CHILD DEVELOPMENT

Child Development, May/June 2012, Volume 83, Number 3, Pages 926–938

Gaze Following, Gaze Reading, and Word Learning in Children at Risk for Autism

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This study investigated gaze-following abilities as a prerequisite for word learning, in a population expected to manifest a wide range of social and communicative skills—children with a family history of autism. Fifty-three 3-year-olds with or without a family history of autism took part in a televised word-learning task. Using an eye-tracker to monitor children's gaze behavior, it was shown that the ability to follow gaze was necessary but not sufficient for successful word learning. Those children who had poor social and communicative skills followed gaze to the labeled object but did not then learn the associated word. These findings shed light on the conditions that lead to successful word learning in typical and atypical populations.

One of the first word-learning strategies employed by typically developing children relies on the use of social referential cues, such as a speaker's direction of gaze or pointing, to select the referent of a new label. Typically developing infants successfully employ referential cues to learn words from about 1 year of age (Baldwin, 1991, 1993; Hollich et al., 2000). Although children eventually make use of a variety of strategies to infer the meaning of words, referential word learning is considered to be crucial for getting vocabulary acquisition ''off the ground.'' There are several proposed reasons for, and underlying mechanisms to explain, children's increasing success with referential word learning over the course of typical development. Much research has focused on infants' gaze-following skills, which are frequently portrayed as a prerequisite for word learning. The ability to match someone's line of sight (Morales, Mundy, & Rojas, 1998; Mundy, Card, & Fox, 2000), and the frequency with which an infant participates in episodes of joint attention (Carpenter, Pennington, & Rogers, 2002), for example, have been shown to predict later vocabulary size. Studies of children with autistic spectrum disorders (ASDs) have also highlighted the pivotal role gaze-following ability plays in word learning. Children with ASD do not reliably follow gaze or pointing gestures (Carpenter et al., 2002), and show delayed or diminished expressive and receptive vocabularies (Charman, Drew, Baird, & Baird, 2003; Hudry et al., 2010). It is therefore plausible that atypical gaze following gives rise to word-learning difficulties in this population. Indeed, although it has been shown that much younger typically developing children shift their gaze away from an object they are holding to an object referenced by an experimenter and then learn the correct word–object association (Baldwin, 1991, 1993), children with ASD do neither (Baron-Cohen, Baldwin, & Crowson, 1997; Preissler & Carey, 2005).

Studies of typically developing infants, however, have suggested that word learning might require more than the co-occurrence of words, deictic cues, and object (Waxman & Gelman, 2009). For example, when a word and a gaze cue are produced by two

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We are very grateful for the enormous contributions BASIS families have made toward this study. We also thank Kim Davies for carefully editing this manuscript. The research is supported by The UK Medical Research Council (G0701484) to M.H. Johnson, a Leverhulme Early Career Fellowship to M. Elsabbagh, and the BASIS funding consortium led by Autistica (http://www.basisnetwork.org/) and Autism Speaks (1292).

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 0009-3920/2012/8303-0014
DOI: 10.1111/j.1467-8624.2012.01750.x

different people, typically developing 1-year-olds do not expect the word to refer to the gazed-at object (Gliga & Csibra, 2009). It is therefore possible that the ability to understand the underlying communicative intention of gaze rather than gaze following per se, is the limiting factor when learning from such cues. Work on nonhuman primates suggests that following gaze and ''reading'' gaze can be dissociated during phylogeny. For example, although nonhuman primates are able to follow gaze and pointing gestures, by contrast with typically developing 2-year-olds, they are unable to infer the presence of a hidden object at a gaze-cued location (Call, Agnetta, & Tomasello, 2000). During typical human development, gaze following and gaze ''reading'' develop in parallel; however, they may become dissociated in atypical development, as for example in ASDs.

The interplay between the different factors influencing early word learning has been difficult to ascertain experimentally; although typically developing children quickly master both gaze following and word learning, children diagnosed with ASD are usually unable to master either. In order to overcome this limitation, more recent studies have looked at the wider range of individual variability observed in the broader autism phenotype (BAP). Younger siblings of autistic individuals are at an increased risk of being diagnosed with ASD themselves (so-called at-risk children), relative to those with no family history of ASD. Although only a small proportion of at-risk children will go on to develop an ASD, a much greater number are expected to manifest subclinical ASD-like atypicalities (Ozonoff, Rogers, Farnham, & Pennington, 1993; Rogers, 2009), including language difficulties (Piven et al., 1997). The few studies that have examined language development in at-risk children show that they are slower to acquire language (Toth, Dawson, Meltzoff, Greenson, & Fein, 2007; Yirmiya, Gamliel, Shaked, & Sigman, 2007; Yirmiya et al., 2006), and require more prompts to follow referential cues to object targets (Presmanes, Walden, Stone, & Yoder, 2007).

Studies that highlight the ability to follow gaze as underlying language acquisition have generally chosen to correlate gaze-following abilities with vocabulary size (Morales et al., 1998; Mundy et al., 2000), and as such fail to show a direct link between gaze-following and *word learning*. In order to explore this relation, we have adapted a paradigm in which typically developing children and children with ASD have to follow an experimenter's gaze to the less salient of two objects in order to learn its name (Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg, 2007). The presence of a salient object adds difficulty to this task, as gaze following requires not only the ability to match someone's line of sight but also the flexibility to reorient and switch attention. Perseveration on objects and difficulties with disengagement of attention have frequently been described in individuals with autism (Landry & Bryson, 2004; Van Der Geest, Kemner, Camfferman, Verbaten, & Van Engeland, 2001), as well as in infants at risk for the disorder (Elsabbagh, Volein, Holmboe, et al., 2009). In our task, therefore, we predict that the presence of a salient distracter will provide an additional source of variability in gaze-following skills.

Studies of at-risk populations provide not only the variability necessary for dissociating word-learning mechanisms, but also contribute to our understanding of the BAP. Although the BAP has been frequently studied in adult relatives of individuals with autism (Kaiser et al., 2010; Piven et al., 1997), far less developmental research has been carried out. By testing a population of at-risk children, who have not received a diagnosis of ASD but can be expected, in at least some cases, to manifest subclinical atypicalities characteristic of the BAP, we can ask whether the gaze-following and word-learning difficulties previously described in ASD are restricted only to diagnosed cases. One question that still remains unanswered is whether there is continuity between the BAP and the autism phenotype proper. A further question of interest is whether children at risk for autism, as a group, will display social learning difficulties, or whether such difficulties will be restricted to those who also show ASD-like atypicalities. ASD-like characteristics can be quantified using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). This semi-structured play assessment quantifies the presence of social and communication atypicalities commonly found in ASD (e.g., lack of pretend play and extent of engagement in social interactions). The few studies that have examined gaze following or language development in children at-risk for ASD have found that, in their 2nd year of life, this group as a whole are impaired in both (Presmanes et al., 2007; Toth et al., 2007; Yirmiya et al., 2006, 2007). Developmental models of autism, however, predict that differences between ''affected'' and ''nonaffected'' at-risk individuals emerge gradually during development, as a result of interactions between genetic and environmental factors (Elsabbagh & Johnson, 2010; Yirmiya & Charman, 2010). It is, therefore, possible that by 3 years of age (the age of participants in the present study), referential word learning should only be problematic for those children who show more pronounced social and communication difficulties, as measured by the ADOS.

This study aims to characterize the ability of 3-year-olds to (a) follow someone's gaze to a labeled object and (b) acquire a novel word–object association. The study also aims to (c) investigate the relation between gaze-following and word-learning abilities in two groups of children: a control group at low risk for ASD, and an at-risk group, and to ascertain whether any differences in these abilities within the at risk group are related to family risk for autism, or to the presence of more pronounced social and communication atypicalities characteristic of the BAP. This study has adapted the paradigm used by Parish-Morris et al. (2007), which involved live interaction, instead measuring children's looking behavior to a videotaped presentation using an eye-tracker. Eye-tracking technology allows us to monitor the distribution of children's attention during the different key events of the task, with much greater spatial and temporal precision, and without the need for sometimes difficult to elicit overt responses.

Method

Participants

Participants were 35 children at high risk for ASD (at-risk children), recruited through the British Autism Study of Infant Siblings (BASIS: http://www.basisnetwork.org.uk), and 18 low-risk controls, recruited from a volunteer database at the Birkbeck Centre for Brain and Cognitive Development. All were participating in a longitudinal study. Informed consent was obtained from parents of all children taking part in the study. Ethical approval was granted by the NHS NRES London Research Ethics Committee 08/H0718/76. The infants were from a varied ethnic and socioeconomic background, predominantly White (British or non-British) or British Black (mixed, African, or Caribbean). Children were considered at risk for ASD by virtue of having an older brother or sister with a diagnosis of autism or ASD. Diagnosis of the proband was confirmed by two expert clinicians (PB, TC) using the Development and Well-Being Assessment (DAWBA; Goodman, Ford, Richards, Gatward, & Meltzer, 2000) and the parent-report Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003). The SCQ is a recently developed screening tool for ASD, based on the Autism Diagnostic Interview–Revised (ADI–R; Lord, Rutter, & Le Couteur, 1994) and is widely used in clinical research and practice. Most probands met criteria for ASD on both the SCQ (n = 33, M = 24.5, SD = 7.1, range = 13–37) and the DAWBA. None of the children in the control group were reported to have any first- or second-degree relatives with ASD, and parents of these children also completed the SCQ for the older sibling of the child in the current study with none scoring around the cutoff point for ASD (15) (n = 16, M = 3.5, SD = 2.9, range = 0–11). Exclusion criteria for both groups included prematurity, low birth weight, medical or neurological conditions, and sensory or motor problems. General developmental level was assessed in all toddlers at 36 months of age, using the Mullen Scales of Early Learning (Mullen, 1995). Group characteristics are shown in Table 1.

Table 1
Participant Characteristics

	Control	At-risk	At-risk typical-skills	At-risk poor-skills
n	18	35	25	10
M:F	12:6	17:18	12:13	5:5
Age (years)	3.2 (.1)	3.3 (.1)*[c]	3.3 (.2)	3.2 (.1)
ADOS[a]				
Total	4.7 (2.0)	6.2 (4.6)	4.5 (2.7)	13.3 (3.8)***[d]
Communication	1.4 (0.7)	2.8 (2.1)*	1.8 (1.3)	5.2 (1.8)***
Social	2.7 (1.8)	4.2 (3.2)	2.6 (1.9)	8.1 (2.2)***
Mullen total[b]	121.3 (15.3)	103.0 (21.0)*	107.7 (17.4)	91.2 (24.9)*

[a]Autism Diagnostic Observation Schedule (average scores and standard deviations). [b]Mullen Early Learning composite score (average standard scores and standard deviations). [c]Significant differences between control and at-risk children. [d]Significant differences between at-risk typical-skills and at-risk poor-skills groups.
*p < .05. ***p < .001.

Behavioral Assessment of Social-Communication Skills

Children's social and communicative functioning was examined using the ADOS (Lord et al., 2000), a semistructured play assessment. Module 2 was typically administered, except in the case of two at-risk participants who had only minimal speech and single words, for whom Module 1 was deemed more appropriate. The ADOS was administered in the standardized way, by researchers trained to high reliability, and then scored from videotaped recordings to ensure the accuracy of coding. The ADOS algorithm scores cover Social and Communication domains, as well as a combined total of the two domains, with higher scores indicating greater social-communication atypicality. Within the at-risk toddler group, we used the ADOS algorithm cutoff thresholds for ASD to delineate a subgroup displaying poor social-communication skills ($n = 10$; hereafter At-risk poor-skills). The remainder, demonstrating better skills, are hereafter referred to as At-risk typical-skills ($n = 25$; see Table 1). In the absence of a full developmental history with a diagnostic instrument such as the ADI–R (Lord et al., 1994), and clinician-led assessment, we did not further classify the children into clinical diagnostic groups. Parental reports obtained at the time of the visit indicated that only one child had recently been diagnosed with ASD by their local clinical team (see the Results and Discussion sections). We decided not to exclude this child from our sample (and the at-risk poor-skills group) as she provides an interesting anchor point for our findings.

Word-Learning Task

Stimuli. The stimuli consisted of eight video sequences: four familiarization clips, in which a new word was taught, and four corresponding test clips, in which word learning was assessed. At the beginning of each familiarization clip, participants saw an actress seated behind a table on which two objects were placed. One of the two objects changed color or had moving parts (the salient object), and the other did not change state in any way (the subsequently referred object). During the first 3 s of each familiarization trial, the actress looked straight at the camera and maintained a smiling still face. After this period, she said in a cheerful voice, ''Hello!'' then turned her gaze toward the Referred object and labeled it using a novel word: ''Look at this! It's a *blicket*. Wow! Look at the *blicket*.'' Looking back toward the camera she then said ''Do you want to play with the *blicket*?'' The other three novel words used were *sefo*, *toma*, and *dax*. Placement of the Referred and Salient objects on each side of the screen was counterbalanced across trials. A central animation was shown at the end of the familiarization clip and was followed by the test clip in which children saw a still image of the two objects on the table, their positions reversed. At the onset of the test clip, the actress's voice was heard to repeat twice, 2 s apart, ''Look at the *blicket!*'' then to repeat twice, also 2 s apart, ''Can you show me the *blicket*.'' Prior to the novel word-mapping sequences, participants were shown two additional familiar words test clips, in which a pair of familiar objects was presented: a rubber duck and a child's shoe. As with the novel word test clips, children were asked to look at and show first the duck and then the shoe (in separate trials). These trials were used to help children understand the purpose of the task. They also ensured that poor performance in the novel words trials, when observed, was not due to unwillingness to comply with the task demands.

Apparatus. Corneal reflection data were recorded with the TOBII T120 eye-tracker (Tobii Technology, Stockholm, Sweden). TOBII has an infrared light source and a camera mounted below a 17-in. flat-screen monitor. Gaze data were recorded at 120 Hz.

Procedure. Toddlers were seated on an adjustable chair in front of the eye-tracking monitor. The height and distance of the screen were slightly adjusted for each child to obtain good tracking of the eyes. The first experimenter (E1) controlled the eye-tracker calibration and stimulus presentation. A second experimenter (E2) sat next to the child and encouraged them to look at the screen when they looked away and to point to objects on the screen during test trials (see below). The child's behavior was monitored using a video camera incorporated in the Tobii monitor. A 5-point calibration sequence was run until at least 4 points were properly calibrated for each eye.

The order of trial presentation was fixed. Each familiarization clip was immediately followed by the corresponding test clip. Toddlers first saw the *duck* test clip, then the *blicket* and *dax* familiarization and test clips, followed by the *shoe* test clip, and the *sefo* and *toma* familiarization and test clips. In addition to monitoring looking behavior to test successful word learning, we also elicited an overt behavioral response—while children heard the actress in the test clips say ''Can you show me the *blicket*?'' E2 prompted them verbally to point to one of the two objects, saying, ''Show me the *blicket*'' or ''Point to the *blicket*.'' Both correct and incorrect responses were rewarded with ''Good job!''

Data extraction and analysis. Tobii Studio software (Tobii Technology, Stockholm, Sweden) was used for eye-gaze data recording and extraction. Fixations were defined automatically using temporal (100 ms) and spatial (35 pixels) filters. Two segments were delimited within each Familiarization clip. The 4-s *baseline* interval started at the beginning of the clip, and the 4-s *teaching* interval started when the actress turned her gaze toward the referred object (see Figure 1). From the whole test clip (12 s), we extracted a 4-s long segment, which started 1 s after the beginning of the clip, at the end of the first prompt to look at the previously labeled object and ending when children were prompted to point. Rectangular areas of interest (AOIs) were defined manually around the two objects and the face of the actress. For each of the segments defined above, we extracted the amount of looking time within each AOI (i.e., fixation length). To analyze the distribution of looks between the two objects during the baseline, we calculated looking toward the referred object as a proportion of the total time spent looking at either object. These were calculated for each of the four novel word trials separately, and then averaged across trials for each child. Two participants were excluded because they did not accumulate any looking time for at least two trials (one from the at-risk typical-skills and one from the control group). The same measure of distribution of looking time was calculated for the teaching sequence (see below) and for the test clip. The same exclusion criteria were applied for the test analysis. This led to the exclusion of another 3 participants (two from the control group and one from the At-risk Poor-skills Group).

Results

A variety of measures of ''gaze following'' and ''word learning'' were derived from the familiarization and the test phases. Within familiarization, we distinguished between a baseline segment and a teaching segment, as these conveyed different types of information within the context of the task. During the baseline period of the familiarization clip (when the actress was looking toward the child), we expected children's attention to be drawn more toward the salient object rather than the other object. Such a pattern would be a validation of the difference in saliency between objects. During the teaching part of the clip, when the actress labeled the referred object, we were interested in measuring a shift in gaze from the salient object to the referred object. Based on previous literature (Senju & Csibra, 2008), we derived two measures of gaze following: the proportion of correct first looks in response to the gaze cue, and the total duration of gaze toward the referent during the teaching part. The proportion of looking time directed to the previously labeled object (the referred object) during the test intervals, and the percentage of correct pointing were used as measures of word learning.

To characterize the social learning abilities of the BAP at this age, we first analyzed the relation between referential word-learning abilities and the severity of social and communicative atypicalities, as measured by the ADOS. As one of our cases in the at-risk group had received a community diagnosis of autism, and may be qualitatively different from the rest of the group, we also ran all statistical analyses excluding this child. We report these results when they change the significance level of any reported effects. Because we have emphasized the importance of studying both the gaze-following and word-learning abilities of individuals in order to determine whether these abilities are associated, we then go on to investigate the relation between various measures of gaze following and word learning.

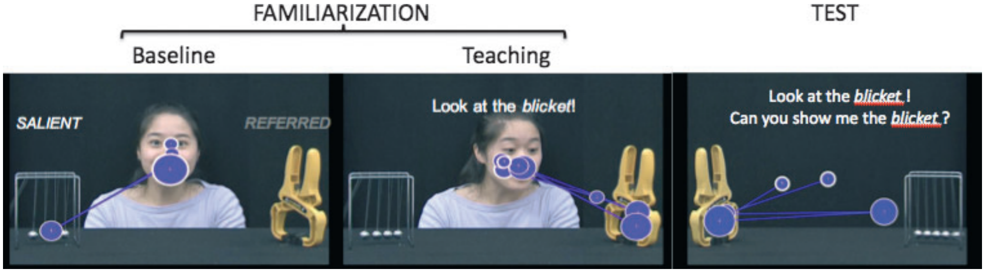

Figure 1. Outline of the experimental display and timeline of the three main intervals used in the analysis.
Note. Overlapped are the fixation data from one of the participants in the study, demonstrating successful gaze following (teaching clip) and word mapping (test clip). Each circle represents a fixation point, the size of which is proportional to the duration of fixation.

The Relation Between Experimental Measures and the ADOS

Both a categorical and a dimensional approach were used to evaluate toddlers' word-learning performance in relation to both familial risk and the presence of social and communication atypicalities. For the categorical approach, we used the ADOS to differentiate two subgroups within the at-risk group: a typical-skills subgroup and a poor-skills subgroup. The gaze-following and word-learning abilities of at-risk typical-skills, at-risk poor-skills, and the low-risk controls were compared using univariate analyses of variance (ANOVAs). Preliminary analyses also considered gender, given previous evidence suggesting that girls and boys may differ in their ability to learn new words (Huttenlocher, Haight, Bryk, Selzer, & Lyons, 1991). However, no main effects of gender, or any Gender × Group interactions were apparent. We therefore excluded gender subgrouping from the final analysis presented here. Chronological age as well as the composite standard scores of the Mullen Scales of Early Development were entered as a covariate to account for any group differences in terms of general development.

Categorical approach. Group differences could be observed in looking behavior during the baseline or teaching intervals. However, the social-communication difficulties characteristic of the BAP, and potentially present in the at-risk subgroups, predict differences mainly during the teaching phase. This is when the whole at-risk group, or the subgroup demonstrating poor-skills, might struggle to reorient their attention toward the referred object. For both baseline and teaching, we start the analysis by testing for group differences in terms of how long children engaged with the screen in general or with particular AOIs (see also Table 2). Three AOIs were considered for this analysis: one that included the two objects, one corresponding to the face of the actress, and another one that contains the rest of the screen (i.e., objects, face, and other). To explore in detail the effects of saliency (during baseline) and labeling (during teaching), we subsequently focus the analysis on the looks directed to the salient and referred objects. Detailed descriptives of looking-time distribution are presented in Table 2.

Baseline interval. There was no main effect of group, $F(2, 50) < 1$, in terms of the amount of time spent exploring the screen during this interval. Separate univariate ANOVAs for each AOI yielded no significant group differences in the amount of time dedicated to the two objects, $F(2, 50) < 1$; the face, $F(2, 50) < 1$; or the other parts of the screen, $F(2, 50) < 1$.

To confirm that the salient object was indeed attracting children's attention, the proportionate duration of gaze toward this object was calculated with respect to the total amount of time spent looking at the two objects. All groups looked longer than expected by chance toward the salient objects—one-sample t tests: at-risk typical-skills, $t(24) = -10.10$, $p < .01$; at-risk poor-skills, $t(9) = -10.90$, $p < .01$; control, $t(17) = -13.70$, $p < .01$. No significant difference between groups was found during this interval, $F(2, 52) < 1$, partial $\eta^2 = .01$. None of the significance levels were affected by including chronological or mental age (Mullen Early Learning standard scores) as covariates, or by removing the child with a community diagnosis of autism.

Teaching interval. Groups spent similar amounts of time looking at the screen during this interval, as well, $F(2, 50) < 1$. As during baseline, no group difference in the total amount of time spent looking at the two objects, $F(2, 50) = 1.7$, $p > 1$; the face, $F(2, 50) < 1$; or the other parts of the screen, $F(2, 50) < 1$, were found.

Two measures of gaze following were used: the direction of the first look and the proportional looking time toward the referred object. At the beginning of the teaching sequence, most children's first saccade after fixating on the face followed the

Table 2
Distribution of Average Looking Time (s) and Standard Deviations Over Three Areas of Interest (Objects, Face, and Other) During the Baseline and Teaching Intervals of Each Trial

	Baseline			Teaching		
	Objects	Face	Other	Objects	Face	Other
At-risk poor-skills	1.31 (0.52)	1.60 (0.74)	0.03 (0.04)	1.64 (0.69)	1.70 (0.72)	0.05 (0.07)
At-risk typical-skills	1.21 (0.56)	1.60 (0.66)	0.03 (0.16)	1.22 (0.56)	1.88 (0.77)	0.07 (0.08)
Control	1.06 (0.39)	1.60 (0.77)	0.08 (0.11)	1.25 (0.63)	1.74 (0.77)	0.04 (0.08)

actress's direction of gaze. Although the at-risk poor-skills group did sometimes fail to follow gaze (control: $M = 0.91$, $SD = 0.16$; at-risk typical-skills: $M = 0.96$, $SD = 0.14$; at-risk poor-skills: $M = 0.80$, $SD = 0.35$), there was no significant overall group effect for this measure, $F(2, 48) = 2.02$, $p > .1$. By contrast, a main effect of group was apparent when analyzing proportional looking toward the referred object, $F(2, 52) = 3.69$, $p = .03$, partial $\eta^2 = .14$ (see Figure 2). This effect decreased in size but remained marginally significant when group differences in chronological age and general developmental level (Mullen scores) were covaried out, $F(2, 52) = 2.49$, $p = .09$, partial $\eta^2 = .09$. Only the control and at-risk typical-skills toddlers looked significantly longer than expected by chance toward the referred object during teaching—at-risk typical-skills ($M = 0.84$, $SD = 0.13$), $t(24) = 13.11$, $p < .001$; control ($M = 0.78$, $SD = 0.17$), $t(17) = 6.84$, $p < .001$—but the performance of the at-risk poor-skills group also approached significance ($M = 0.66$, $SD = 0.25$), $t(9) = 1.99$, $p = .07$. When excluding the child with a community diagnosis, the looking-time distribution for the at-risk poor-skills group was significantly different than chance ($p = .02$); therefore, the main effect of group was nonsignificant, $F(2, 51) = 2.17$, $p > .1$.

Testing word knowledge. We first analyzed the performance during the familiar words test trials, both in terms of looking time and pointing behavior (Figure 3). Fifteen control toddlers and 32 at-risk toddlers (22 at-risk typical-skills and 10 at-risk poor-skills) contributed data to this measure. Although

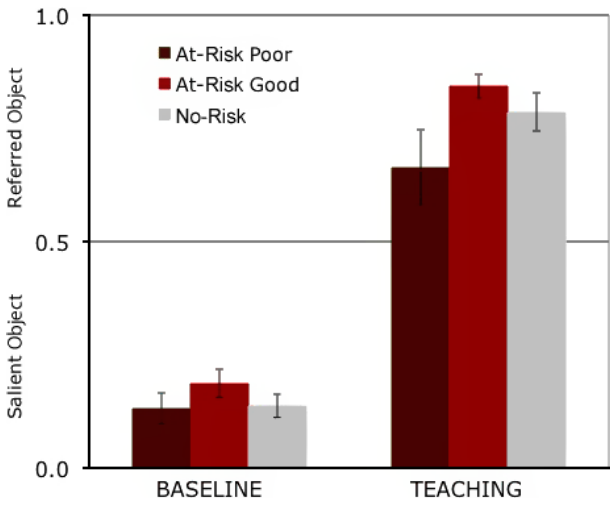

Figure 2. Proportionate looking time toward the referred object, during baseline and teaching sequences of the familiarization clip (averaged across all four novel word-learning trials).

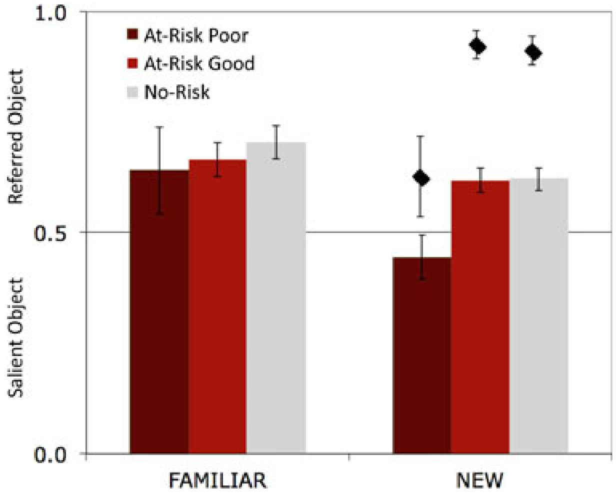

Figure 3. Proportionate looking time (bars) in the familiar and novel words test trials and pointing (♦) performance in the novel words test trials. Pointing performance in the familiar test trials was errorless.

there was no effect of group on looking time, $F(2, 47) < 1$, only the controls and the at-risk typical-skills toddlers looked toward the correct referent above-chance level—control, $t(14) = 4.89$, $p < .001$; at-risk typical-skills, $t(21) = 4.08$, $p < .01$ and at-risk poor-skills, $t(9) = 1.42$, $p > .1$. Removing data from the child with ASD did not change any of the reported significance levels.

All but three toddlers pointed to the duck or shoe when prompted to do so, and their choice was correct in all cases. One control and two at-risk poor-skills toddlers failed to point within 8 s of prompting (including the child with the community diagnosis). The looking behavior of these children was variable; the control toddler spent 80% of the time looking toward the correct object, whereas the two at-risk poor-skills toddlers looked correctly for 40% and 85% of the time, respectively. Hence, the great majority of participants from all groups (apart from possibly one at-risk poor-skills participant) recognized the familiar words.

The performance of toddlers during the novel test trials was analyzed in a similar way. A main effect of group was evident in toddlers' proportionate gaze toward the referred object, $F(2, 49) = 6.92$, $p < .01$, partial $\eta^2 = .22$, and this remained highly significant once group differences in age or general developmental level were considered, $F(2, 49) = 5.60$, $p < .01$, partial $\eta^2 = .20$. We were also concerned that the differences in looking behavior during the novel words test trials might be due to children's willingness to comply with the request to look at the target object, as possibly suggested by the poor performance of the at-risk poor-skills group in the familiar words condition. We therefore entered the looking performance during the familiar words condition as a covariate. The main effect of group remained significant, $F(2, 45) = 5.59$, $p < .01$. Post hoc independent samples t tests, using the Bonferroni correction, confirmed the interaction to be due to the at-risk poor-skills group looking significantly less toward the referred object than both the controls ($p < .01$) and at-risk typical-skills groups ($p < .01$). Although control and at-risk typical-skills toddlers looked significantly longer than chance toward the referred object—control ($M = 0.62$, $SD = 0.1$), $t(15) = 4.45$, $p < .01$; at-risk typical-skills ($M = 0.61$, $SD = 0.13$), $t(23) = 3.90$, $p < .01$—this was not so for the at-risk poor-skills group ($M = 0.44$, $SD = 0.15$), $t(9) = -1.13$, $p > .1$. None of the significance levels were affected by removing data from the child with a community diagnosis of autism.

Three out of the 55 toddlers failed to point during the novel word test trials (and these were the same individuals who failed to point during the familiar words trials). Performance of the remaining children was significantly different across the groups, $F(2, 49) = 9.17$, $p < .01$, partial $\eta^2 = .28$, again remaining significant when differences in general development were considered, $F(2, 49) = 7.01$, $p < .01$, partial $\eta^2 = .23$. Post hoc t tests confirmed that the at-risk poor-skills toddlers performed worse than both the control ($p < .01$) and at-risk typical-skills toddlers ($p < .01$). Only performance of control and at-risk typical-skills toddlers was above-chance—control ($M = 0.87$, $SD = 0.14$), $t(16) = 10.60$, $p < .01$; at-risk typical-skills ($M = 0.93$, $SD = 0.15$), $t(24) = 12.39$, $p < .001$; and at-risk poor-skills ($M = 0.59$, $SD = 0.29$), $t(7) > .1$. As for the familiar words trials, looking-time measures for the children who failed to point were variable; the control child and one at-risk poor-skills child looked more toward the referent during the test clip (63% of the time), whereas the other at-risk poor-skills toddler looked more toward the incorrect object (73%). This suggests that the absence of overt pointing response does not necessarily indicate failure to map the novel words.

Dimensional approach. The differences found between at-risk poor-skills and at-risk typical-skills children are suggestive of a relation between the severity of social and communicative atypicalities and word learning. To strengthen our findings, we followed the previous categorical analysis with a dimensional analysis. Multiple regression analysis was used to test whether ADOS and Mullen scores predict looking behavior during baseline, teaching, and test phases. The results of regression indicated that ADOS scores significantly predicted the proportional looking time toward the referred object during teaching ($\beta = -.32$, $p = .04$) and during the novel words test trials ($\beta = -32$, $p = .04$), but not during baseline ($\beta = .03$, $t < 1$). By contrast, it was the Mullen scores predicted the proportional looking time toward the correct object during the familiar words test trials ($\beta = .37$, $p = .02$). ADOS scores on their own explained 41% of variance of the looking-time measure during teaching, $F(1, 49) = 10.7$, $p < .01$, and 33% of variance for the novel words test, $F(1, 49) = 6.2$, $p = .01$.

Correlation Between Familiarization and test Clip Measures

The first measure of gaze following, the proportion of correct first looks, was not correlated with the proportional looking time toward the correct object during the test phase. However, we did find a correlation between individuals' proportional gaze toward the referred object during the teaching sequences and test trials, for the sample as a whole (Pearson's $r = .35$, $p = .01$) and for the at-risk group in particular ($r = .39$, $p = .02$; see Figure 4). Further splitting the at-risk group into poor- and typical-skills subgroups led to nonsignificant

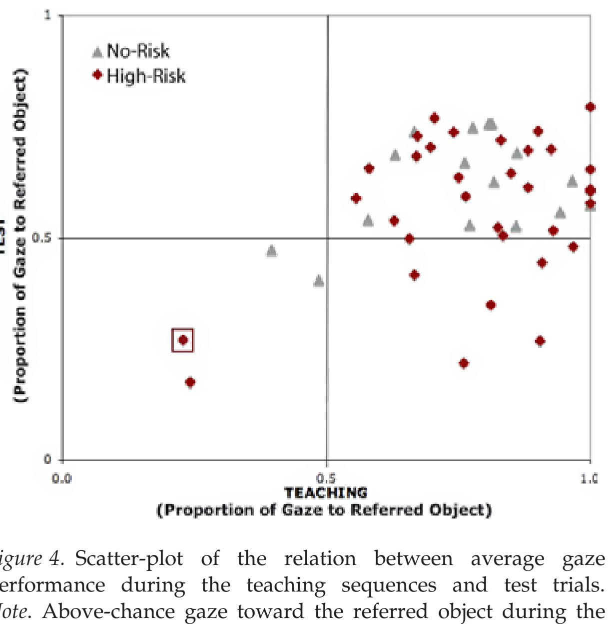

Figure 4. Scatter-plot of the relation between average gaze performance during the teaching sequences and test trials. *Note.* Above-chance gaze toward the referred object during the teaching sequences is associated with above-chance gaze toward the referred object during test trials. The highlighted case is the child for whom the parents reported a community diagnosis of autism spectrum disorder at the time of testing.

correlations, probably due to diminished sample sizes. The correlations between teaching and test measures became marginally significant when the child with a community diagnosis was excluded. To make sure the correlation between teaching and test measures did not reflect a mere preference for the referred objects, we also tested the association between proportional looking toward the referred object during the baseline sequence and during the test phase. These measures were uncorrelated when either the whole sample or the three groups were analyzed. We also ran nonparametric tests after transforming looking-time performance during the teaching sequence and test trials into dichotomous variables, based on whether proportional gaze toward the referred object was above or below the chance level. Thus, teaching and test measures were coded as 0 if they were below or equal to 50%, and as 1 if they were above 50%. Below-chance-level gaze toward the referred object during teaching sequences always resulted in below-chance-level performance during the test trial, as confirmed by a nonparametric analysis applied to the whole sample (McNemar test, $p = .03$). Interestingly, however, 6 participants (all in the at-risk group) who looked more than expected by chance to the referred object during teaching, did not succeed in learning the word–object associations (below chance looking toward the correct object during test). Thus, gaze-following and word-learning performance was only moderately correlated.

Discussion

Gaze following is frequently described as a prerequisite for social learning in general, and even more so for word learning. To investigate the link between gaze-following and word-learning abilities, we made use of the wider range of individual variability observed in the BAP (i.e., in children at risk for autism). We focused on two behavioral subcomponents of gaze following: the ability to follow someone's gaze, previously shown to correlate with vocabulary growth (Morales et al., 1998; Mundy et al., 2000), and the distribution of looking between a gazed-at object and a distracter. We found that the ability to follow someone's gaze did not relate to word-learning performance in our task but that the distribution of looking between a gazed-at object and a distracter, a measure not previously studied in relation to vocabulary size, was a better predictor of word-learning success. However, although children's looking behavior during teaching correlated positively with their test performance, test performance of the at-risk poor-skills group was at chance level, despite their good gaze-following abilities. The first saccade made by these children followed the direction of the actress's gaze above chance level, and they tended to look somewhat longer toward the referent during the teaching sequence. It seems, therefore, that the ability to follow gaze, although a prerequisite for establishing joint attention and learning from social cues, does not guarantee the success of social learning. When gaze following is impaired, preventing children from fixating the object they are supposed to learn about, social learning will obviously be affected. Indeed, all children who attended more toward the salient object than the referred object during the teaching sequence had below-chance test performance (Figure 4). This was also the case of the child that had received a diagnosis of autism. This child spent very little time on the referred object during teaching, and her removal from the statistical analysis brought group performance above chance level. It is possible that gaze following per se may be a limiting factor for the most affected of children, either because they cannot triangulate someone's direction of looking or because they cannot disengage with distracting objects (Elsabbagh, Volein, Holmboe, et al., 2009).

Perhaps a more surprising finding is that learning can still be affected despite unimpaired gaze-following abilities. Several language acquisition models consider gaze following to have a pivotal role (Carpenter et al., 2002; Morales et al., 1998; Mundy et al., 2000). However, our findings suggest that something more than gaze following is required for successful word learning. It has been previously proposed that in addition to identifying a gazed-at object, a child needs to understand the relation between the word she hears and the object she is looking at, in order to learn a word (Waxman & Gelman, 2009). How children discover this relation has been the subject of much debate. One proposed mechanism is that of general purpose associative learning, which suggests that word learning requires the ability to associate co-occurring audio–visual events (Houston-Price, Plunkett, & Duffy, 2006; Smith & Yu, 2008). Alternatively, it has been proposed that whether or not words and objects become associated depends on the pragmatics of the situation—word learning occurring only if ostensive communicative cues and clear referential cues are available (Baldwin, 1995; Gliga & Csibra, 2009). This second position is supported by evidence that typically developing children do not associate a word they hear with the object they are holding and looking at if the person uttering the word is not present (communicative signals absent) or not looking at the same object (contradictory referential cues; Baldwin, 1991, 1993). Our study adds to this body of evidence by describing a population (our at-risk poor-skills group) in which word learning does not occur despite the fact that the child and the experimenter are looking at the same object. In this case, it is not the absence of clear pragmatic cues that prevents learning, but the absence of the ability to use these cues, which characterizes children with ASD and to a certain extent our at-risk poor-skills group. As the high ADOS scores suggest, these children are not very sensitive to communicative cues (e.g., are slower to respond to their name being called or to the experimenter trying to establish eye contact). The dissociation we see here between gaze following and gaze ''reading'' is also reminiscent of a dissociation previously found in children with ASD; being able to tell where someone is looking but not being able to infer, based on the direction of gaze, what that person wants (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995). Little is currently known about the neural substrate of the ability to perceive gaze shifts as conveying communicative reference and intentions. One brain-imaging study found that the superior temporal sulcus (STS) differentiated between eye gaze, which was congruent or incongruent with the position of an object in control participants, but not in individuals with autism (Pelphrey, Morris, & McCarthy, 2005). However, this study only shows that the STS encoded the expectancy that people look at objects. Future studies will have to investigate the relation between STS activation and learning from gaze cues.

In addition to understanding word-learning mechanisms, studying at-risk children allows us to investigate the BAP during development. One of the questions of interest in the field of autism is whether we are indeed dealing with a phenotypic continuum. Several recent neurobiological and developmental models of autism highlight the need to examine autism-related characteristics, which extend as a *continuum of severity across those with or without a formal diagnosis* (Constantino, 2011). Such quantitative trait analysis will clarify apparent inconsistencies in terms of the linguistic abilities of children with ASD, which stem from the study of groups with diverse ASD severity levels. It is therefore of interest to highlight that the performance of our at-risk poor-skills group paralleled that of autistic children in Parish-Morris et al. (2007). This suggests that difficulties with using social cues to learn words are not only characteristics of diagnosed cases but also more generally characteristics of the BAP. This continuity in the severity of social learning skills is also supported by the strong correlations between ADOS scores and word-learning performance. Our study differs from that of Parish-Morris et al. in terms of using televised stimuli instead of live interactions. However, we feel confident that any difficulties with word learning were not due to the use of televised scenes. Televised social stimuli have been used in many studies of social learning, with typically developing children of various ages easily able to engage with and learn from them (Gliga & Csibra, 2009; Houston-Price et al., 2006; Mumme & Fernald, 2003). Moreover, video-modeling of social skills is frequently and successfully used with children with ASD (Cardon & Wilcox, 2011; Charlop-Christy, Le, & Freeman, 2000; Nikopoulos & Keenan, 2007).

Interestingly, neither the previous sample of children with ASD (Parish-Morris et al., 2007) nor our at-risk children consistently showed incorrect mapping of the new word to the salient object (all but 1 child pointed at least twice toward the correct referent during test trials). Children with autism have been reported, anecdotally, to form incorrect associations between new words and the objects that happened to attract their attention at the time (Kanner, 1973). The sometimes atypical use of language in this group has previously been explained on the basis of such incorrect mappings (Baron-Cohen et al., 1997). However, despite the challenging attentional context of our experiment, which prevented a subset of our participants from learning the correct mapping, saliency cues did not completely override the presence of referential cues to result in incorrect mapping. Further studies are needed to determine whether instances of incorrect mapping might be the characteristic of only diagnosed cases and not the BAP in general, or whether they might require exceptional conditions in order to occur (e.g., repeated incorrect pairings or relevance to an individual's particular circumscribed interests).

A second question we aimed to answer was whether children at-risk for autism as a group manifest social learning difficulties, or only those that also show ASD-like atypicalities. Studies of younger siblings have found that at younger ages, at-risk children differed as a group from low-risk controls on several measures (Elsabbagh, Volein, Csibra, et al., 2009; Elsabbagh, Volein, Holmboe, et al., 2009; Presmanes et al., 2007). at the time of their publication, these studies did not include follow-up measures of social and communicative abilities. We therefore do not know whether these differences were due to only a subset of at-risk children, specifically those who demonstrated social-communication atypicalities characteristic of the BAP. We were able to address this question in the present study by using the ADOS. Our main finding was that family risk did not affect children's performance equally, with both gaze-following and word-learning performance being closely linked to individual ADOS scores. Although all children correctly followed the direction of the actress's gaze while she was labeling the object, the at-risk poor-skills group spent slightly less time looking at the referred object than did the rest of the at-risk children or the control group. During the test phase, only the at-risk poor-skills group showed poor word learning, as evidenced by their chance-level looking time and pointing performance. By contrast, the performance of the remaining at-risk children was indistinguishable from that of children with no family history of autism, and this was the case during both the teaching sequence and the test phase. It is possible that the absence of difference between at-risk typical-skills and control groups is due to a lack of sensitivity of our task. Had we made the task more demanding (e.g., shorter familiarization, more distracting objects) such a difference might have emerged. However, the contextual characteristics of our task were not unlike real-life situations, in which caregivers provide rich social cues, especially when addressing children. We show that at-risk children with typical social and communicative cues are able to learn in these situations as well as low-risk controls. Developmental models of autism hypothesize that some children who earlier in life show atypical behaviors may improve in time as a result of either ''compensatory'' mechanisms or beneficial environmental conditions (Elsabbagh & Johnson, 2010; Yirmiya & Charman, 2010). It is therefore possible that earlier differences in word-learning abilities exist between at-risk typical-skills and control groups. Future studies could address this by looking at word-learning abilities at even younger ages, in order to shed light on the existence of different developmental trajectories.

We argue here for the importance of studying not just the ability to understand and express language but also the mechanisms by which language is learned. Follow-up studies will be required to assess the impact different word-learning abilities, as measured at 3 years of age, might have on linguistic abilities later in life. Measuring both looking and pointing behaviors allowed us to determine that lack of an overt response (i.e., pointing) did not necessarily reflect failure in the word-learning task, thus revealing what would otherwise have been hidden abilities. This is encouraging for the future use of implicit measures of cognitive abilities with groups of individuals from whom it may be difficult to elicit overt responses, such as children with ASD, which provide us with invaluable information to further our understanding of cognitive development.

Conclusion

Because children with an ASD have difficulties with language acquisition as well as with following gaze, a causal link has been proposed to relate these two skills. We have shown, however, that following someone's gaze to a referred object is necessary but not sufficient to learn the associated word. Children manifesting BAP-like social and communicative atypicalities are able to follow gaze but do not use this cue to learn words. Intervention programs aimed at training gaze-following skills, in order to improve social and communicative abilities in children with a diagnosis of ASD or at risk for developing this disorder, are already available (Isaksen & Holth, 2009; Klein, Macdonald, Vaillancourt, Ahearn, & Dube, 2009). Our findings highlight the importance of going beyond quantifying overt behaviors (e.g., gaze following) in order to understand and improve the social learning difficulties characteristic of autism.

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