

Visual Scanning and Pupillary Responses in Young Children with Autism Spectrum Disorder

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Using eye-tracking technology we investigated visual scanning and pupillary responses to face and non-face stimuli in nine children (M = 49.6 months) with Autism Spectrum Disorder (ASD) compared to six mental-age and nine chronological-age matched children. The results revealed a significant decrease in visual scanning to landscapes. In addition, the ASD group showed pupillary constriction to children's faces, while control groups showed pupillary dilation. Visual scanning responses to landscapes had a negative correlation with the Behavior subscale of the Autism Diagnostic Observation Schedule-Generic for the ASD group. Potential use of these measures as early indicators of ASD is discussed.

Introduction

The diagnosis of Autism Spectrum Disorder (ASD) is based on deficits in social interaction, communication, and the presence of repetitive or stereotyped behaviors (American Psychiatric Association [APA], 1994). However, the disorder is also typified by a varied range of behavioral symptoms (e.g., deficits in arousal, orienting, and executive attention) that may have a correspondingly diverse range of underlying neurological impairments. This diversity has challenged attempts to characterize ASD coherently, and to identify its neurological basis.

To explicate a connection between these deficits, many researchers have adopted a primary deficit model that posits a single neurological disturbance as the cause of these behavioral and neurological impairments. Most believe that the primary impairment in ASD originates prenatally and causes a neural misorganization, leading to secondary deficits. Identification of a *primary* deficit could lead to interventions targeted at prevention of the primary deficit or from its ability to cause secondary effects. While many researchers have investigated and suggested impairments in a variety of neurological structures and functional systems as the primary impairment in ASD (e.g., medial temporal lobe, cerebellum, brainstem, and frontal lobes), no primary neurological impairment has been definitively found.

One of the problems associated with identification of a primary deficit in ASD is the inability to determine if the deficit is present throughout the lifespan. If the primary impairment occurs prenatally, some characteristic impairments of ASD should be present

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from birth. Currently, ASD can be reliably diagnosed starting between 18 and 36 months of age (National Institute of Mental Health, 2004), although the average age of diagnosis is six years (Howlin & Moore, 1997); therefore, due to late diagnosis, primary deficit candidates currently cannot be investigated during infancy.

Early infancy would be a particularly advantageous time to investigate the primacy of a deficit because the deficit would presumably be less influenced by the environment, and less entangled with the many secondary deficits that might be present in early childhood. For example, the preferential attention to social stimuli, which is reported to occur in newborns (e.g., Johnson, Dziurawiec, Ellis, & Morton, 1991), is thought to be a precursor to joint attention (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson et al., 2004), which emerges between 6 and 12 months of age (e.g., Carpenter, Nagell, & Tomasello, 1998; Morales, Mundy, & Rojas, 1998). In turn, joint attention is thought to be a precursor to theory of mind (Baron-Cohen, 1989), which develops during the fourth year of life (Flavell, 1993; Wellman, 1994). Thus, deficiencies in the neurological structures underlying a precursor could be the primary cause of impairments in later developing skills. However, the early identification of impairments in precursor skills would be necessary to determine their primacy. Therefore, the ability to explore primary deficits during the more rudimentary stages of infancy would aid investigations of primary deficits; and the ability to determine if a primary deficit is present in early infancy is necessary to support the primary deficit model.

Impairments in lower-order systems, such as attentional and arousal systems, show promise as early indicators and primary deficit candidates in ASD because impairments in these domains are likely to be present early in life and can alter neuronal activity in areas responsible for sensory, motor, and emotional processing (Posner & Raichle, 1994). In fact, retrospective analyses of home videos taken prior to 18 months of age have found attention to be one of the constructs that most commonly differentiates those with ASD during the first year of life; these attentional measures include decreased orienting to faces (Maestro et al., 2002; Osterling & Dawson, 1994), lack of social smiles (Adrien et al., 1993; Maestro et al., 2002), and decreased orienting to vocalizations of the child's name (Baranek, 1999; Osterling & Dawson, 1994; Werner, Dawson, Osterling & Dinno, 2000).

In addition, prospective examinations, using more controlled methods and measures, have provided information regarding the specific nature of this social attention impairment. For example, Sweetenham and colleagues (1998) found that 19- to 20-month-old children with autism spend less time looking at faces and have fewer shifts per minute from object to face and face to face than both delayed and typically developing controls. Dawson and her colleagues (1998, 2004) have found a general orienting deficit to all auditory stimuli in 30- to 64-month-old children with ASD, with the most pronounced deficits to social auditory stimuli. Finally, eye-tracking technology has revealed distinct scanning patterns in adults with autism compared to typically-developing controls while examining dynamic social scenes (Klin, Jones, Schultz, Volkmar, & Cohen, 2002) and still photographs of human faces (Pelphrey et al., 2002). In particular, Klin and colleagues (2002) found that persons with autism looked more at the mouth region than the eyes, while controls looked most at the eyes, and Pelphrey and colleagues (2002) found that persons with autism looked less often at all internal features (eyes, nose and mouth) than controls. The orienting response to social stimuli may therefore best distinguish persons with ASD from controls (Dawson et al., 2004). Such a measure might be useful for early identification, and for the delineation of putative primary deficits.

Nevertheless, the measures used in the investigation of social attention deficits in infants with ASD during the first year of life have been largely retrospective, naturalistic,

and unspecific. However, more controlled methods and measurements have become increasingly available. For example, prospective measurements of social attention using measures of eye-tracking and physiological responses to social stimuli during the first year of life might provide increased sensitivity to ASD classification over the retrospective findings. However, because the use of eye-tracking technology has only revealed atypical scanning patterns to faces in adults with autism (Klin et al., 2002; Pelphrey et al., 2002), its demonstration in children with ASD is first necessary to ensure that these measures can differentiate children with ASD as well as adults.

The purpose of the current investigation was to determine if eye-tracking responses (visual scanning and pupil diameter) to face and non-face stimuli would differentiate young children with ASD from controls. Visual scanning was chosen due to previous successes in discriminating adults with autism (Klin et al., 2002; Pelphrey et al., 2002). In addition, eye tracking has advantages over observational measures of social attention because the exact location of gazes can be determined and examined by specific regions within the stimulus; this could result in a more detailed analysis of attention to faces.

We also chose to measure pupil diameter because pupillary responses have long been associated with attentional engagement and information processing (Hess, 1975; Hess & Polt, 1964). Indeed, pupillary responses change with social content as early as one to four months of age; greater pupillary dilation occurs with the presentation of social stimuli (Fitzgerald, 1968). In addition, this measure is arguably a more reliable and sensitive autonomic measure for small sample sizes than other autonomic measures (e.g., Beatty & Lucero-Wagoner, 2000).

We examined participants' visual scanning and pupillary responses to face (children and animal) and non-face (toys and landscapes) stimuli. Based on the extant literature indicating that social attention deficits are discernable and sensitive indicators of ASD (e.g., Dawson et al., 2004; Klin et al., 2002; Maestro et al., 2002; Sweetenham et al., 1998), we expected visual scanning patterns and pupillary responses to faces to discriminate children with ASD from controls. Specifically, based on previous eye-tracking examinations (Klin et al., 2002; Pelphrey et al., 2002), we hypothesized that the ASD group would show less scanning to children's faces, in particular the internal features (eye, nose, and mouth), than controls. Based on Fitzgerald (1968), we also expected the ASD group to show less pupillary dilation to children's faces, specifically within the internal region, than controls. Animal faces were built into the design to determine whether such responses occurred to global facial configurations or to human faces specifically; and if general responses to faces were affected then the pattern of responses to animal and human faces should be similar. Finally, we evaluated responses to non-face stimuli as controls and no effects of ASD were expected to emerge.

Method

Participants

Inclusion Criteria. Children between the ages of 12 and 72 months were recruited for the study if they had a diagnosis of Autistic Disorder (AD), Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS), a diagnosed developmental disability (DD), or were typically developing (TD). We recruited these children from a variety of organizations that had contact with families whose children could meet the inclusion criteria in metropolitan and suburban areas of Kansas City, KS and MO, and from a commercial new-parent list.

Table 1
Participant attrition reasons

	AD	PDD-NOS	DD	TD
Unable to calibrate	5	0	2	17
Poor eye detection	1	0	0	5
Experimenter error	0	0	0	1
Child refusal	5	0	0	9
Parent/child interference	0	0	1	4

The values represent the number of subjects. AD = Autistic Disorder; PDD-NOS = Pervasive Developmental Disorder-Not Otherwise Specified; DD = developmental disability; TD = typically developing.

Attrition/Exclusion Criteria. Children were excluded from participation if they had impairments in vision, hearing, and/or motor abilities, and if they were ill or had taken medications 48 hours prior to the visual testing appointment.¹ Additionally, we did not include the data of 12 TD participants in the final analysis because of the group matching strategy, in which characteristics of the ASD group dictated the composition of the other groups (see section on group assignment). Thus, 86 children were seen for testing appointments and data from 24 participants were used in the final analysis. As can be seen in Table 1, 58% of the data was unusable due to attrition (see section on visual testing session for further explanation of the attrition categories).

Group Assignment. Twenty-four participants were assigned to one of three groups, Autism Spectrum Disorder (ASD; $n = 9$), delayed ($n = 6$), or typically developing (TD; $n = 9$). The ASD group consisted of children who had a previous diagnosis of AD ($n = 7$) or PDD-NOS ($n = 2$). The delayed group consisted of children who had an Early Learning Composite score on the Mullen (Mullen Scales of Early Learning; Mullen, 1995) that was greater than one standard deviation below the test mean; two of the children in this group had a diagnosed language delay, but none had a diagnosis of an ASD. The TD group was comprised of children who had scores on all Mullen subscales that were not less than one standard deviation below the test mean and did not have a diagnosed DD or ASD. We confirmed the presence or absence of an ASD diagnosis through administration of the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord, Rutter, & DiLavore, 1997). Table 2 presents descriptive information for all groups. There were no differences among the three groups in parent education level, $F(2, 20) = 0.18, p > .05$.

The age and gender composition of the ASD group dictated the recruitment and formation of the control groups (delayed and TD). Thus, we matched control groups with the ASD group on mean age and frequency of each gender. Age was considered a match if between-group differences in mean age were nonsignificant, and gender was considered a match if between-group gender frequencies were equal. Using these criteria, the delayed group was matched with the ASD group on chronological age (CA) and mental age (MA: based on their composite scores on the Mullen), and was approximately matched on gender (see Table 2 for further detail). The TD group was matched with the ASD group on CA and gender, but not on MA, $t(16) = -2.71, p < .025$.

¹One exception to this was a child with PDD-NOS who had comorbid seizure disorder but who was medication-free only 24 hours prior to the visual test because the medication was prescribed to prevent the occurrence of seizures.

Table 2
Descriptive information

Measure	Group		
	ASD (<i>n</i> = 9; 8 M, 1 F)	Delayed (<i>n</i> = 6; 6 M, 0 F)	TD (<i>n</i> = 9; 8 M, 1 F)
CA (months)	49.6	46.3	49.8
Mullen (months)			
Visual Reception AE	34.33	36.29	53.44
Fine Motor AE	37.44	38.43	48.89
Receptive Language AE	30.78	37.29	54.00
Expressive Language AE	30.67	35.29	58.11
Composite (MA)	33.31	38.25	53.61
ADOS-G			
Social	10.56	0.16	0
Communication	13.00	1.33	0
Behavior	3.13	0	0
Parents education level ^a	3.25	3.42	3.78

The values are represented as means. ASD = Autism Spectrum Disorder group; TD = typically-developing; M = male; F = female; CA = chronological age; Mullen = Mullen Scales of Early Learning (Mullen, 1995); AE = age equivalent; MA = mental age; ADOS-G = Autism Diagnostic Observation Schedule-Generic (Lord, Rutter, & DiLavore, 1997); Social = Qualitative impairments in reciprocal social interaction; Behavior = Stereotyped behaviors and restricted interests.

^aNumber of years of education beyond high school for both parents.

Visual Testing Session

We recorded scanning and pupillary responses using an ASL Model 504 eye-tracking system (Applied Science Laboratory [ASL], 2001) with a Flock of Birds magnetic head tracker (Ascension Technology Corporation, 1999) in a partitioned interior room that was divided into participant and experimenter areas (see Figure 1).

In the participant area, children were secured in a child-sized car seat that was strapped onto a hydraulic chair, used to adjust each child's eye height to be approximately 124.5 cm from the floor. Stimuli were presented on a 40.6 cm computer monitor (21.6° visual angle) placed in front of the participant. The pan/tilt camera was centered below the stimulus monitor and used to capture an image of the left eye. Automatic head tracking allowed the pan/tilt camera to follow the child's eye as they moved, and required the use of a head mounted magnetic sensor that was secured with Velcro™ coins onto a CoFlex™ headband and positioned over the child's left eye. Because not all children would tolerate wearing the headband, we also employed a manual mode of tracking as necessary.

Prior to stimulus presentation, we obtained pupil and corneal reflection thresholds, and then calibrated the participant's eye movements using a five-point calibration array (i.e., dynamic cartoons at four corners and a center point). If initial calibration was unsuccessful (i.e., thresholds were unsteady and cross hairs were inconsistently present and/or not centered over each of the five points while the child was looking at the stimulus monitor), the calibration procedure was repeated up to five times.

After successful calibration, stimuli were presented using the Gaze Tracker™ interface program (ERICA, 2001). Prior to stimulus presentation, participants were instructed

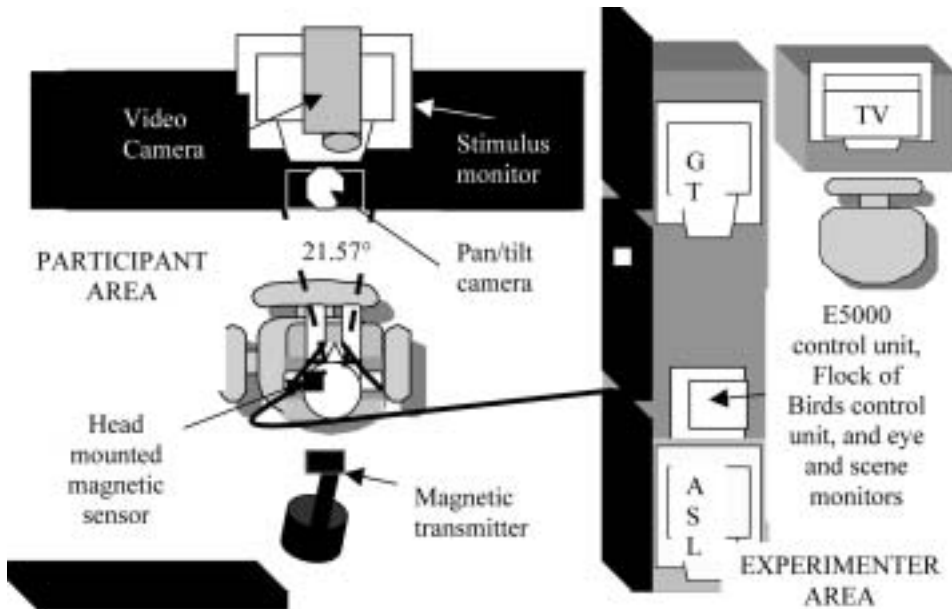


Figure 1. Schematic of the visual testing room setup.

to look at the pictures and not touch the headband, if being worn; no further instructions were given once the presentation began. Throughout the session, pupil and CR thresholds were monitored and adjusted as necessary. In addition, the child's behavior was monitored via a video camera connected to a television monitor in the experimenter area to ensure safety and compliance with instructions. If the child touched or tried to remove the headband and disrupted head tracking, we removed the headband during an interstimulus slide and engaged manual tracking. The visual test was considered "usable" if calibration remained accurate throughout the session (i.e., good eye detection, which consisted of steady and consistent crosshairs while the child looked at the screen) and parents and participants complied with instructions.

Stimuli. The stimuli consisted of still color photographs presented in a central location at the participant's midline on the stimulus monitor. The stimuli were randomly ordered into eight presentation sets, and each child was presented with one set. Each set was comprised of eight stimuli, two from each of the following categories: (a) children's faces (two boys and one girl; one of each gender was always presented), (b) animal faces (dog, cat, fox, and lion), (c) toys (shapersorter, ball, boat, and puzzle), and (d) landscapes (clouds, rocks, grass, and water).

Stimuli were presented for 15 s on a grey background with approximate average luminance (4.5–5.4 lx) and size (25.8 cm²; visual angle = 5.45°) held constant. During the interstimulus interval, blank grey slides were presented and were matched for luminance with the stimulus slides. Each presentation set began and ended with an interstimulus slide; and these slides were presented for 3, 5, 7, 9, 11, 13, 15, and 17 s; times were randomly dispersed within each stimulus set. Thus, eight interstimulus slides were presented, plus a final blank grey slide was presented at the end of the series for 10 s.

Measurement and Reduction of Data. The GazeTracker (GT) interface program was used to extract line of gaze and pupil size from the ASL 504 eye-tracking system. This program

allows for analysis of scanning and pupil size based on specific areas of interest (i.e., “look zones”), which were created for each stimulus slide. For the non-face slides, the look zone was the entire picture (excluding the grey border around the picture). For face slides, three look zones were created: (a) eyes, (b) nose and mouth, and (c) head region (excluding the previous two zones). The distance of the perimeter of the look zone from the actual object was determined using a 1° margin of error that is associated with a five-point calibration (see Figure 2). “Fixations” were also specified based on the use of a five-point calibration and were set to be gazes that (a) occurred within a 1° visual angle diameter of the stimulus feature of interest, and (b) lasted for a duration of at least 500 msec.

Visual scanning data. The following variables that reflected looking to the picture (i.e., within the one look zone for the non-face stimuli, and the combined three look zones for the face stimuli) were measured: (a) time tracked, (b) duration of fixations, and (c) average duration of fixations. We also used these variables to analyze scanning of the three face stimuli look zones separately.

Pupillary response data. For each stimulus slide, pupillary data were inspected for artifacts (blinks, loss of tracking, partial eyelid closures, head movements, etc.). We used pupil traces at least 500 ms in length with artifacts that were either no longer than 500 ms or no more than 20% of the duration of the trace. Once adequate pupil traces were found and corrected for artifacts using linear interpolation, an average pupil size was computed for stimulus and interstimulus slides. For stimulus slides, the average pupil size was sub-



Figure 2. Representative stimulus slides with defined look zones. The white lines around the pictures represent the look zones and were not visible to the participants. Each picture represents an example of the children’s face (upper left), animal face (upper right), toy (lower left), and landscape (lower right) stimuli.

tracted from that of the previous interstimulus slide to control for habituation, fatigue, or adaptation effects. Artifact removal and difference score computation methods were similar to those used in other studies (e.g., Granholm, Asarnow, Sarkin, & Dykes, 1996; Reinhard & Lachnit, 2002; Verney, Granholm, & Dionisio, 2001).

Standardized Testing Session

The ADOS-G and Mullen (excluding the Gross Motor subscale) were administered during one testing session that took place within two weeks of the visual test. Both tests were administered according to standardization procedures in a distraction-free room equipped with child-sized table and chairs. The ADOS-G was administered first, followed by the Mullen.

Results

Responses to the Overall Stimulus Type

Scanning Measures

Between-group differences. We analyzed between-group differences in time tracked, total time fixating, and average duration of fixations on the picture region of each stimulus using the Kruskal-Wallis test² (see Figure 3 for corresponding medians; Table 3 shows means and standard deviations). Table 4 shows that this analysis was significant for time tracked, total time fixating, and average duration of fixations for only the landscape stimulus, which was unexpected. Follow-up pairwise comparisons, using the Mann-Whitney *U* test^{2,3}, revealed that the ASD group had significantly less time tracked, total time fixating, and average duration of fixations on the landscape stimulus than the delayed (p 's = .004, .004, and .006, respectively) and TD groups (p 's = .00032, .034, and .008, respectively); the control groups did not differ from each other.

Relationship with ADOS-G scores. Because scanning measures to the landscape stimulus significantly differentiated the ASD group from both controls, the relationship between these measures and scores on the ADOS-G were analyzed using the Spearman's *rho*. This test was conducted only for the ASD group, as controls showed no variability on the ADOS-G subscores. Table 5 shows that the ADOS-G Stereotyped Behaviors and Restricted Interests (Behavior) subscale had a moderate to large negative correlation with all scanning variables; the relationship between this subscale and total time fixating and average duration of fixations was significant. Thus, briefer fixation time on the landscape stimulus was associated with decreased behavioral impairments as measured by the ADOS-G.

Pupil Measures

Between-group differences. Between-group differences for change in the average pupil size to each stimulus type was analyzed using a Kruskal-Wallis test. This test yielded a significant difference in pupil size change to the children's face stimulus $\chi^2(2, N = 20) = 9.413$, $p < .01$ ($\eta^2 = .50$)². Follow-up pairwise comparisons, using the Mann-Whitney *U* test, revealed significant pupillary constriction to the children's face stimulus for the ASD group. This differed from the TD ($p = .004$) and delayed groups ($p = .019$), who had pupillary

²All tests were corrected for ties among ranks if present.

³Type I errors were controlled for using the Holm's Sequential Bonferroni method for all follow-up comparisons.

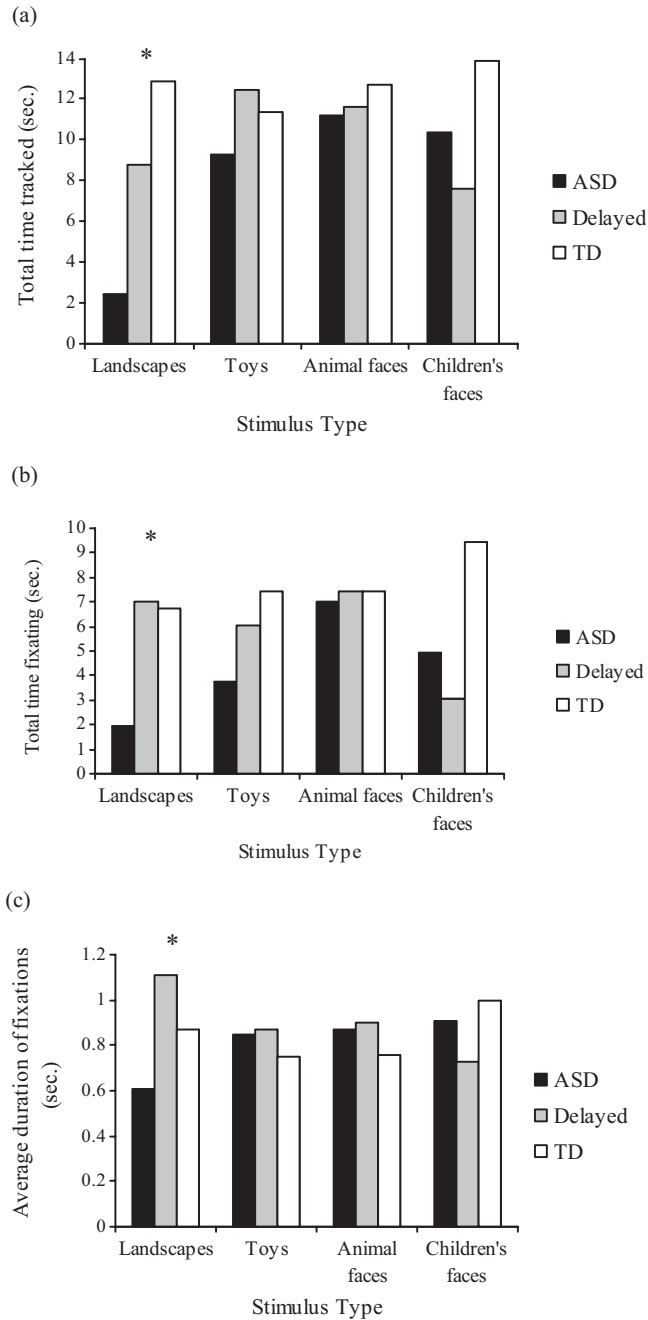


Figure 3. Scanning responses to the overall stimulus type for the Autism Spectrum Disorder (ASD), delayed, and typically-developing (TD) groups: (a) total time tracked on the picture, (b) total time spent in fixations on the picture, and (c) average duration of time spent in fixations on the picture. Graphed values are represented as medians.

* $p < .05$, for landscapes.

Table 3
Means of visual scanning and pupillary responses to the overall stimulus type

	ASD ^a	Delayed ^b	TD ^a
Total time tracked			
Landscapes	4.36 (4.00)	9.16 (2.07)	11.88 (5.77)
Toys	10.50 (0.15)	11.51 (7.32)	12.39 (5.93)
Animal faces	10.67 (4.75)	11.06 (6.39)	13.99 (6.83)
Children's faces	9.82 (5.91)	9.51 (7.86)	14.00 (4.19)
Total time fixating			
Landscapes	2.61 (2.87)	6.38 (2.17)	7.01 (4.50)
Toys	5.73 (4.04)	7.02 (5.68)	7.29 (4.76)
Animal faces	6.11 (2.95)	7.06 (4.22)	9.30 (5.95)
Children's faces	5.76 (4.02)	5.56 (6.35)	9.19 (4.24)
Average duration of fixations			
Landscapes	0.82 (0.22)	1.21 (0.51)	0.94 (0.27)
Toys	0.84 (0.15)	0.99 (0.24)	0.78 (0.10)
Animal faces	0.91 (0.18)	0.91 (0.21)	0.82 (0.16)
Children' Faces	1.04 (0.50)	0.91 (0.34)	1.01 (0.19)
Change in average pupil size			
Landscapes	-0.020 (0.11)	0.107 (0.11)	0.012 (0.06)
Toys	-0.004 (0.17)	0.065 (0.05)	-0.010 (0.13)
Animal faces	-0.036 (0.13)	-0.022 (0.08)	0.053 (0.10)
Children's faces	-0.086 (0.08)	0.033 (0.07)	0.110 (0.13)

SDs are in parentheses. ASD = Autism Spectrum Disorder group; TD = typically-developing.

^aN = 9.

^bN = 6.

Table 4
Between-group differences in scanning each stimulus type

	Landscapes		Toys		Animal faces		Children's faces	
	χ^2	N	χ^2	N	χ^2	N	χ^2	N
Time tracked	8.57*	24	0.47	24	0.88	24	3.01	24
Total time spent	6.16*	24	0.34	24	1.52	24	4.11	24
Fixating								
Average duration of fixations ^a	7.82*	21	2.43	23	1.44	23	1.69	23

For all χ^2 df = 2.

^aSample sizes differed for this variable because some participants did not fixate to all of the slides, therefore averages could not be computed for them.

* $p < .05$.

Table 5
Spearman rho correlations between ADOS-G subscores
and scanning measures on the landscape stimulus for the ASD group

	Communication	Social	Behavior
Time tracked	-0.38	-0.44	-0.54
Total time fixating	-0.43	-0.53	-0.76*
Average duration of fixations	-0.62	-0.71	-0.97**

Social = Qualitative Impairments in Reciprocal Social Interaction; Behavior = Stereotyped Behaviors and Restricted Interests.

* $p < .05$. ** $p < .01$.

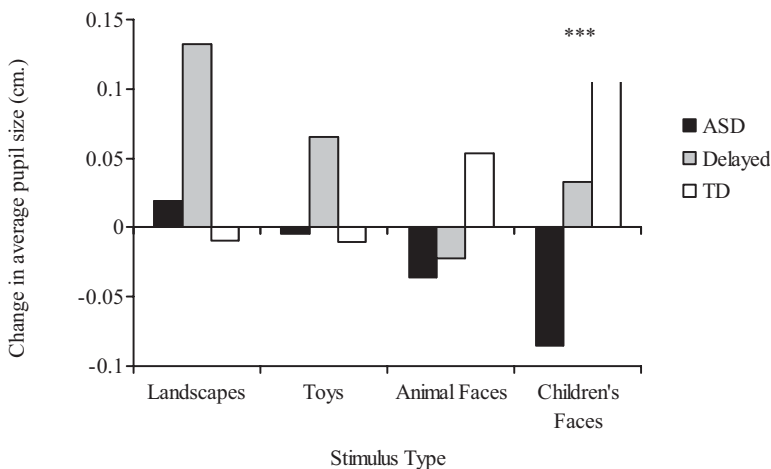


Figure 4. Average change in pupil size from the average pupil size of the previous blank slide to the overall stimulus type for the Autism Spectrum Disorder (ASD), delayed, and typically-developing (TD) groups. Graphed values are represented as medians.

*** $p < .01$, for children's faces.

dilation and did not differ from each other (see Figure 4 for corresponding medians; Table 3 shows means and standard deviations).

Relationship with ADOS-G scores. There were no statistically significant relationships between pupillary responses to the children's face stimulus and the ADOS-G subscales; the magnitude of these correlations were no larger than .12.

Responses to the Internal and External Features of the Face Stimuli

The face stimuli were initially divided into three look zone regions (eyes, nose and mouth, and head); however, responses to the eye and the nose and mouth regions yielded similar scanning and pupillary responses that consistently varied from the rest of the head region. Thus, the eye and nose and mouth regions were combined to form one look zone (the *internal feature* region), and the remainder of the head region formed another (the *external feature* region).

Scanning Measures

Between-group differences. Between-group differences in time tracked, duration of fixations, and average duration of fixations within internal and external regions of the face stimuli were examined using the Kruskal-Wallis test (see Figure 5 for corresponding medians; Table 6 shows means and standard deviations). Table 7 indicates that there was a significant difference in total time fixating in the external region of the children's face. No significant differences were found for any other test. None of the follow-up pairwise comparisons attained statistical significance using the Mann-Whitney *U* test.

Pupil Measures

Between-group differences. Between-group differences in pupillary responses to the internal and external regions of face stimuli were examined using the Kruskal-Wallis test. Table 8 shows a significant difference for the change in average pupil size to the internal feature region of the children's face stimulus (see Figure 6 for corresponding medians; Table 6 shows means and standard deviations). Follow-up pairwise comparisons, using the Mann-Whitney *U* test, revealed significant differences between the ASD group and the delayed ($p = .008$) and TD groups ($p = .009$). The ASD group showed pupillary constriction to internal features of the children's face; pupillary dilation was observed in the delayed and TD groups; the latter two did not differ from each other ($p = .354$).

Relationship with ADOS-G scores. Pupillary measures were not correlated with ADOS-G subscales; *rhos* were not significant, and the magnitude of these correlations did not exceed .05.

Classification of Group Membership

Given that pupillary responses (constriction to the overall and internal region) to children's faces and looking time (time tracked, total time fixating, and the average duration of fixations) to the landscape stimulus significantly differentiated all three groups in the group-based analysis, we sought to determine whether these variables could successfully identify the diagnostic groups using a discriminant analysis. The overall Wilks' lambda was significant, $\Lambda = .304$, $\chi^2(10, N = 23) = 21.429$, $p < .025$, with a non-significant residual Wilks' lambda, $\Lambda = .854$, $\chi^2(4, N = 23) = 2.850$, $p > .05$; thus only the first discriminant function will be interpreted. Table 9 presents the within-group correlations between the predictors and the first discriminant function as well as the standardized weights.

The discriminant analysis successfully predicted diagnostic classification for 78% of the participants (kappa coefficient = .67). Additionally, we cross-validated the classification using the "leave-one-out" technique and correctly classified 52% of the cases. Thus, classification for the overall sample based on these variables was good. In particular, classification of diagnostic status using these predictors yielded 100% correct classification (75% cross-validated) for the ASD group, 50% (17% cross-validated) for the delayed group, and 78% (56% cross-validated) for the TD group.

Discussion

The focus of the current study was to determine if scanning and pupillary responses were discriminable indicators of ASD in young children. We did not design the current investigation to test or support a specific primary deficit theory of ASD, but instead to generate

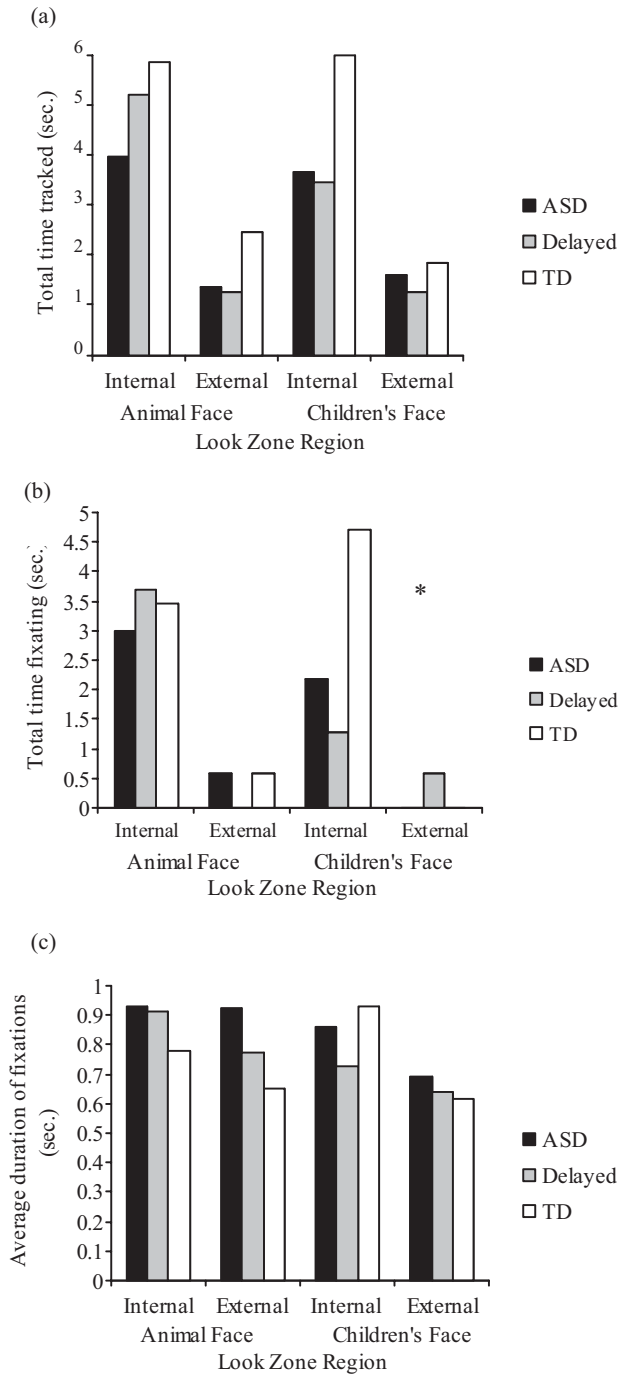


Figure 5. Scanning responses to the internal and external feature regions for the Autism Spectrum Disorder (ASD), delayed, and typically-developing (TD) groups: (a) total time tracked in each region, (b) total time spent in fixations in each region, and (c) average duration of time spent in fixations in each region. Graphed values are represented as medians.

* $p < .05$, for external region of the children's face.

Table 6
Means of visual scanning and pupillary responses to the internal and external regions of the face stimuli

	ASD ^a		Delayed ^b		TD ^a	
	Internal	External	Internal	External	Internal	External
Total time tracked						
Animal	4.37 (2.11)	1.93 (1.65)	4.79 (3.02)	1.48 (0.10)	5.78 (2.87)	2.42 (1.35)
Children's	4.03 (2.60)	1.75 (1.64)	3.89 (3.21)	1.72 (1.71)	6.13 (2.03)	1.74 (0.73)
Total time fixating						
Animal	2.77 (1.52)	0.56 (0.64)	3.26 (2.23)	0.55 (1.04)	4.10 (2.14)	1.09 (2.17)
Children's	2.62 (1.92)	0.52 (1.38)	2.51 (3.12)	0.54 (0.51)	4.45 (2.16)	0.30 (0.72)
Average duration of fixations						
Animal	0.92 (0.17)	0.83 (0.17)	0.94 (0.20)	0.77 (0.13)	0.82 (0.17)	0.83 (0.48)
Children's	1.09 (0.56)	0.69 (0.20)	1.10 (0.72)	0.64 (0.06)	1.06 (0.36)	0.61 (0.15)
Change in average pupil size						
Animal	-0.04 (0.11)	0.02 (0.16)	-0.03 (0.91)	0.07 (0.00)	0.65 (0.11)	0.01 (0.21)
Children's	-0.08 (0.09)	0.05 (0.00)	0.06 (0.07)	-0.04 (0.08)	0.13 (0.14)	0.17 (0.00)

SDs are in parentheses. ASD = Autism Spectrum Disorder group; TD = typically-developing
^aN = 9.
^bN = 6.

Table 7
Between-group differences in scanning face stimuli in each look zone

	Internal		External	
	χ^2	N	χ^2	N
Animal faces				
Total time tracked	0.64	24	2.39	24
Total time fixating	2.45	24	0.49	24
Average duration of fixations ^a	2.72	23	2.03	12
Children's Faces				
Total time tracked	3.54	24	0.70	24
Total time fixating	4.96	24	5.17*	24
Average duration of fixations ^a	1.25	23	0.17	8

For all χ^2 df = 2. Sample sizes varied for averages because not all participants fixated to each look zone region, therefore an average could not be computed.

* $p < .05$.

hypotheses about early indicators of the disorder in order to assist in primary deficit detection. The study was limited by the wide age range of participants, and although this allowed us to recruit an adequate sample size of children with ASD, we cannot determine whether the differential responses were specific to one particular age or age range. The study was also limited by the heterogeneous nature of the delayed group. A more homogeneous control group might have allowed the detection of more subtle group differences

Table 8
Between-group differences in pupillary responses to face stimuli in each look zone region

Look zone region	χ^2	<i>N</i>
Animal faces		
Internal	5.15	21
External	0.34	9
Children's faces		
Internal	8.80*	20
External	2.13	5

For all χ^2 df = 2. Sample sizes varied for these measures because not all participants fixated within each look zone region, therefore a pupillary measure could not be obtained.

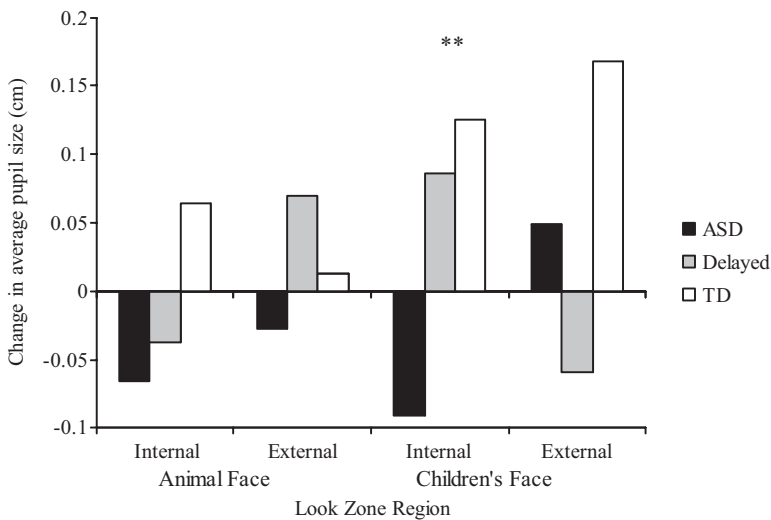


Figure 6. Average change in pupil size from the average pupil size of the previous blank slide to the internal and external features of the animal and children's face stimuli for the Autism Spectrum Disorder (ASD), delayed, and typically-developing (TD) groups. Graphed values are represented as medians. ** $p < .025$, for the internal region of the children's face.

that could have been valuable for specific diagnostic status in ASD. Finally, the current results were obviously based on a relatively small sample size. While the ability of the measures to discriminate ASD with a small sample may reveal an increased sensitivity to ASD classification, and thus has advantages for early detection purposes, the small sample size is problematic for the generalizability of these findings. Replications or extensions of this work that address these limitations would be useful in pursuing this line of inquiry.

Responses to Non-Face Stimuli

Unexpectedly, the ASD group was significantly differentiated from controls in their scanning of landscapes, but not by their pupillary responses to non-face stimuli (landscapes

Table 9
Correlations and standardized coefficients of predictor variables
with the first discriminant function

	Correlation	Standardized coefficients ^a
Average change in pupil size to children's faces	0.61	-0.29
Average change in pupil size to the internal region of children's faces	0.59	1.18
Time tracked on landscapes	0.54	1.08
Total time fixating on landscapes	0.39	-0.63
Average duration of fixations on landscapes	0.24	0.60

^aStandardized canonical discriminant function coefficients.

and toys). The landscape slides consisted of high-spatial frequency features or "local" elements without a dominant low spatial frequency component or global configuration. It may be that individuals with ASD will not orient to stimuli without strong figure-ground contrast. However, previous research suggests that persons with ASD may be superior to controls in their processing of parts over whole objects (Happé, 1996; Shah & Frith, 1983, 1993). This finding, at face value, could be interpreted as support for this position, such that the ASD group's decreased time spent looking at the landscape stimulus might reflect faster processing time of such stimuli. In addition, all three scanning measures were specifically sensitive to ASD classification and associated with the Behavior subscale of the ADOS-G. Thus, while differential responses to this measure were unexpected, the ability of scanning responses to this class of stimulus to distinguish those with ASD makes this a candidate for an early marker.

Responses to Face Stimuli

Scanning Responses. We were not able to differentiate the three groups based on their scanning of face stimuli. This is inconsistent with the results of some previous investigations of attention to social stimuli in ASD during the first year of life (e.g., Adrien et al., 1993; Osterling & Dawson, 1994) and beyond (e.g., Dawson et al., 2004; Klin et al., 2002; Pelphrey et al., 2002; Sweetenham et al., 1998). These inconsistencies may be a function of methodological differences. In most previous investigations, at least two distinct stimuli were present; we only presented one stimulus to maximize the opportunity for an automatic response to each stimulus type. Furthermore, most previous investigations presented dynamic and multimodal stimuli; we presented static stimuli. It may be that multiple or multimodal stimulus presentations significantly affect the response of individuals with ASD; this may be a topic for future research.

Pupillary Responses. As predicted, the ASD group was differentiated from controls by pupillary responses to the children's face stimulus, specifically by pupillary responses when looking to the internal feature region of those faces. These responses may be a more sensitive indicator of ASD than scanning responses. In addition, because pupillary

responses to social stimuli have been demonstrated in early infancy (Fitzgerald, 1968), the candidacy of these responses as an early indicator of ASD is warranted.

To our knowledge, this is the first demonstration of pupillary responses to social stimuli in young children with ASD. Pupillary responses have long been associated with attentional engagement and information processing (Hess, 1975; Hess & Polt, 1964); and these responses have often been used as an index of specific cognitive activity: cognitive load (Ahern & Beatty, 1979, 1981; Hess & Polt, 1964), perception (Hakerem & Sutton, 1966), memory (Granholm, et al., 1997), responses to target stimuli (Richer, Silverman, & Beatty, 1983), and attention (Beatty, 1982). In addition, Rajkowski, Kubiak, and Aston-Jones (1993) have linked pupillary responses with the activity of the locus coeruleus-norepinephrine system activity in non-human primates. Thus, the investigation of pupillary responses to social stimuli in early infancy may also provide clues about the primary deficit.

Summary

The results of the current investigation indicate that scanning responses to landscapes and pupillary responses to children's faces are able to discriminate young children with ASD from both delayed and TD controls; in addition, a discriminant analysis revealed that together these variables were able to correctly classify 78.3 % of the total sample, with 100% of the ASD group being correctly classified. This study was designed to find measures that could distinguish individuals with ASD from controls and generate hypotheses about early indicators of the disorder. However, future investigations should be aimed at first replicating the findings of the current study with a smaller age range, more homogeneous delayed group, and larger sample size. In addition, because of the high attrition rate, attributed primarily to the use of eye-tracking technology (i.e., poor eye detection and inability to calibrate), future investigations may need to use different technologies and methods (e.g., video images of pupil change and visual responses). Future research should also try to determine whether the ASD groups scanning responses to the landscapes were actually a function of superior local processing. If the current results are replicable, future investigations of visual responses to stimuli with local elements and no global configuration and pupillary responses to social stimuli should be examined in infants with a familial risk for ASD to determine if these measures can detect ASD in infancy.

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