The Official Journal of the International Society on Infant Studies
Infancy

Infancy, ***17***(4), 416–431, 2012

ISSN: 1525-0008 print / 1532-7078 online
DOI: 10.1111/j.1532-7078.2011.00082.x

WILEY-BLACKWELL

Eye-Tracking as a Measure of Responsiveness to Joint Attention in Infants at Risk for Autism

Anahita Navab* and Kristen Gillespie-Lynch*
Department of Psychology
University of California

Scott P. Johnson
Department of Psychology
University of California
Department of Psychiatry & Biobehavioral Sciences
Semel Institute for Neuroscience & Human Behavior
University of California

Marian Sigman and Ted Hutman
Department of Psychiatry & Biobehavioral Sciences
Semel Institute for Neuroscience & Human Behavior
University of California

Reduced responsiveness to joint attention (RJA), as assessed by the Early Social Communication Scales (ESCS), is predictive of both subsequent language difficulties and autism diagnosis. Eye-tracking measurement of RJA is a promising prognostic tool because it is highly precise and standardized. However, the construct validity of eye-tracking assessments of RJA has not been established. By comparing RJA an eye-tracking paradigm to responsiveness to joint attention during the ESCS, the current study evaluated the

Correspondence should be sent to Ted Hutman, Ph.D., UCLA Semel Institute for Neuroscience & Human Behavior, 760 Westwood Plaza, Room 68-237, Los Angeles, CA 90095-1759. E-mail: thutman@mednet.ucla.edu
*These authors made equal contributions to this work.

construct validity of an eye-tracking assessment of RJA for 18-month-old infant siblings of children with autism. Relations between measures of RJA and concurrent language skills and autistic symptomatology were assessed. Correlations between measures of ESCS RJA and eye-tracking RJA were statistically significant, but few relations between either ESCS or eye-tracking assessments of RJA and language or symptoms were observed. This study establishes the construct validity of eye-tracking assessments of RJA.

Responsiveness to joint attention (RJA), defined as gaze or point following, is correlated with the linguistic and social development of both typically developing and autistic individuals (Brooks & Meltzoff, 2005; Luyster, Kadlec, Carter, & Tager-Flusberg, 2008; Mundy & Gomes, 1998; Mundy, Sigman, Ungerer, & Sherman, 1987; Sigman et al., 1999). RJA typically emerges between 2 and 18 months (Butterworth & Jarrett, 1991; Corkum & Moore, 1995; Deák, Flom, & Pick, 2000; Scaife & Bruner, 1975). Two-month-old infants often look in the same general direction as an adult (Scaife & Bruner, 1975), but infants younger than 12 months of age tend to fixate on the first object in their scan path rather than locate the exact target of the adult's gaze (Butterworth & Jarrett, 1991). By 12 months of age, infants are capable of following cues to attend to objects located behind them (Deák et al., 2000). However, they require more cues to do so than 18-month-olds do.

Given relations between RJA and social-communicative development, a large body of research has focused on the assessment of RJA in individuals with autism, a developmental disorder characterized by impairments in social-communicative skills (DSM-IV; American Psychiatric Association, 2000). Children with autism (Mundy, Sigman, Ungerer, & Sherman, 1986; Stone, 1997) and their siblings (Presmanes, Walden, Stone, & Yoder, 2007) often exhibit less RJA than typically developing children. Reduced RJA in infancy is predictive of a diagnosis of autism (Rozga et al., 2010; Yoder, Stone, Walden, & Malesa, 2009). Therefore, accurate measurement of RJA during infancy may support early detection of autism.

As eye-tracking enhances the detection of subtle shifts in visual attention (Aslin, 2007), eye-tracking assessments have recently been developed to measure RJA in typically developing infants (Gredebäck, Fikke, & Melinder, 2010; Gredebäck, Theuring, Hauf, & Kenward, 2008; von Hofsten, Dahlström, & Fredriksson, 2005; Senju & Csibra, 2008). However, previous research has not established whether eye-tracking assessments of RJA measure the same skill as interactive assessments of RJA. While face-to-face assessments of RJA often involve mutual monitoring of attention by both interactants (Tomasello, 1995), eye-tracking assessments of RJA generally preclude the possibility of shared attention by using pre-recorded stimuli

(Gredebäck et al., 2008; von Hofsten et al., 2005; Senju & Csibra, 2008). The current study examines the construct validity of an eye-tracking paradigm used to assess RJA in 18-month-old infant siblings of children with autism.

ASSESSMENTS OF RJA

Relations between RJA, language skills, and autism diagnosis have been established through naturalistic, laboratory-based, face-to-face assessments such as the Early Social Communication Scales (ESCS; Mundy et al., 2003). During the ESCS, an examiner calls the infant's name while turning his or her entire torso to visually orient and point to a poster. The targets of the examiner's gestures are positioned to the left, right, and behind the infant on the walls of the testing room. The video-recorded assessment is later coded for the percentage of trials during which the infant accurately orients in the direction of the examiner's gestures (Mundy et al., 2003). However, coding from video is not optimal for precise determination of infants' looking targets. Eye-tracking assessments of RJA may provide more precise spatial and temporal information than face-to-face assessments (von Hofsten et al., 2005). During the eye-tracking RJA assessment employed in the current study (adapted from Senju & Csibra, 2008), a model addressed the participant with eye contact but did not call his or her name. She then directed the infant's attention to one of two identical objects within his or her visual field as the infant's eye movements were recorded with an eye tracker.

The two paradigms are similar in that they both involve a person, recorded or live, addressing a child in infant-directed speech and shifting gaze to an object of interest. While the ESCS involves naturalistic face-to-face interaction, the eye-tracking assessment of RJA utilizes a pre-recorded scene presented on a video monitor. As most eye-tracking assessments of RJA are pre-recorded, they are more consistent across administrations than the ESCS and thus potentially useful as standardized prognostic instruments. However, opportunities for RJA that infants typically experience are highly interactive. Variability in ESCS presentation among participants, including the use of each child's name to capture his or her attention before the opportunity for RJA is presented, may make the ESCS more engaging than eye-tracking assessments of RJA wherein the pre-recorded greeting prior to RJA opportunities is not individualized.

Additional differences between the two measures of RJA may reflect limits in the construct validity of standardized eye-tracking assessments of RJA. Fewer cues to elicit RJA are provided during many eye-tracking assessments of RJA than are available during the ESCS. The referencing targets are further from the child's view during the ESCS than is possible in eye-tracking assessments of RJA. Unlike the ESCS, a stationary eye tracker cannot capture infants' looks away from the video monitor and therefore cannot test RJA to targets located behind the child.

Previous research employing eye-tracking to assess RJA has not addressed construct validity or sought to determine whether they are related to interactive assessments of RJA. When assessed in different populations, pre-recorded eye-tracking assessments of RJA yield lower rates of RJA than interactive eye-tracking assessments of RJA (Gredebäck et al., 2010). However, relations between pre-recorded eye-tracking assessments of RJA and interactive assessments of RJA have never been examined in the same sample.

The goal of the current study was to determine whether an eye-tracking assessment of RJA was related to RJA as measured by the ESCS within a population for whom early detection of RJA difficulties was particularly relevant: a group of infant siblings of children with autism, who are known to be at heightened risk for being diagnosed with autism (Bailey et al., 1993). We also evaluated potential relations between both RJA paradigms and concurrent language skills and autistic symptomatology. We expected that the eye-tracking and ESCS assessments of RJA would be correlated, and that both types of RJA assessment would be related to language skills and autistic symptomatology.

METHOD

Participants

Fifty-two 18-month-old infant siblings of children with autism participated in this study. Twelve infants were excluded from the study due to computer malfunction in the form of data loss ($n = 2$), imprecise calibration ($n = 4$), or excessive motion during eye-tracking ($n = 6$). Forty infants, 17 of whom were female, provided usable data. The ESCS was administered to all infants who completed the eye-tracking task. However, two children did not complete a portion of the ESCS, the proximal RJA task, due to fussiness.

Participants were recruited through the UCLA Autism Evaluation Clinic, through other studies at the UCLA Center for Autism Research and Treatment, and through organizations that provide services for children with autism and their families. Participants were included based on their siblings' diagnosis with autistic disorder, confirmed by the UCLA Autism Evaluation Clinic. The confirmation of diagnosis was based on DSM-IV criteria (American Psychiatric Association, 2000), the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), and the Autism Diagnostic Interview-Revised (Lord, Rutter, & LeCouteur, 1994). At the time of the study, the sample of infant siblings had not reached the age at which diagnoses are considered stable (Charman et al., 2005; Turner & Stone, 2007), but was considered to be at risk for autism diagnosis because all had at least one older sibling with autistic disorder (Bailey et al., 1993). Neither the proband nor the sibling had severe visual, auditory, or motor impairments. The primary language of participating families was English.

Measures

The Early Social Communications Scales (Mundy et al., 2003)

The ESCS is a structured observation of nonverbal communication skills that typically emerge in children between 8 and 30 months of age. The 25-min assessment yields frequency counts of joint attention, requesting, and social interaction behaviors. RJA is assessed with respect to distal and proximal looking targets. Distal targets were three colorful posters hung on the walls of the testing room. Two posters were on each side of the child, within the child's view at approximately 40° from the child's midline. The third poster was behind the child and to his/her right, outside his/her view at approximately 150° from the child's midline. Proximal RJA was evaluated with a colorful picture book.

The distal RJA task began with the examiner engaging the child's attention by singing a song and tickling the child. The examiner then recruited the child's eye contact by either gently touching the infant or tapping the table. Once eye contact was ensured, the examiner turned, looked, and pointed to one of the three posters on the wall. While pointing at the poster, the examiner called the child's name three times with increasing intensity. The examiner attempted to direct the child's attention to the poster on the right, then left, then rear wall of the testing room from the child's perspective. Each pointing episode was maintained for at least 6 sec. Two sets of three pointing trials were presented at different times during the ESCS, one near the midpoint and the other near the end of the assessment.

For the proximal RJA task, the examiner sat at the table and presented a picture book with distinct pictures. The examiner pointed to pictures in the book for 3 sec, positioning her finger about 2 in. from each picture. The examiner said the child's name as she pointed to a picture on the left and right side of the book. The examiner then repeated the procedure two times on different pages of the book.

Coders watched video recordings of the ESCS to determine the proportion of times the child successfully completed a head turn or gaze switch to the referenced poster or picture in the book relative to the total number of opportunities for RJA. Higher proportions indicate higher levels of RJA performance. Reliability between two independent coders was assessed for 20% of the sample. The percentage agreement was 88 for the pointing task and 96 for the book task. The Cohen's Kappa coefficients were 0.75 for the pointing task and 0.91 for the book task, indicating an acceptable level of agreement between coders.

Mullen Scales of Early Learning (MSEL; Mullen, 1995)

The MSEL is a standardized developmental assessment of cognitive and motor development. It measures verbal and nonverbal IQ for children less than 6 years of age. It provides an overall index score as well as verbal subscale scores (Receptive Language and Expressive Language) and nonverbal subscale scores (Visual Reception and Fine Motor). The Mullen provides T scores, age equivalent scores, and raw scores. The Mullen has good test-retest reliability and high internal consistency. Relations between eye-tracking and ESCS measures of RJA and both raw and standardized language scores were analyzed.

Autism Diagnostic Observation Schedule (Lord et al., 2000)

The ADOS is a semistructured, standardized observational assessment of social interaction, communication, play, and imaginative use of materials used to diagnose autism spectrum disorders. Participants were tested with module 1 of the ADOS, which is designed for children who do not consistently use phrase speech. While the ADOS does not provide a stable measure of autism diagnosis by 18 months (Ozonoff et al., 2011), it can be used to assess autistic symptomatology in infancy. Social-affective symptoms and restricted and repetitive behaviors were calculated based upon the revised ADOS algorithms for infants with and without speech (Gotham et al., 2008). Higher ADOS scores indicate greater levels of autistic symptomatology.

Eye-tracking assessment of RJA

Infant looking behaviors were recorded by a Tobii 1750 Eye Tracker (Tobii Technology AB, Danderyd, Sweden), integrated with a 17-in. monitor, while the infant was seated on a parent's lap approximately 65 cm from the monitor. Cameras beneath the monitor recorded reflections from an infrared light at a frequency of 50 Hz to assess the distance between the cornea and the pupil of both eyes. The accuracy of these recordings approximates 0.5–1° of visual angle. While the eye tracker compensates for head movements, movements faster than 10 cm/sec occasion 100-msec recovery time. Stimuli were displayed with ClearView software (Tobii Technology AB; http://www.tobii.com). Fixations were defined as gaze within a 30-pixel radius for at least 100 msec. The "normal" ClearView validity filter averaging across both eyes was used. A five-point calibration was administered prior to the assessment.

The eye-tracking RJA task was a modification of a task reported by Senju and Csibra (2008). Each of the four RJA trials was preceded by a colorful, sound-paired, animated "attention getter" that was displayed until the infant looked to the center of the screen. This phase was analogous to the distal RJA ESCS task's attention-getting song, as it required re-centering of the eyes before commencement of the trial. Once attention was secured, the pre-recorded RJA video replaced the attention getter. The video consisted of a black background and a model wearing a neutral-colored shirt and her hair tied back. Two colorful, identical Lego structures were placed in front and on either side of the model, atop a black table (see Figure 1). During the baseline period, the model's gaze remained fixed on the table in front of her (~2 sec). This phase was followed by a social greeting phase (~1.8 sec), during which the model looked into the camera, smiled, and said in infant-directed speech: "Hello there." The final stage, wherein the model turned her head toward one of the two objects and then fixated on the object, provided an opportunity for RJA (~4 sec). The model maintained a neutral facial expression and remained silent when turning her head and gazing at the object. Across the four trials presented to each child, the model attended twice to the object on her right and twice to the object on her left. The order of looks to either side was counterbalanced across participants.

The model's face measured 5.1° and 3.6° of vertical and horizontal angle. Each object measured 2.3° and 2.9° of vertical and horizontal angle. Rectangular areas of interest, defined manually using Clearview software, subtended approximately 1° from the edge of stimuli. Usable trials were defined by at least one fixation upon the attention getter prior to each trial and one fixation upon the screen during the opportunity for RJA. Only fixations

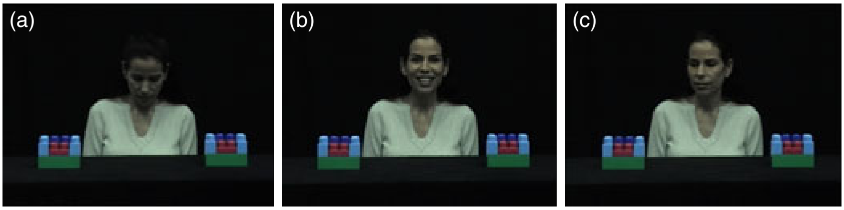

Figure 1 Still frames of eye-tracking stimuli illustrating (a) baseline phase, (b) social greeting phase, and (c) RJA opportunity.

upon an object immediately preceded by a fixation upon the model's face were considered for classification as successful or unsuccessful instances of RJA. Higher ratios indicate higher levels of RJA performance. Five eye-tracking measures of RJA were adopted from previous studies:

A *standard difference score* was calculated by subtracting the frequency with which the infant's first look from the model to an object was incongruent with the model's gaze from the frequency with which the first look was congruent (Gredebäck et al., 2010).

The *percentage of accurate gaze shifts* was calculated by dividing the number of trials with congruent first gaze shifts by the total number of usable trials (Gredebäck et al., 2010).

A *restrained standard difference score* was calculated by dividing the standard difference score by the total number of trials during which the infant looked to either object (Senju & Csibra, 2008). This calculation, and the subsequent two calculations, effectively excluded from analysis seven infants who never looked from the model to either object because the denominator was zero under such conditions.

A *restrained transitions difference score* was calculated by subtracting the total number of transitions between the model's face and the incongruent object from the total number of transitions to the congruent object. This number was then divided by the total number of transitions from the model's face to either object across trials (Senju & Csibra, 2008).

A *restrained duration difference score* was calculated by subtracting the total duration (in msec) of all fixations upon the incongruent object from the total duration of all fixations upon the congruent object. This number was then divided by the total duration of all fixations upon either object (Senju & Csibra, 2008).

RESULTS

The kurtosis and skew of all variables was assessed (Tabachnick & Fidell, 2001). All three "restrained" measures of RJA exhibited excessive negative skew. As less extreme transformations were ineffective at reducing skew, they were transformed by reflecting them and applying inverse transformations. As social-affective symptoms and restricted and repetitive behaviors were positively skewed, ADOS symptoms were transformed using logarithmic transformations.

No latency differences between congruent (M = 1,802 msec, SE = 198) and incongruent (M = 1,965 msec, SE = 224) first looks from the model to an object during eye-tracking assessments of RJA were observed (p = .60).

Relations between RJA measures

Relations between eye-tracking RJA measures and ESCS assessments of RJA are summarized in Table 1. RJA during the distal ESCS task was positively correlated with RJA during the proximal ESCS task ($p = .004$). Standard difference scores ($p = .02$) and the percentage of accurate gaze shifts ($p = .009$) were positively correlated with distal ESCS. Neither measure was correlated with RJA during the proximal ESCS task. Neither the restrained measures of RJA, nor their transformations, were related to RJA during ESCS tasks. As "restrained" eye-tracking measures excluded participants who did not attend to objects ($n = 7$), reduced power and variability may have obscured relations between these measures and ESCS assessments of RJA. However, standard difference scores and the percentage of accurate gaze shifts appear to be more useful measures of RJA when extrapolating from eye-tracking assessments to interactive abilities.

Relations with language skills

Relations between eye-tracking and ESCS measures of RJA and language scores are presented in Table 2. RJA during the proximal ESCS task was positively correlated with raw ($p < .001$) and standardized ($p = .001$) concurrent (18-month) receptive language scores and raw ($p = .002$) and standardized ($p = .002$) expressive language scores. RJA during the distal ESCS task and eye-tracking measures of RJA were unrelated to concurrent language abilities. RJA while attending to a book may be more influenced by language abilities than less literacy-related opportunities for RJA.

TABLE 1
Relationships Between ESCS and Eye-Tracking RJA Rates

	ESCS-Distal			*ESCS-Proximal*		
Measure	*n*	*r*	*p*	*n*	*r*	*p*
ESCS-Distal				37	.46	.004
ESCS-Proximal	37	.46	.004			
Standard difference score	40	.37	.02	37	.15	.39
Percentage of accurate gaze shifts	40	.41	.009	37	.13	.43
Restrained standard difference score	33	.26	.15	30	.28	.14
Restrained transitions difference score	33	.23	.20	30	.11	.58
Restrained duration difference score	33	.19	.29	30	.06	.77
Transformed restrained standard difference score	33	.22	.23	30	.23	.21
Transformed restrained transitions difference score	33	.17	.35	30	.03	.87
Transformed restrained duration difference score	33	.15	.42	30	.01	.96

Note. ESCS = Early Social Communications Scales.

TABLE 2
Pearson Correlations Between RJA Rates and Language Skills

		RLR		*ELR*		*RLT*		*ELT*	
Measure	*n*	*r*	*p*	*r*	*p*	*r*	*p*	*R*	*p*
ESCS-Distal	40	.23	.16	.08	.62	.08	.62	.07	.65
ESCS-Proximal	37	.56	.000	.50	.002	.54	.001	.49	.002
SDS	40	.00	.99	.12	.48	−.05	.75	.08	.62
PAGS	40	.05	.74	.09	.57	.002	.99	.05	.74
RSDS	33	.21	.24	.24	.19	.17	.34	.22	.23
RTDS	33	.11	.53	.09	.62	.09	.64	.08	.66
RDDS	33	.12	.49	.12	.52	.09	.62	.10	.58
TRSDS	33	.18	.33	.20	.26	.15	.41	.19	.30
TRTDS	33	.05	.77	.04	.83	.03	.85	.04	.83
TRDDS	33	.09	.64	.08	.66	.06	.72	.07	.69

Notes. ESCS = Early Social Communications Scales; SDS = standard difference score; PAGS = percentage of accurate gaze shifts; RSDS = restrained standard difference score; RTDS = restrained transitions difference score; RDDS = restrained duration difference score; TRSDS = transformed restrained standard difference score; TRTDS = transformed restrained transitions difference score; TRDDS = transformed restrained duration difference score; RLR = Receptive language raw; ELR = expressive language raw; RLT = receptive language transformed; ELT = expressive language transformed.

Alternatively, shared experiences with books may influence the development of both proximal RJA and language abilities.

Relations with autistic symptomatology

Given that all participants in the current study were at heightened risk for developing autism, we examined relations between measures of RJA and autistic symptomatology. Relations between eye-tracking and ESCS measures of RJA and symptoms of autism can be viewed in Table 3. The restrained transitions difference score and the social-affective domain of the ADOS were negatively correlated ($p = .04$). Thus, higher RJA performance as indexed by this variable co-occurred with less severe social-affective symptoms. These findings suggest that the overall frequency of correct relative to incorrect gaze shifts is more closely related to the social features of autism than first gaze shifts.

However, relations between transformed restrained RJA scores and transformed social-affective symptoms only approached significance. Thus, the correlation between the restrained transitions difference score and social-affective symptoms may have been driven by skew. In addition, seven infants never looked from the model to either object, resulting in a denominator of

TABLE 3
Pearson Correlations Between RJA Rates and Autistic Symptomatology

		SAA		*RRA*		*TSAA*		*TRRA*	
Measure	*n*	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*
ESCS-Distal	39	−.04	.82	−.03	.84	−.01	.94	−.13	.42
ESCS-Proximal	36	−.16	.37	−.12	.47	−.17	.32	−.20	.24
SDS	39	−.20	.23	.22	.18	−.17	.30	.20	.24
PAGS	39	−.12	.46	.18	.26	−.70	.67	.18	.27
RSDS	33	−.32	.07	.15	.40	−.31	.08	.09	.63
RTDS	33	−.36	.04	.13	.46	−.29	.10	.06	.73
RDDS	33	−.33	.07	.14	.44	−.28	.12	.08	.68
TRSDS	33	−.34	.05	.14	.44	−.34	.05	.06	.74
TRTDS	33	−.31	.08	.15	.42	−.25	.17	.07	.68
TRDDS	33	−.33	.06	.19	.29	−.28	.12	.12	.52

Notes. ESCS = Early Social Communications Scales; ADOS = Autism Diagnostic Observation Schedule; SDS = standard difference score; PAGS = percentage of accurate gaze shifts; RSDS = restrained standard difference score; RTDS = restrained transitions difference score; RDDS = restrained duration difference score; TRSDS = transformed restrained standard difference score; TRTDS = transformed restrained transitions difference score; TRDDS = transformed restrained duration difference score; SAA = social-affective ADOS; RRA = restricted and repetitive ADOS; TSAA = transformed social-affective ADOS; TRRA = Transformed Restricted and Repetitive ADOS.

zero in the calculation of the restrained difference score. Accordingly, infants who did not attend to objects were excluded from analyses involving restrained scores. To investigate the possibility that relations between eye-tracking variables and ESCS performance were due to exclusion of these infants, we assigned the seven infants who never looked to either object (exhibited no joint attention across trials) scores of zero on the restrained eye-tracking variables. When those infants were included in analyses, no relations between the restrained eye-tracking measures and distal ESCS performance were observed. Thus, no clear evidence for relations between eye-tracking variables and autistic symptomatology were observed in the current study.

Frequency of RJA across contexts

The percentage of accurate gaze shifts is the eye-tracking measure of RJA that is most behaviorally similar to ESCS measures of RJA. Post-hoc comparisons following a repeated-measures univariate test of behavior frequency, $F(2, 74) = 11.56$, $p < .001$, indicated that RJA as indexed by the percentage of accurate gaze shifts during eye-tracking ($M = .38$, $SE = .05$) was less frequent than both distal ($M = .57$, $SE = .05$, $p < .001$) and proximal ($M = .62$, $SE = .05$, $p < .001$) ESCS measures of RJA, which did not differ from one another ($p = .30$). Thus, infants exhibited RJA less frequently in response to pre-recorded relative to interactive stimuli.

DISCUSSION

The current study validated the use of eye-tracking to assess RJA in forty 18-month-old siblings of children with autism. Two eye-tracking measures of RJA, the standard difference score and the percentage of accurate gaze shifts, were related to RJA during the distal pointing task of the ESCS. As the eye-tracking assessment of RJA did not assess infants' ability to follow gaze behind themselves, correlations between eye-tracking measures of RJA and performance on the distal ESCS task might have been stronger had we excluded from analysis ESCS trials during which infants were prompted to follow gaze behind themselves. However, the development of RJA is characterized by increasing ability to follow gaze outside of one's own frame of reference (Butterworth & Jarrett, 1991; Deák et al., 2000). Thus, it was important to assess relations between eye-tracking measures of RJA and the complete distal ESCS task, which is a theoretically based measure of a child's current level of joint attention ability (Siebert, Hogan, & Mundy, 1982). As the ESCS distal task is widely used, comparing eye-tracking measures with the complete task also increased the generalizability of findings.

Despite strong relations between the distal ESCS task and the proximal ESCS task, eye-tracking measures of RJA were not related to RJA during the proximal ESCS task. Thus, eye-tracking measures and the proximal task may measure different aspects of RJA, each of which overlap with aspects of RJA as assessed by the distal ESCS task.

Unexpectedly, the proximal ESCS task was the only RJA measure that was associated with concurrent language abilities. The lack of relations between concurrent language ability and RJA as assessed by both eye-tracking measures and the distal ESCS RJA task was surprising given that RJA to distal targets has been related to concurrent language skills (Luyster et al., 2008; Sigman et al., 1999) and to subsequent language gains (Morales et al., 2000; Mundy & Gomes, 1998; Sigman et al., 1999) in typically developing children and in children with autism. While concurrent relations between language and RJA have been observed in children whose average age is above 18 months (Luyster et al., 2008; Sigman et al., 1999; but see Morales et al., 2000), they are often not observed at an average age equal to or below 18 months (Mundy & Gomes, 1998). Relations between joint-attention skills and language development appear to be moderated by an interplay between developmental level and autism (Mundy & Gomes, 1998;

Mundy, Sigman, & Kasari, 1990). As joint attention skills scaffold linguistic development (e.g., Carpenter, Nagell, & Tomasello, 1998), the likelihood of observing concurrent relations between joint attention and language may be increased during developmental transitions when new skills are emerging.

"Restrained" eye-tracking measures of RJA, which excluded from analysis infants who did not attend to objects, were unrelated to ESCS measures of RJA. While standard difference scores are commonly used to assess RJA (Corkum & Moore, 1995; Meltzoff & Brooks, 2008), difference scores are not typically divided by total looks to either object in face-to-face measures as they were for the restrained eye-tracking scores (Senju & Csibra, 2008). Eye-tracking scores that are calculated in a manner that most closely match established methodologies for assessing joint attention are those that were correlated with ESCS measures of RJA. The more innovative restrained scores were not related to the ESCS.

The restrained transitions difference score was related to social-affective symptoms of autism while ESCS assessments of RJA and other eye-tracking measures of RJA were not. However, relations between the restrained transitions difference score and symptoms of autism were no longer apparent when infants who did not attend to either object were included in analyses. The absence of clear relations between both eye-tracking and ESCS measures of RJA and autistic symptomatology may be due to the types of cues for eliciting RJA each method employed. Mildly redundant cues, such as verbally directing a child to "look" coupled with a head turn, may be more effective at identifying RJA difficulties in the infant siblings of children with autism than highly redundant cues, such as those used during the ESCS, or subtle cues, such as the model's head turn during the eye-tracking RJA assessment (Presmanes et al., 2007).

Extending previous research comparing RJA in response to pre-recorded and interactive stimuli across different populations (Gredebäck et al., 2010), the current study demonstrates that pre-recorded eye-tracking assessments of RJA yield lower rates of RJA than interactive eye-tracking assessments of RJA when assessed in the same population. Eye-tracking RJA rates were lower in the current study than in previous studies using both interactive (Gredebäck et al., 2010) and noninteractive cues to joint attention (Gredebäck et al., 2008). Low RJA rates may be attributable to characteristics of the participants, the stimuli, or both. The infant siblings of children with autism may (e.g. Presmanes et al., 2007) or may not (Yirmiya et al., 2006) exhibit reduced rates of RJA relative to infants who are not at risk for autism. As participants in the current study may have followed gaze less frequently than typically developing infants would, caution is advised when extending the results of the current study to predict relations between eye-tracking and interactive assessments of RJA with typically developing infants. The use of two identical objects as potential targets of RJA may also have contributed to lower rates of RJA. Nonidentical objects, such as those used in previous eye-tracking assessments of RJA (e.g. Gredebäck et al., 2008, 2010), elicit higher rates of RJA than identical objects (Deák et al., 2000).

More interactive eye-tracking assessments of RJA utilizing head mounted eye trackers and varied RJA targets may provide a better index of RJA ability than assessments involving pre-recorded stimuli. Indeed, one of the limitations of eye-tracking during the current study was the loss of data due to inattention or motion. However, pre-recorded stimuli are more consistent across administrations. Gaze-contingent eye-tracking assessments of RJA might maximize standardization of assessment while minimizing data loss due to inattention.

The current study demonstrated that both ESCS and eye-tracking assessments can be used to assess RJA in infants at risk for autism. However, neither the distal ESCS RJA task nor the eye-tracking assessments of RJA were concurrently correlated with language at 18 months. Further research is needed to clarify whether and at what ages concurrent relations between RJA and language are evident for both eye-tracking and ESCS assessments of RJA, as well as potential longitudinal relations between more proximal and distal measurements of RJA, language, and autistic symptomatology. A follow-up to the current study will determine which measure of RJA during infancy is the best predictor of subsequent autism diagnosis.

ACKNOWLEDGMENTS

This research was approved by the Office for the Protection of Research Subjects at the University of California, Los Angeles and supported by NICHD/NIH Autism Centers of Excellence (ACE) grant number P50-HD-055784 (S. Bookheimer, P.I.)

The authors extend special thanks to the families who participated in this study and the following research assistants who helped collect and code the data: Jenna M. Barnwell, Mithi del Rosario, Lovella Gomez, and Stephanie Marshall.

REFERENCES

American Psychiatric Association (2000). *Diagnostic and statistical manual on mental disorders* (4th ed., TR). Washington, DC: American Psychiatric Association.

Aslin, R. N. (2007). What's in a look? *Developmental Science*, *10*, 48–53.

Bailey, A., Bolton, P., Butler, L., Le Couteur, A., Murphy, M., Scott, S., … Rutter, M. (1993). Prevalence of the fragile × anomaly amongst autistic twins and singletons. *Journal of Child Psychology and Psychiatry*, *34*, 673–688.

Brooks, R., & Meltzoff, A. N. (2005). The development of gaze following and its relation to language. *Developmental Science*, *8*(6), 535–543.

Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology*, *9*, 55–72.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Joint attention, and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development*, *63*(4), 1–174.

Charman, T., Taylor, E., Drew, A., Cockerill, H., Brown, J. A., & Baird, G. (2005). Outcome at 7 years of children diagnosed with autism at age 2: Predictive validity of assessments conducted at 2 and 3 years of age and pattern of symptom change over time. *Journal of Child Psychology and Psychiatry*, *46*, 500–513.

Corkum, V., & Moore, C. (1995). Development of joint visual attention in infants. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 61–83). Hillsdale, NJ: Erlbaum.

Deák, G. O., Flom, R. A., & Pick, A. D. (2000). Effects of gesture and target on 12- and 18-month olds' joint visual attention to objects in front of or behind them. *Developmental Psychology*, *36*(4), 511–523.

Gotham, K., Risi, S., Dawson, G., Tager-Flusberg, H., Joseph, R., Carter, A., & Lord, C. (2008). A replication of the Autism Diagnostic Observation Schedule (ADOS) revised algorithms. *Journal of the American Academy of Child and Adolescent Psychiatry*, *47*(6), 642–651.

Gredebäck, G., Fikke, L., & Melinder, A. (2010). The development of joint visual attention: A longitudinal study of gaze following during interactions with mothers and strangers. *Developmental Science*, *13*(6), 839–848.

Gredebäck, G., Theuring, C., Hauf, P., & Kenward, B. (2008). The microstructure of infants' gaze as they view adult shifts in over attention. *Infancy*, *13*, 533–543.

von Hofsten, C., Dahlström, E., & Fredriksson, Y. (2005). 12-month-old infants' perception of attention direction in static video images. *Infancy*, *8*(3), 217–231.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., … Rutter, M. (2000). The autism diagnostic observation schedule—generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, *30*(3), 205–223.

Lord, C., Rutter., M., & LeCouteur, A. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of children with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685.

Luyster, R. J., Kadlec, M. B., Carter, A., & Tager-Flusberg, H. (2008). Language assessment and development in toddlers with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *38*, 1426–1438.

Meltzoff, A. N., & Brooks, R. (2008). Self-experience as a mechanism for learning about others: A training study in social cognition. *Developmental Psychology*, *44*(5), 1257–1265.

Morales, M., Mundy, P., Delgado, C. E. F., Yale, M., Messinger, D., Neal, R., & Schwartz, H. K. (2000). Responding to joint attention across the 6- through 24-month age period and early language acquisition. *Journal of Applied Developmental Psychology*, *21*(3), 283–298.

Mullen, E. M. (1995). *Mullen scales of early learning*. Circle Pines, MN: American Guidance Service, Inc.

Mundy, P., Delgado, C., Block, J., Venezia, M., Hogan, A., & Seibert, J. (2003). *A manual for the Abridged Early Social Communication Scales (ESCS)*. Coral Gables, FL: University of

Miami. Retrieved from http://www.ucdmc.ucdavis.edu/mindinstitute/ourteam/faculty_staff/escs.pdf

Mundy, P., & Gomes, A. (1998). Individual differences in joint attention skill development in the second year. *Infant Behavior & Development*, *21*, 469–482.

Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. *Journal of Autism & Developmental Disorders*, *20*, 115–128.

Mundy, P., Sigman, M., Ungerer, J., & Sherman, T. (1986). Defining the social deficits of autism: The contribution of non-verbal communication measures. *Journal of Child Psychology and Psychiatry*, *27*, 657–669.

Mundy, P., Sigman, M., Ungerer, J., & Sherman, T. (1987). Nonverbal communication and play correlates of language development in autistic children. *Journal of Autism and Developmental Disorders*, *17*(3), 349–364.

Ozonoff, S., Young, G., Hutman, T., Sigman, M., Rogers, S. J., Hill, M. M., … Rozga, A. (2011, April). *Stability of ASD classification from 18 to 36 months in infants at risk for ASD*. Paper presented at biennial meeting of the Society for Research in Child Development, Montreal, QC.

Presmanes, A. G., Walden, T. A., Stone, W. L., & Yoder, P. J. (2007). Effects of different attentional cues on responding to joint attention in younger siblings of children with autism spectrum disorders. *Journal of Autism & Developmental Disorders*, *37*, 133–144.

Rozga, A., Hutman, T., Young, G. S., Rogers, S. J., Ozonoff, S., Dapretto, M., & Sigman, M. (2010). Behavior profiles of affected and unaffected siblings of children with autism: Contribution of measures of mother–infant interaction and nonverbal communication. *Journal of Autism and Developmental Disorders*, *40*, 287–301.

Scaife, M., & Bruner, J. S. (1975). The capacity for joint visual attention in the infant. *Nature*, *253*, 265–266.

Senju, A., & Csibra, G. (2008). Gaze following in human infants depends on communicative signals. *Current Biology*, *18*, 668–671.

Siebert, J. M., Hogan, A. E., & Mundy, P. C. (1982). Assessing interactional competencies: The early social communication scales. *Infant Mental Health Journal*, *3*(4), 244–258.

Sigman, M., Ruskin, E., Arbeile, S., Corona, R., Dissanayake, C., Espinosa, M., … Zierhut, C. (1999). Continuity and change in the social competence of children with autism, Down syndrome, and developmental delays. *Monographs of the Society for Research in Child Development*, *64*, 1–114.

Stone, W. L. (1997) Autism in infancy and early childhood. In D. Cohen & F. R. Vokmar (Eds.), *Handbook of autism and pervasive developmental disorders* (pp. 266–282). New York, NY: Wiley & Sons.

Tabachnick, B. G., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed.). Needham Heights, MA: Allyn & Bacon.

Tomasello, M. (1995). Joint attention as social cognition. In C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 103–130). Hillsdale, NJ: Erlbaum.

Turner, L. M., & Stone, W. L. (2007). Variability in outcome for children with an ASD diagnosis at age 2. *Journal of Child Psychology and Psychiatry*, *48*, 793–802.

Yirmiya, N., Gamliel, I., Pilowsky, T., Feldman, R., Baron-Cohen, S., & Sigman, M. (2006). The development of siblings of children with autism at 4 and 14 months: Social engagement, communication, and cognition. *Journal of Child Psychology and Psychiatry*, *47*(5), 511–523.

Yoder, P., Stone, W. L., Walden, T., & Malesa, E. (2009). Predicting social impairment and ASD diagnosis in younger siblings of children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *39*(10), 1381–1391.