials

The ASL Mobile Eye (Applied Science Laboratories; Bedford, MA) and two Logitech HD webcams were used to record gaze allocation and the social interaction between the participant and

Table 1  
*Participant Characteristics*

Characteristic	ASD ( <i>n</i> = 17)	TD ( <i>n</i> = 15)	<i>p</i>
Age in years	11.81 (2.31), 8.08–15.66	12.18 (2.41), 8.16–16.00	>.66
Gender ratio	14M:3F	12M:3F	>.86
ABIQ	104.59 (10.24), 82–121	107.80 (7.92), 94–127	>.33
SRS total raw score	88.13 (32.31), 32–143	24.40 (15.42), 7–50	<.001
SRS total scaled score <60 = normal range; 60–75 = mild/moderate range; >76 severe range	74.63 (13.36), 49–90	46.47 (8.03), 37–62	<.001

*Note.* ABIQ = Abbreviated IQ (based on Stanford-Binet Abbreviated IQ Battery); SRS = Social Responsiveness Scale; M = male; F = female. SRS data was missing for one autism spectrum disorder participant. Data are presented as means, standard deviations (in parentheses), and range.

the experimenter during the games. One webcam was positioned in front and to the right of the participant and was aimed at the participant's partial profile as well as the experimenter's profile; the second webcam was placed behind and to the left of the participant and was aimed at the experimenter to confirm cue delivery. The testing room was arranged with a variety of colorful objects and books to serve as gaze targets (see Figure 1 for a schematic with dimensions of the testing room). Due to unreliable eye tracking data for the majority of participants, we coded only the HD webcam footage.<sup>1</sup>

## Procedure

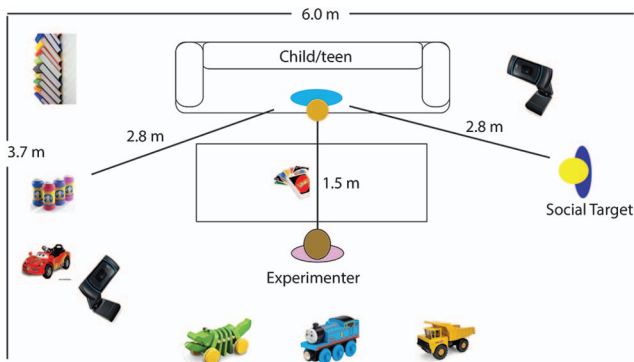
Participants were told that they would be playing a series of games with the experimenter. A female experimenter (Krista Johnston, KJ) and the participant sat directly across from one another at a table throughout the experiment, at a distance of approximately 1.5 m. A female observer (Elina Birmingham, EB), who served as the social target, sat on a chair at the side of the room, to the left of the participant (approximately 2.8 m away). This observer sat quietly throughout the experiment and participants were told that she would be monitoring the eye tracking and video equipment and assisting with calibration. The participant and experimenter played two games: first a card game (UNO or Go Fish, chosen by the participant), followed by a board game (SORRY! or TROUBLE, chosen by participant). Each game lasted approximately 30 min.

During each game, the experimenter averted her gaze four times, spaced out across the duration of the game at pseudorandom intervals (the average interval between cues was 153.3 s). The goal was to make the gaze event appear as natural as possible, occurring seamlessly throughout the social interaction and unrelated to the game. The target of the experimenter's gaze was either a social target (the observer) or a nonsocial target (an object on the left or

right side of the room—although note that specific objects chosen as targets and their relative positions were not tightly controlled across trials or participants). Order of gaze target (social or nonsocial) was assigned to a random order before the experiment; the experimenter was able to reference this target order on a run-sheet concealed from the participant's view. Two social targets and two nonsocial targets were delivered for each game, giving a total of eight trials (4 cues  $\times$  2 games). Target side (to the left or right of the participant) was partially counterbalanced, as the social target position was necessarily fixed (as the observer remained seated throughout the experiment); thus, only nonsocial target positions were counterbalanced between left and right sides of the room (although their relative positions were not controlled). The experimenter varied between a neutral (card game) and smile expression (board game) for all participants, but we chose not to analyze the effect of expression due to low power and because the order of expression was not counterbalanced. Thus, our analyses collapsed across the trials in the card and board games.

Timing of cue delivery was as follows: near the end of the participant's turn in a game (i.e., when the participant was putting their cards down or moving their pawn), the experimenter averted her head and gaze (without vocalization), and held this cue for approximately 10 s, or until the participant responded by following her gaze. Importantly, the experimenter delivered this cue when the participant was not looking at her, to avoid cuing attention via motion signals. If the participant responded by looking at the experimenter and following her gaze, she ended her cue and returned her gaze to the game. If the participant looked at the experimenter but did not follow her gaze (or failed to look at her at all) she ended the cue after approximately 10 s and returned her attention to the game.

When a trial ended, the experimenter sometimes provided a semi-scripted cover story to smooth out the social interaction, to avoid raising suspicion or mistrust in the participant. For example, after ending a gaze cue to the social target, the experimenter might say "I like your hair today," "you'll get to play next time," "we don't need



**Figure 1.** Experimental setup with dimensions. A female experimenter and the participant sat directly across from one another at a table throughout the experiment, at a distance of approximately 1.5 m. A female observer, who served as the social target, sat on a chair at the side of the room, to the left of the participant (approximately 2.5 m away). One webcam was positioned in front and to the right of the participant and was aimed at the participant's partial profile as well as the experimenter's profile; the second webcam was placed behind and to the left of the participant, and was aimed at the experimenter to confirm cue delivery. The testing room was arranged with a variety of colorful objects and books to serve as gaze targets. See the online article for the color version of this figure.

<sup>1</sup> Eye tracking data was unreliable for the majority of participants ( $n = 25$ ), due to (a) difficulty calibrating or (b) loss of calibration during the experiment. (a) Difficulty calibrating ( $n = 11$ ). The Mobile Eye has two cameras mounted on the frame of a pair of goggles; one camera (scene camera) records the scene from the participant's point of view, the other (eye camera) records the movements of the right eye by capturing its image reflected on a clear plastic disk. Calibration relies on dark pupil detection and detection of corneal reflections; difficulty detecting of either of these signals will compromise calibration. If we were unable to calibrate the eye tracker, it was due to fluorescent lighting from the ceiling that created a glare in the reflective lens, interfering with the detection of corneal reflectors; and/or the participant's facial structure did not support the goggles and the camera did not adequately capture the eye; and/or calibration failed for unknown reasons, possibly due to limitations of this older eye tracking system. Because we were testing a special population, we limited the calibration procedure to 10 min; if adequate calibration was not obtained within this time frame, we moved forward with the experiment. (b) Loss of calibration during the experiment ( $n = 14$ ). Reasons for loss of calibration included the following: participant's facial structure did not adequately support the eye tracking glasses on the face, causing the glasses to slip and lose the image of the pupil; participant accidentally bumped the eye tracking glasses during the experiment, or made facial expressions, or squinted, leading to intermittent loss of signal; glare from overhead lighting interfered with corneal detection; scene camera did not capture the experimenter's face at certain positions of the participant's head, making it impossible to code gaze selection in those frames.

that card for the game, thanks though.” After ending a cue to a nonsocial target, the experimenter might say, “sorry, I’m getting distracted today,” or “huh, there was something interesting over there,” or “I was just noticing that they spelled “welcome” on the board” (after gazing at a white board). These responses varied depending on the gaze target.

## Data Handling

Participants were excluded from analysis (3 ASD, 2 TD) for the following reasons. ASD: IQ testing revealed that the participant’s IQ was below 80 ( $n = 1$ ); behavioral/hyperactivity issues prevented completion of the experimental protocol ( $n = 2$ ); TD: video data loss due to equipment malfunction ( $n = 2$ ). After participant exclusions, data was carefully screened at the trial level. There were 262 trials in total across the whole sample; 14 of these (5%) were excluded because the participant unexpectedly looked up at the experimenter as she was delivering the cue; 12 trials (4.6%) were excluded because of poor video quality; nine (3%) were excluded because of poor timing of cue delivery (e.g., the participant had not actually ended their turn). This left a total of 227 analyzable trials across both groups.

In all analyses, we analyzed only trials on which participants looked at the experimenter at least once after her gaze cue was delivered, which ensured that they would have had a chance to process the cue. Thus, we excluded a small number (six of 227) of total trials on which participants failed to look at the experimenter at all.

Two researchers (KJ and EB) first cocoded the following behaviors to consensus. Using Chronoviz V2.0.0 (Fouse, Weibel, Hutchins, & Hollan, 2011) for annotating videos, time stamps were first placed at the moment that the participant’s turn ended (the moment at which he or she finished any and all physical actions associated with his or her turn, such as placing a final card down or resting the pawn on its final square on the board); note that at this point in time, the participants’ gaze was directed downward at his or her cards or game pieces, and the experimenter’s gaze was surreptitiously averted. A 30-s window was then computed with this time stamp as the start-point. Within this 30-s window, we then time-stamped (a) the start and end points of any looks to the experimenter’s face; (b) the start and end points of gaze following behaviours (i.e., from the moment the participant turned his or her head and eyes (or eyes only) in the direction of the target, to the moment s/he turned her head and eyes back to the experimenter or the game); and (c) cue time-out, if the participant did not follow the experimenter’s gaze. These time stamps were used to calculate the following variables (see Figure 2 for a visual representation):

- Gaze selection: frequency (number of individual glances to the experimenter’s face within a trial); latency (of) first look (at the experimenter’s face after the end of the participant’s turn); mean duration (of individual glances to the experimenter’s face)
- Gaze following: proportion of trials, latency from (participant’s) turn end, latency from first look (at experimenter), latency from last look, duration (of following response).

KJ and EB coded all data collaboratively and to consensus; an independent coder, who was blind to diagnosis and research hypotheses, coded a subset (70%) of the data. Interrater reliability (IRR) was high for the binary coding of gaze following (follow vs. no follow; Cohen’s  $\kappa = .89$ ,  $p = .035$ ). For a subset of (nonre-

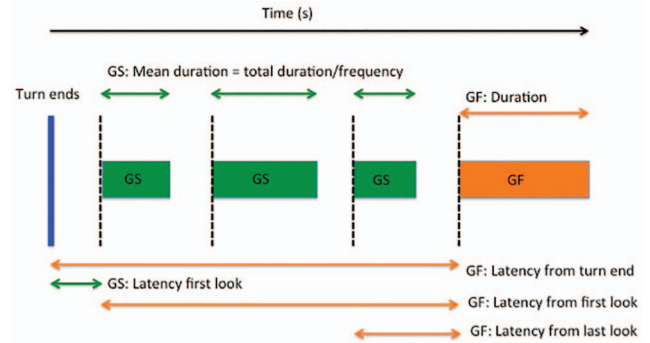


Figure 2. Timeline schematic illustrating gaze selection and gaze following latency variables, for a hypothetical example in which a child makes three looks to the experimenter and then follows the experimenter’s gaze after the third look. GS = gaze selection; GF = gaze following. See the online article for the color version of this figure.

dundant) latency and duration analyses, IRR was assessed using a two-way mixed, absolute agreement, single-measures intraclass correlation coefficient (ICC; Hallgren, 2012; McGraw & Wong, 1996) to assess the degree that coders were in absolute agreement in their coding of latency across subjects. The resulting ICC was .65 ( $p < .001$ ) for gaze selection: latency first look; ICC = .75 ( $p < .001$ ) for gaze selection: mean duration; ICC = .79 ( $p < .001$ ) for gaze following: latency from turn end; ICC = .82 ( $p < .001$ ) for gaze following: latency from last look; ICC = .87 ( $p < .001$ ) for gaze following: duration follow. Data from KJ and EB’s coding was used for all subsequent analyses.

**Null hypothesis statistical testing.** For each dependent variable, we conducted traditional null hypothesis statistical testing (NHST) using mixed repeated measures analyses of variance (ANOVAs) in SPSS with group (ASD, TD) as the between-subjects factor and gaze target (social, nonsocial) as the within-subjects factor. Means, Cohen’s  $d$ , and 95% CIs are presented in each figure (plotted in *Exploratory Software for Confidence Intervals* [ESCI]; Cumming, 2011).

**Bayesian analyses.** To supplement NHST, additional Bayesian analyses were run in JASP (Version 0.7.5.6), comparing the fit of the data under the null hypothesis (no group difference) and the alternative hypothesis ( $ASD \neq TD$ ). Given the novelty of the current paradigm and lack of data on naturalistic gaze following in school-age children with ASD, we chose to run default Bayesian  $t$  tests with a Cauchy’s distribution of priors (centered on  $\delta = 0$ , with effect sizes ranging from  $-2.0$  to  $2.0$ ) with a default width of 0.707. The reported Bayes factor ( $BF_{01}$ ) reflects the degree of support for the null hypothesis versus the alternative hypothesis, with higher values indicating more support for the null hypothesis versus the alternative (e.g.,  $BF_{01} > 3$  substantial evidence for the null;  $BF_{01} = 1$  no evidence;  $BF_{01} = .33$ – $1$  anecdotal evidence for the alternative hypothesis;  $BF_{01} < .33$  substantial evidence for the alternative hypothesis vs. the null; Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011).

## Exploratory Analysis of Participant Responses

We also analyzed patterns of gaze following in more exploratory ways. First, akin to previous work that categorized partici-

pants as different types of responders (e.g., “passing” or “failing” a gaze monitoring test based on the number of trials on which the participant successfully followed gaze; e.g., Leekam et al., 1997; Scaife & Bruner, 1975), we assigned participants into categories: never follows, follows on less than half of trials, follows on over half of trials, and always follows. This was accomplished by assigning a value of 0 (*did not follow*) or 1 (*followed*) to each trial, summing the scores and assigning each participant to one category. Chi-square analyses were performed on the data to look for group differences in patterns of responding.

Second, we had a naïve observer transcribe and tabulate all the vocalizations and behaviors (e.g., overt gestures by participants) made by participants in each trial. As we were interested in participants’ reactions to the experimenter’s averted gaze cue, EB and KJ then assigned a code of 1 to each vocalization occurring after the experimenter averted her gaze, but before the gaze following response (or trial time-out). This was done separately for each trial, regardless of whether or not the participant followed the experimenter’s gaze. Each participant was then assigned to one of four possible categories: never vocalized, vocalized on less than half of trials, vocalized on over half of trials, or always vocalized. The same procedure was used to code behaviors. Chi-square analyses were performed on the data to look for group differences in patterns of vocalizations and behaviors produced in response to the experimenter’s averted gaze. In addition, the main researchers (EB and KJ) reviewed the data to make qualitative observations.

### Power Limitations

Our analyses were limited by low power, a common issue in research with special populations. Data collection and analyses were very time intensive, and it was not feasible to run a larger group of participants. Because of the small sample size, we were also unable to explore individual differences in gaze selection and gaze following behaviors. To assist with interpretation of NHST analyses, we provide Bayesian analyses to quantify the evidence in favour of the null versus alternative hypothesis, and to indicate where additional data will be needed to make strong conclusions.

## Results

### Gaze Selection

**Frequency.** Here we analyzed the number of looks to the experimenter over the whole trial. In the mixed ANOVA, there was no effect of group,  $F < 1$ ; no effect of target,  $F(1, 30) = 1.12, p = .30, \eta^2 = .036$ ; and no interaction,  $F < 1$ . Although NHST revealed no group effect, it is important to note that the between-groups effect sizes (see Table 2) were small but in the expected direction ( $d = -.23$  for social targets;  $d = -.34$  for nonsocial targets). In addition, Bayesian  $t$  tests point to the need for more evidence before concluding that ASD and TD did not differ in their gaze selection frequency: for social targets, the estimated Bayes factor was 2.52 in favor of the null hypothesis, and for nonsocial targets, the estimated Bayes factor was 2.07 in favor of the null hypothesis.

**Latency first look.** How long did it take participants to first look at the experimenter’s face and to what extent was this latency different in ASD versus TD? The ANOVA revealed no main effect of group,  $F(1, 30) = 2.96, p = .10, \eta^2 = .090$ , suggesting that children

Table 2

*Means, Between-Groups Effect Size Estimates (Cohen’s  $d$ ), and 95% Confidence Intervals for Measures of Gaze Selection*

Gaze selection variable	Social target	Nonsocial target
Frequency		
ASD	2.59 [2.26, 2.91]	2.49 [2.12, 2.85]
TD	2.43 [2.04, 2.83]	2.27 [1.96, 2.57]
$d$	-.23 [-.93, .47]	-.34 [-1.04, .36]
Latency first look(s)		
ASD	2.87 [1.94, 3.81]	2.77 [1.30, 4.25]
TD	1.89 [1.40, 2.39]	1.92 [1.32, 2.52]
$d$	-.67 [-1.38, .046]	-.38 [-1.08, .32]
Mean duration (s)		
ASD	1.20 [.91, 1.49]	1.72 [1.39, 2.05]
TD	1.21 [.98, 1.44]	1.19 [.83, 1.56]
$d$	.01 [-.68, .71]	-.81 [-1.53, -.08]

*Note.* ASD = autism spectrum disorder; TD = typically developing.

with ASD were not statistically slower than TD children to initially look at the experimenter, despite numerical trends in that direction (Table 2, second row; Figure 3, top row). No other effects were significant (target:  $F < 1$ ; Group  $\times$  Target,  $F < 1$ ). Although NHST testing revealed no group effects, Bayesian analyses suggested that evidence for this conclusion is rather weak. For social targets, there was an estimated Bayes factor of 1.30 in favour of the alternative hypothesis; whereas for nonsocial targets, the estimated Bayes factor was 1.90 in favor of the null hypothesis. Taken together with the moderate effect sizes in the expected direction (social:  $d = -.67$ ; nonsocial  $d = -.38$ ), these analyses do not provide conclusive support for either the null or the alternative hypothesis, and suggest trends toward a possible group difference with increased power.

**Mean duration.** What was the average duration of looks to the experimenter, and did this differ between groups? NHST revealed no effect of group,  $F(1, 30) = 2.45, p = .13, \eta^2 = .075$ , but did reveal a main effect of target,  $F(1, 30) = 4.37, p = .045, \eta^2 = .13$ , indicating that participants made longer looks to the experimenter when she was gazing at nonsocial targets relative to social targets. A Significant Group  $\times$  Target interaction,  $F(1, 30) = 4.89, p = .035, \eta^2 = .14$ , indicated that this effect of target was driven by the ASD group, who made particularly long looks to the experimenter when she was gazing at nonsocial targets.

Bayesian analyses explored the degree of support for this pattern of results. For social targets, the estimated Bayes factor was 2.97 in favor of the null hypothesis, which is fairly substantial support for the conclusion that the groups did not differ in their duration of glances to the experimenter when she was gazing at a social target. In contrast, for nonsocial targets the estimated Bayes factor was 2.32 times in favor of the alternative hypothesis (modest evidence). The Bayes factors, along with the estimates of effect size (social:  $d = .01$ ; nonsocial:  $d = -.81$ ) provide support for the observed NHST interaction.

### Gaze Following

**Proportion of trials.** Here we analyzed the proportion of trials on which participants followed the experimenter’s gaze cue, to assess whether the ASD group was less likely, relative to the TD group, to follow the gaze of another person. NHST revealed no effect of group,  $F(1, 29) = 1.27, p = .27, \eta^2 = .042$  (see Table 3,

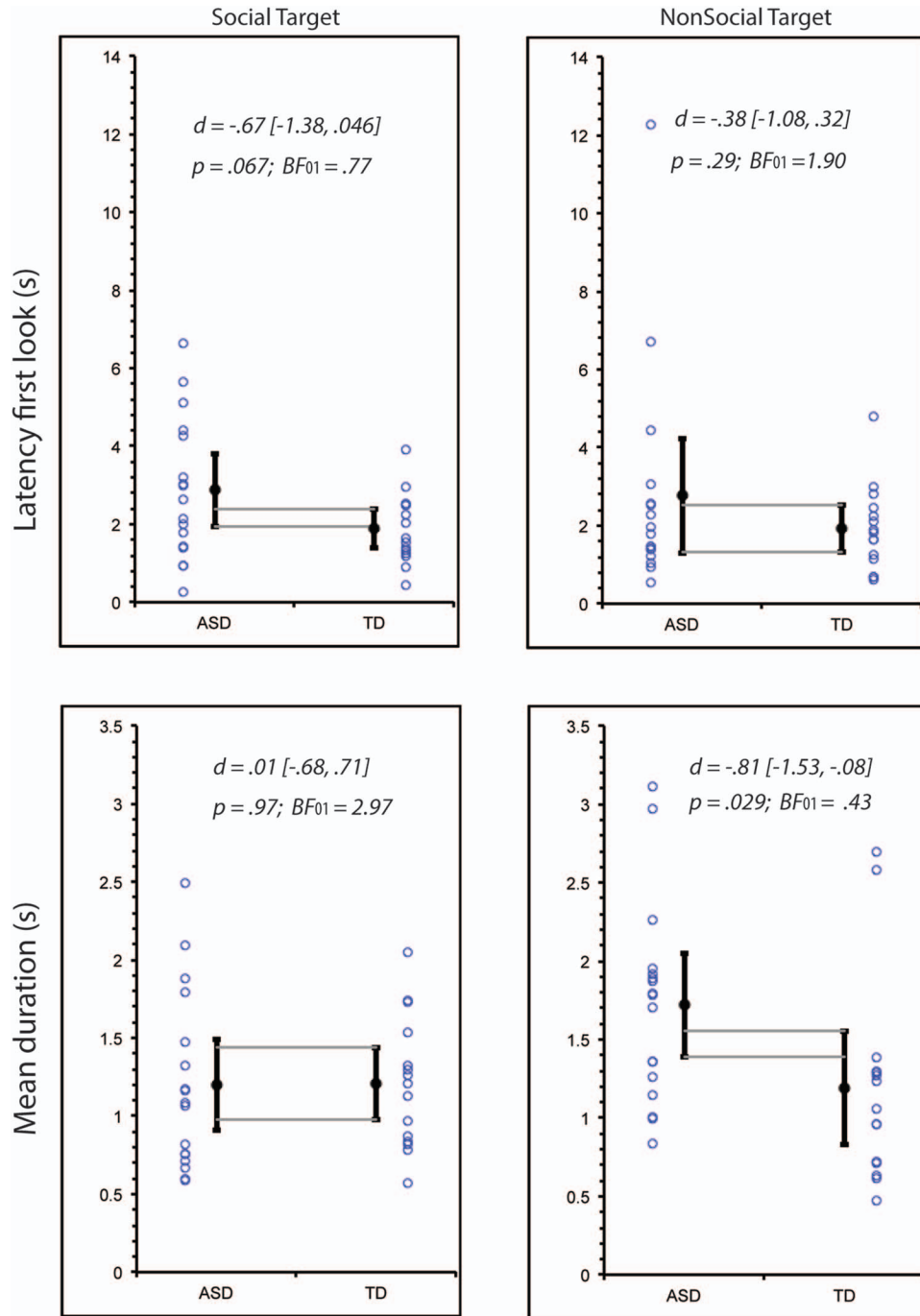


Figure 3. Timing of gaze selection in children with autism spectrum disease (ASD) and typically developing (TD) children. Data are plotted as means and 95% confidence intervals (CIs; error bars); Cohen's *d* (with 95% CIs), *p* values, and Bayes factors are provided for pairwise comparisons (two-tailed *t* tests, uncorrected). Circles represent individual data points. See the online article for the color version of this figure.

top row). The effect of target was also not significant,  $F(1, 29) = 3.15, p = .09, \eta^2 = .10$ . There was also no significant interaction,  $F(1, 29) = 1.03, p = .32, \eta^2 = .034$ , despite trends toward the groups differing in the nonsocial condition ( $d = .52 [- .21, 1.23]$ )

and converging somewhat in the social condition ( $d = .19 [- .51, .89]$ ).

Although NHST failed to reveal significant effects, the estimated Bayes factor was 2.65 in favor of the null hypothesis for



Table 3  
Means, Between-Groups Effect Size Estimates (Cohen's  $d$ ), and 95% Confidence Intervals for Measures of Gaze Following

Gaze following variable	Social target	Nonsocial target
Proportion of trials		
ASD	.72 [.55, .89]	.52 [.32, .73]
TD	.78 [.60, .96]	.71 [.53, .90]
$d$	.19 [-.51, .89]	.52 [-.21, 1.23]
Latency from turn end (s)		
ASD	5.96 [4.86, 7.05]	6.66 [4.83, 8.49]
TD	4.26 [3.32, 5.20]	4.13 [3.00, 5.27]
$d$	-.93 [-1.70, -.16]	-1.05 [-1.88, -.20]
Latency from first look (s)		
ASD	3.40 [2.34, 4.45]	4.30 [2.41, 6.19]
TD	2.41 [1.53, 3.29]	2.50 [1.39, 3.61]
$d$	-.57 [-1.31, .18]	-.74 [-1.54, .08]
Latency from last look (s)		
ASD	1.14 [.79, 1.49]	2.10 [1.48, 2.73]
TD	1.56 [.98, 2.14]	1.44 [1.06, 1.83]
$d$	.51 [-.24, 1.24]	-.80 [-1.61, .02]
Duration (s)		
ASD	1.60 [.75, 2.44]	1.68 [.83, 2.54]
TD	1.47 [.98, 1.95]	1.21 [.96, 1.46]
$d$	-.10 [-.83, .63]	-.48 [-1.27, .32]

Note. ASD = autism spectrum disorder; TD = typically developing.

social targets, and 1.37 in favor of the null hypothesis for nonsocial targets. This provides rather weak support for the null hypothesis, particularly in the nonsocial condition, and suggests the need for more evidence before concluding that the groups did not differ in gaze following frequency.

The chi squared analysis on the types of responders (see Table 4) revealed no significant association between diagnosis and rate of gaze following;  $\chi(3) = 4.27, p = .23$ . For both TD and ASD groups, the most frequent type of responder was one who followed on over half the trials; very few participants never followed the experimenter's gaze, and only a minority of participants always followed her gaze.

**Latency from turn end.** When participants followed the experimenter's gaze, how long did it take them to do so relative to the end of their turn? A Mixed Group  $\times$  Target Type repeated measures ANOVA on "follow" trials revealed a strong main effect of group,  $F(1, 22) = 14.79, p = .001, \eta^2 = .40$ , indicating that the ASD group was slower overall to follow the experimenter's gaze than the TD group. No other effects were significant (target:  $F < 1$ ; Condition  $\times$  Target:  $F < 1$ ; Group  $\times$  Target:  $F < 1$ ). Indeed, the between-groups effect sizes were large in both the social

condition ( $d = -.93 [-1.70, -.16]$ ) and in the nonsocial condition ( $d = 1.05 [-1.88, -.20]$ ). See Figure 4.

Bayesian analyses provide strong support for this interpretation. For social targets, the estimated Bayes factor was 3.26 in favor of the alternative hypothesis; for nonsocial targets, the estimated Bayes factor was 3.72 times in favor of the alternative hypothesis. This is considered substantial evidence for the alternative hypothesis (Wagenmakers et al., 2011), supporting the conclusion that ASD and TD differed in their latency to follow the experimenter's gaze relative to the end of their turn, for both social and nonsocial target conditions.

Given that the analysis of "latency to look" revealed numeric trends toward the ASD group being slightly slower to look at the experimenter's face, we were concerned that group differences in gaze following when anchored to the participant's turn end might be inflated. Thus, next we anchored their gaze following response to their very first look at the experimenter.

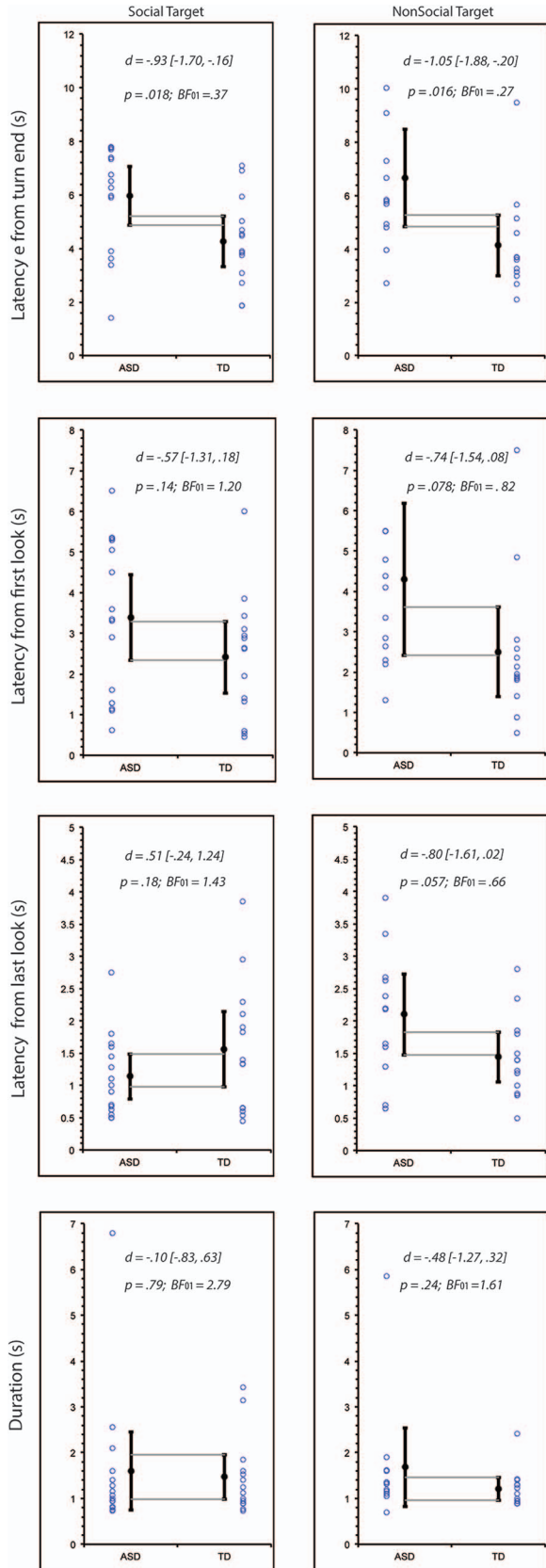
**Latency from first look.** The results echoed the previous analysis, but with slightly smaller effect sizes for the group difference (social:  $d = -.57 [-1.31, .18]$ ; nonsocial:  $d = -.74 [-1.54, .08]$ ). NHST revealed a main effect of group,  $F(1, 22) = 4.47, p = .046, \eta^2 = .17$ , with the ASD group taking significantly longer than the TD group to follow the experimenter's gaze. No other effects were significant (target:  $F(1, 22) = 1.03, p = .32, \eta^2 = .045$ ; Group  $\times$  Target,  $F < 1$ ). However, these data should be interpreted with caution, as Bayesian analyses provided rather weak support for the NHST finding of a main effect of group. That is, for social targets, the estimated Bayes factor was 1.20 in favor of the null hypothesis; for nonsocial targets with the Bayes factor 1.22 in favor of the alternative hypothesis. These analyses speak to the need for additional evidence. Indeed, Figure 2 (second row) shows very wide 95% CIs around the group means, indicating highly variable responding, particularly in the ASD group.

**Latency from last look.** We examined the latency between the participant's very last look to the experimenter and his or her gaze following response. Unlike in the previous analyses, NHST revealed no significant effect of group,  $F < 1$ . A significant effect of target type,  $F(1, 22) = 6.03, p = .022, \eta^2 = .22$ , indicated that gaze following latencies were longer for nonsocial targets than for social targets. A marginal Group  $\times$  Target interaction,  $F(1, 22) = 3.79, p = .065, \eta^2 = .15$ , indicated that the ASD participants were particularly slow to follow the experimenter's gaze toward nonsocial targets relative to social targets,  $t(11) = 3.32, p < .01$ , whereas the TD showed equivalent gaze following times for social and nonsocial targets,  $t(11) = .34, p = .74$ . This marginal interaction is also evidenced by a positive between-groups effect size for social targets (ASD  $<$  TD,  $d = .51 [-.24, 1.24]$ ) and a negative

Table 4  
Types of Responders: Gaze Following

Responder	Never follows	Follows on less than half of trials	Follows on over half of trials	Always follows
ASD ( $n = 17$ )	2 (11.8%)	2 (11.8%)	11 (64.7%)	2 (11.8%)
TD ( $n = 15$ )	0 (0%)	3 (20.0%)	7 (46.7%)	5 (33.3%)

Note. ASD = autism spectrum disorder; TD = typically developing.



between-groups effect size for nonsocial targets (ASD > TD,  $d = -.80 [-1.61, .02]$ ). Figure 4 illustrates this trend.

Again, however, it is important to interpret these findings cautiously. For social targets, the estimated Bayes factor was 1.43 in favor of the null hypothesis, whereas for nonsocial targets, the data were 1.51 in favor of the alternative hypothesis. These analyses speak to the need for additional evidence.

**Duration.** Once the gaze following behavior occurred, how long did it last? That is, how long did participants gaze at the target before returning their attention to the game? NHST revealed no effect of group,  $F(1, 22) = 1.30, p = .27, \eta^2 = .056$ , or any interactions with group (Group  $\times$  Target,  $F < 1$ ). There was also no effect of target,  $F < 1$ . For social targets, the estimated Bayes factor was 2.79 in favor of the null hypothesis, and for nonsocial targets, 1.61 in favor of the null hypothesis, again limiting the conclusions that can be drawn, particularly for the nonsocial condition ( $d = -.48 [-1.27, .32]$ ).

### Exploratory Analyses Other Responses

Although secondary to our main objectives, we wish to comment that in addition to some subtle differences in gaze following behavior, we noticed some very clear differences in how youth with ASD socially responded to the experimenter’s averted gaze. Several participants with ASD responded to the experimenter’s averted gaze with an attention-seeking vocalization or behavior. These included examples such as an ASD child yelling “woohoo!” and clapping his hands to gain the experimenter’s attention. This never occurred in the TD group, who, if they reacted at all, did so in much subtler ways (e.g., softly saying “it’s your turn”). We list some examples of these vocalizations and behaviors in Table 5.

Whereas 82% of the ASD participants directed vocalizations at least once at the experimenter while she was gazing at a target, only 47% of the TD participants did so,  $t(30) = 2.22, p = .034$  (and as mentioned, these vocalizations were much more subtle and socially “graceful” in nature). In addition, 47% of the ASD participants engaged in some kind of overt behaviour to ostensibly attract the experimenter’s attention (e.g., banging the table, clapping hands together); whereas only 20% of the TD participants did this, although the comparison was not reliable,  $t(30) = 1.62, p = .12$ . Notably, the nature of these behaviors was quite different (one TD child pointed to the experimenter to indicate that it was her turn; one tapped the game piece on the board; and one tilted their head while looking at the experimenter). Our Chi-square analysis on types of responders (see Table 6) revealed a significant association between diagnosis and rate of vocalization;  $\chi(3) = 10.27, p = .016$ . In the TD group, the most frequent type of responder was one who never vocalized; in contrast, most ASD participants vocalized on less, or on more, than half of trials. Whereas two participants with ASD vocalized on every trial, no TD participants

Figure 4. Timing of gaze following in children with autism spectrum disease (ASD) and typically developing (TD) children. Data are plotted as means and 95% CIs (error bars); Cohen’s  $d$  (with 95% CIs),  $p$  values, and Bayes factors are provided for pairwise comparisons (two-tailed  $t$  tests, uncorrected). Circles represent individual data points. See the online article for the color version of this figure.

Table 5  
*Examples of Vocalizations and Behaviors Observed*

Example	ASD	TD
Examples of vocalizations	“Hellooo?!” (repeated)	“It’s your turn”
	“Woohoo! Pay attention!!”	“uh . . .”
	“Well? It’s your turn!!” (repeated)	“hee hee, I tripled up”
	“I put two cards down, see?”	Clears throat to get attention of examiner
Examples of behaviors	“What are you doing?”	Tells a story to engage the examiner
	Claps hands	Points at the game
	Takes the examiner’s turn for her	Takes a drink and waits
	Knocks on the table repeatedly to get examiner’s attention	Crosses arms, laughs
	Waves hand in front of the examiner’s face	Looks away and waits
	Grimaces	Frowns

Note. ASD = autism spectrum disorder; TD = typically developing.

did so. The Chi-square analysis of behaviors, however, revealed no association between diagnosis and rate of behaviors,  $\chi(2) = 2.36$ ,  $p = .31$ .

**Discussion**

There is a gap in the literature on gaze following abnormalities in ASD: while there is a plethora of work on naturalistic gaze following in very young (preschool aged) children, there has been little research to date on gaze following of school-age children and adolescents within naturalistic contexts. What little work has been done on school-age children has examined gaze following in settings in which gaze selection has been circumvented, in that the gaze cue has been preselected for observers. Here we examined both gaze selection and gaze following in the context of a novel, naturalistic paradigm in which observers were free to select information from their environment. We were interested in both the frequency of spontaneous gaze selection and gaze following, as well as the timing of these behaviors, and whether or not these differ in school-age children and adolescents with ASD relative to their TD peers.

As with most studies of special populations such as ASD, our statistical power was limited by a small sample size. Indeed, there were only two findings that received strong support from both NHST and Bayesian statistics. However, we feel that our other, less robust findings nonetheless reveal some interesting patterns that are worthy of discussion and may shed light on the main findings.

The finding with the strongest support from both NHST and Bayesian statistics was that relative to TD children, children with ASD were slower overall to follow the experimenter’s gaze rela-

tive to the end of the participant’s turn in the game (i.e., when it would be expected that the experimenter make her next move in the game). This was evident both when the experimenter’s gaze was directed at a social target (a person in the room) and when it was directed at nonsocial targets (various objects in the room). To examine possible sources for this delay in gaze following, we examined measures of gaze selection, that is, glances made to the experimenter before following her gaze. Although not borne out by NHST or Bayesian analyses, there was certainly a trend for ASD children to take longer to initially look at the experimenter. Although further study is needed, this suggests the possibility that slower gaze selection may have contributed to delayed gaze following in ASD. However, notably, when we anchored the gaze following response to the first look at the experimenter, NHST still revealed a slower gaze following response in ASD relative to TD, with medium to large effect sizes in the expected direction. This finding suggests that additional factors other than delayed gaze selection contributed to the slower gaze following response in ASD, a possibility that we turn to next.

The second finding that received fairly conclusive support from both NHST and Bayesian analyses, was that the ASD group made longer glances at the experimenter (relative to the TD group) when she gazed at nonsocial targets (but not when she gazed at social targets). Given this finding, it is perhaps not surprising that when we anchored gaze following to the participant’s last look at the experimenter before following her gaze, NHST revealed that participants with ASD were slower to follow the experimenter’s gaze toward nonsocial targets than to social targets. In contrast, for TD participants gaze following latencies were no different for social versus nonsocial targets. An alternative way of stating this is that

Table 6  
*Types of Responders: Vocalizations and Behaviors*

Responder	Never vocalized	Vocalized on less than half of trials	Vocalized on over half of trials	Always vocalized	No behaviors	Behaviors on less than half of trials	Behaviors on over half of trials	Behaviors on all trials
ASD ( $n = 17$ )	3 (17.6%)	6 (35.3%)	6 (35.3%)	2 (11.8%)	8 (47.1%)	6 (35.3%)	3 (17.6%)	0 (0%)
TD ( $n = 14$ )	8 (53.3%)	7 (46.7%)	0 (0%)	0 (0%)	11 (73.3%)	3 (20.0%)	1 (6.7%)	0 (0%)

Note. ASD = autism spectrum disorder; TD = typically developing.

when anchored to the last look at the experimenter, group differences in gaze following latencies were revealed, but for nonsocial targets only. Although the reason for this is unclear, one possibility is that the youth with ASD had a more difficult time determining where the experimenter might be looking, given that nonsocial targets could be anywhere in the room. This possibility is supported by Rombough and Iarocci (2013), who found that 10-year-old children with ASD were less accurate relative to TD children at determining the line of sight of a gazing face in the presence of multiple distractors. Although we did not measure accuracy of gaze following responses in the current study, it may be that in the nonsocial target condition participants with ASD needed to select the gaze cue for longer to compute its direction, because there were many possible nonsocial targets in the room. Alternatively, the ambiguity and unexpectedness of the nonsocial cue situation (viewing an experimenter looking off at something to the side for no apparent reason) may have led to differential responding in ASD, paralleling the finding that children with ASD are more likely to diverge from typical behavior in ambiguous social situations (Phillips et al., 1992). Future research with larger sample sizes is needed to tease apart these possibilities.

Contrary to our initial expectations, we did not find evidence (either through NHST or Bayesian analyses), of less frequent gaze following in ASD, despite some numerical trends in the expected direction (particularly for nonsocial targets—see Table 3). While interpreted cautiously, this is consistent with the larger body of research showing “intact” gaze following in ASD (i.e., no difference when compared with a control group) in response to images presented on a computer screen (see Birmingham et al., 2012; Freeth et al., 2010; Nation & Penny, 2008). Given that our participants were in the average to above average range of intelligence, these results also parallel those of Leekam et al. (1998), who found that more cognitively able school-age children with ASD showed no differences in the frequency of naturalistic (face-to-face) gaze following relative to matched TD children. Indeed, in the present study, most participants in the TD and ASD groups followed the experimenter’s gaze on over 50% of trials; very few participants never followed her gaze, and only a minority of participants always followed the experimenter’s gaze. The finding that few participants in either group followed the experimenter’s gaze on every single trial is consistent with previous findings (Leekam et al., 1997).

In a more exploratory analysis, we noted some qualitative differences in how children with ASD responded to the averted gaze of the experimenter. We noticed that children with ASD were much more likely than their TD peers to direct a vocalization at the experimenter in a seeming attempt to get her attention, and a subset of participants with ASD also produced overt attention-grabbing behaviours (e.g., clapping hands, knocking the table). These behaviors in ASD may reflect a refreshing absence of social inhibition commonly associated with the autism phenotype, in which individuals “say what they are thinking.” In doing so, our impression was that participants with ASD were trying to rectify the social interaction, which had been interrupted by the experimenter averting her attention away from the game. While it is entirely possible that the TD participants were also discomforted by the experimenter’s seemingly distractible nature, they certainly did not express this irritation, at least not in obvious ways. Instead, TD youth appeared to observe and patiently wait for the experimenter

to return to the game (e.g., shifting eyes down, frowning, waiting, or softly saying “your turn”).

Although we do not have the power to link these more qualitative behaviors with the quantitative measures of gaze selection and following, we suspect that these behaviors in our ASD youth may have contributed to slower gaze following in the ASD group. Although these ideas are certainly speculative and require exploration with further research, we were interested to find evidence of a similar finding in previous work. Although not reported as a formal finding, Leekam et al. (1997) supplied a figure in which it a male participant with ASD “attempts to get the experimenter’s attention” as she is gazing at the target (see p.82, bottom panel of Figure 1 in Leekam et al., 1997). We hope that future research will continue to explore not only the quantitative aspects of gaze following, but also the qualitative responses that may impact social interactions in ASD.

### Limitations and Future Directions

As mentioned in the introduction, our study was limited by small sample size, a common issue in research with special populations. Indeed, the results of our Bayesian analyses indicated a need for more evidence in many cases. We did however find some interesting patterns that are worthy of replication with larger sample sizes. There was a high degree of variability in both groups, and it would be of future interest to explore possible sources of this variability at the individual level (e.g., age, IQ, parent ratings of social competence, other measures of social-cognitive ability such as theory of mind). Furthermore, in the present study we aimed to uncover whether gaze following abnormalities persist in school-age children with ASD, however follow-up with longitudinal studies with younger children would address whether our finding of overall intact gaze following in ASD indicates that children “catch up” to their TD peers with age. This is an important consideration that was not addressed by the present study.

Our mobile eye tracker proved to be unreliable, forcing us to rely on video data for coding. Although live and video observations are common in joint attention research, we had hoped to make use of more precise data with respect to participants’ gaze. We look forward to making use of more modern eye mobile trackers that were not available to us at the time of data collection. For researchers using these methods, we recommend carefully determining constraints around lighting, participant facial structure, and participant movement (see Footnote 1 for the issues we experienced). Although we were able to reliably detect gaze behavior from the high definition video data, we cannot rule out the possibility that participants were attending covertly to the experimenter (i.e., using peripheral vision) even in instances where they were not gazing at her overtly (Gernsbacher, Stevenson, Khandakar, & Goldsmith, 2008). As covert and overt attention can be dissociated (Klein & Pontefract, 1994), this is an important limitation, particularly in studies of real world attention (Kuhn & Tatler 2005; Kuhn, Tatler, & Cole, 2009; Macdonald & Tatler, 2013). This issue could be addressed in part by manipulating the experimenter’s eye direction separately from head direction, as the two were purposefully confounded in our study. For instance, Thorup et al. (2016) found that infants at high risk for developing ASD were less likely to follow the gaze of an experimenter when

it was indicated by eye direction alone, relative to when the experimenter used both eye and head cues. Providing a gaze cue that is indicated solely by eye direction would presumably prevent observers from being able to process the cue covertly (i.e., without looking at the experimenter's face), a manipulation we will consider for future research. As with any naturalistic paradigm, it was impossible to have total control over all aspects of the experimental setting; thus, despite our best efforts, variables such as cue duration and timing were not tightly controlled.

We must acknowledge the possibility that participants' behavior may have been influenced by the presence of eye tracking equipment and the awareness that their eye movements were being tracked (Nasiopoulos, Risko, Foulsham, & Kingstone, 2015; Risko & Kingstone, 2011). Future research using this paradigm should compare gaze selection and following with and without the presence of eye tracking equipment. However, although not formally quantified, our impressions from debriefing sessions with participants is that they were unaware that the games were part of the study, and did not know the purpose of the study. Indeed, on a few occasions, participants asked the experimenter when the games would be over so that they could start the actual experiment. Although this does not circumvent the issue that wearing an eye tracker may alter one's behavior, it does at least suggest that participants may not have been motivated to alter their behavior during the experiment if they were unaware the experiment had even started. However, we flag this issue as relevant to all researchers using mobile eye trackers to understand social behavior in real-world environments.

In addition to the possible influence of eye tracking equipment on participant behavior, there are other methodological and contextual differences in studying gaze selection within live interactions, as opposed to viewing images of faces presented on a computer screen. Specifically, in live interactions the social stimuli themselves have personal agency, whereas in images of social interactions, they do not (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012). This agency, and thus potential for social interaction with the observer, may alter social attention processes, because the observer's gaze behavior toward the social stimulus carries a very different meaning than it does in asocial contexts (i.e., looking at pictures of people). This notion is supported by recent work with TD adults showing that observers made fewer fixations to the face of a person within a live interaction than to that same face displayed on a computer screen (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011). Other work has shown that TD observers who expected that they would be later interacting with people in a video clip were less likely to look at the heads of those people (and less likely to follow their gaze), relative to participants who did not hold this expectation (Gregory et al., 2015). These findings no doubt underscore the importance of studying social attention within a variety of contexts (Birmingham & Kingstone, 2009; Risko et al., 2012), including live social interactions (Macdonald & Tatler, 2013; Magrelli et al., 2013; Noris et al., 2012; Vabalas & Freeth, 2016; see Skarratt, Cole, & Kuhn, 2012, for a review).

We would also like to point out that our paradigm involved a very specific type of social interaction—a game between a relative stranger and a child—and that our results may not generalise to other social situations. For instance, when not gazing at the experimenter, participants' gaze was naturally focused on the game

(their hand of cards, the game board), and so gaze selection may have been reduced relative to other types of social interactions. Future research should examine gaze selection and following in ASD during other live social situations (e.g., conversations: Vabalas & Freeth, 2016; misdirection during live magic tricks: Kuhn & Tatler, 2005; real-world object search: Macdonald & Tatler, 2013) as well as with other social interaction partners (e.g., familiar adult, familiar vs. unfamiliar peer). Although our study was designed to measure spontaneous gaze following in a natural setting in which gaze cues were unrelated to task demands, it is but one possible design that can be used to understand how children with ASD attend to and make use of socially informative cues.

Beyond the realm of ASD research, we think these findings have implications for the social attention literature more broadly. The approach of measuring gaze selection as an integral component of gaze following, as opposed to preselecting gaze cues to measure gaze following in isolation, is one that has been proposed before (Birmingham & Kingstone, 2009) and is gaining traction—both in research involving images of social interactions (e.g., Freeth et al., 2010; Kuhn et al., 2010), and in research of gaze following in live social interactions (e.g., Macdonald & Tatler, 2013). Indeed, we have noted that one of the key limitations of the gaze cueing paradigm is that because it circumvents the gaze selection process, it may lead gaze cues to be processed differently from how they would be in the real world. Although our data did not support our hypothesis that allowing observers the freedom to select gaze would reveal differences in the *amount* of gaze following in ASD, we did find interesting effects for the timing of gaze following that would not have been detectable in a design with a preselected gaze cue. Certainly, more research is needed in this area, both in the general population and with special populations such as ASD.

## Conclusion

This study is the first of hopefully many to come, using a new naturalistic paradigm in which observers were free to both select and follow gaze cues in their environment. By measuring both the frequency and the timing of these behaviors, we were able to reveal some subtle differences in the ways that school-age children with ASD attend to and utilize gaze cues in their environments. Far from being “impaired” at gaze following, we find that children with ASD respond in qualitatively and quantitatively different ways in response to gaze cues, ways that may be important for our understanding of autism, and for everyday attention more broadly.

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## Résumé

En utilisant un paradigme naturaliste novateur permettant aux participants de sélectionner et suivre spontanément les indices de regard dans leur environnement, cette étude vient approfondir des recherches précédemment menées auprès de jeunes enfants afin de déterminer si les enfants d'âge scolaire atteints du trouble du spectre de l'autisme (TSA,  $n = 17$ ) affichent un suivi du regard anormal par rapport aux enfants au développement plus typique (DT,  $n = 15$ ). Le participant et l'expérimentatrice se sont livrés à une série de jeux, durant lesquels l'expérimentatrice détournait son regard de manière pseudo-aléatoire vers une cible sociale (une personne) ou une cible non-sociale (un objet). Une autre constatation importante était que, relativement aux enfants DT, les enfants

atteints du TSA prenaient plus de temps pour suivre le regard de l'expérimentatrice comparativement au début de l'essai (cibles sociales  $d = -0,93$  [-1,70, -0,16], cibles non-sociales  $d = -1,05$  [-1,88, -0,20]). Lorsque nous avons analysé la durée des regards dans la direction de l'expérimentatrice, nous avons noté que le regard des enfants du groupe TSA s'attardait davantage par rapport à leurs congénères du groupe DT, mais seulement dans les conditions de cibles non-sociales (cibles sociales  $d = 0,01$  [0,68, 0,71], cibles non-sociales  $d = -0,81$  [-1,53, -0,08]). D'autres analyses ont mis en lumière des schémas de sélection et de suivi de regard susceptibles de contribuer à l'interprétation des principaux résultats. Malgré les variances au niveau de la synchronisation de la sélection et du suivi du regard, le type de répondant le plus courant dans les deux groupes était celui qui suivait le regard de l'expérimentatrice pendant plus de la moitié des essais. Ce schéma de résultats s'oppose à un déficit clair d'attention sociale chez les enfants d'âge scolaire atteints du TSA et souligne l'importance de tenir compte des moments pendant lesquels se produisent les mécanismes distincts de l'attention sociale ainsi que du contexte dans lequel ces comportements se produisent.

**Mots-clés :** trouble du spectre de l'autisme, suivi de regard, monde réel, naturaliste.

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