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

Abstract

Reduced responsiveness to joint attention (RJA), as assessed by the Early Social Communication Scales (ESCS), is predictive of both subsequent language difficulties and an 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 in response to an eye tracking paradigm to RJA during the ESCS, the current study evaluated the 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 & Ruskin, 1999). RJA typically emerges between 2 and 18 months (Butterworth & Jarrett, 1991; Corkum & Moore, 1995; Scaife & Bruner, 1975). RJA specificity increases with development from simply gazing in the same direction as another person, to fixating upon a proximal target, to physically turning to locate out-of-view targets (Butterworth & Jarrett, 1991).

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 Psychological Association [APA], 2000). Autistic children (Mundy, Sigman, Ungerer, & Sherman, 1986; Stone, 1997) and their siblings (Presmanes, Walden, Stone, & Yoder, 2007) 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 facilitate early detection of autism.

Because 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, Theuring, Hauf, & Kenward, 2008; Gredebäck, Fikke, & Melinder, 2010; Senju & Csibra, 2008; von Hofsten, Dahlström, & Fredriksson, 2005). 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 prerecorded stimuli (Gredebäck et al., 2008; Senju & Csibra, 2008; von Hofsten et al., 2005). 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 Responsiveness to Joint Attention

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, Delgado, Block, Venezia, & Seibert, 2003). During the ESCS, an examiner calls an 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. Because 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 across participants, such as 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 most 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 limit 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 they are during many 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 population.

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 were 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 (2), imprecise calibration (4), or infant inattention or excessive motion during eye tracking (7). Forty infants, seventeen of whom were female, provided usable data.

Participants were recruited through the UCLA Autism Evaluation Clinic, through other ongoing 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 (APA, 2000), the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), and the Autism Diagnostic Interview-Revised (ADI-R; 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 Scale (ESCS; 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-minute 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 degrees from the child's midline). The third poster was behind the child and to his/her right, outside his/her view (at approximately 150 degrees 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. Once the examiner recruited the child's eye contact, s/he 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 seconds. 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 seconds, positioning her/his finger about two inches from each picture. The examiner said the child's name as s/he 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. Three children did not complete this proximal RJA task.

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 Cohen's Kappa coefficients were 0.75 for the RJA pointing task and 0.91 for the RJA 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 non-verbal 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 non-verbal 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. Relationships between eye tracking and ESCS measures of RJA and both raw and standardized language scores were assessed.

Autism Diagnostic Observation Schedule (ADOS; 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, integrated with a 17-inch 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 .5-1° of visual angle. While the eye tracker compensates for head movements, movements faster than 10 cm/s occasion a 100-ms recovery time. Stimuli were displayed with ClearView software (Tobii Technology AB; www.tobii.com). Fixations were defined as gaze within a 30 pixel radius for at least 100 ms. 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 were 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 similar 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 fixated on the table in front of her (~2 seconds). This phase was followed by a social greeting phase (~1.8 seconds), 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 seconds). 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 (AOIs) 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. Infants who did not provide at least 3 usable trials out of 4 opportunities for RJA were excluded from analysis based upon inattention as indexed in the description of participants. Only fixations upon an object immediately preceded by a fixation upon the model's face were considered when calculating RJA. Higher ratios indicate higher levels of RJA performance. The following 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 effectively excluded from analysis 6 infants who never looked from the model to either object because the denominator was 0 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 ms) 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 and Fidell, 2001). All three "restrained" measures of RJA exhibited excessive negative skew. Because less extreme transformations were ineffective at reducing skew, they were transformed by reflecting them and applying inverse transformations. Because social-affective symptoms and restricted and repetitive behaviors were positively skewed, ADOS symptoms were transformed using logarithmic transformations.

No latency differences between congruent (M= 1802.848, SE= 198.310) and incongruent (M=1965.909, SE= 224.698, p= .600) first looks from the model to an object during eye tracking assessments of RJA were observed.

Relations Between RJA Measures

<Place Table 1 here>

Relationships between eye tracking RJA measures and ESCS assessments of RJA are portrayed in Table 1. RJA during the distal ESCS task was positively correlated with RJA during the proximal ESCS task (p = 0. 004). Standard difference scores (p = 0. 02) and the percentage of accurate gaze shifts (p = 0. 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. Because "restrained" eye tracking measures excluded participants who did not attend to objects, reduced power and variability may have obscured relationships between these measures and ESCS assessments of RJA. However, standard difference scores and the percentage of accurate gaze shifts may be more useful eye tracking measures of RJA if one wishes to extrapolate from eye tracking assessments to interactive abilities.

Relations with Language Skills

<Place Table 2 here>

Relationships between eye tracking and ESCS measures of RJA and language scores are portrayed in Table 2. RJA during the proximal ESCS task was positively correlated with raw (p< 0.001) and standardized (p= 0.001) concurrent (18-month) receptive language scores and raw (p= 0.002) and standardized (p= 0.002) 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.

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

Relations with Autistic Symptomatology

<Place Table 3 here>

Given that all participants in the current study were at heightened risk for developing autism, we examined relationships between measures of RJA and autistic symptomatology. Relationships between eye tracking and ESCS measures of RJA and autistic symptoms can be viewed in Table 3. Only the restrained transitions difference score and the social affective domain of the ADOS were negatively correlated (p= 0.042). Thus, higher RJA performance as indexed by this variable co-occurred with less severe social affective symptoms. Relationships between transformed restrained RJA scores and transformed social affective symptoms approached significance. Thus, the correlation between the restrained transitions difference score and social affective symptoms may have been driven by skew. Alternatively, the overall frequency of correct relative to incorrect gaze shifts may be more related to autistic symptomatology than first gaze shifts.

Frequency of RJA Across Contexts

The percentage of accurate gaze shifts is the eye-tracking measure of RJA which is most behaviorally similar to ESCS measures of RJA. Post-hoc comparisons following a repeated measures univariate test (F(2,74)=11.56, p <.001) indicated that RJA as indexed by the percentage of accurate gaze shifts during eye tracking (M=.375, SE= .045) was less frequent than both distal (M=.57, SE= .045, p<.001) and proximal (M=.62, SE= .045, p<.001) ESCS measures of RJA, which did not differ from one another

(p= .312). Thus, infants exhibited lower levels of RJA in response to pre-recorded relative to interactive stimuli.

Discussion

The current study validated the use of eye tracking to assess RJA in forty eighteen-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. Despite strong relationships between the distal ESCS task and the proximal ESCS task, eye-tracking measures of RJA were unrelated 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 & Ruskin, 1999) and to subsequent language gains (Morales et al., 2000; Mundy & Gomes, 1998; Sigman & Ruskin, 1999) in both typical and autistic populations. While concurrent relations between language and RJA have been observed in children whose average age is above 18 months (Luyster et al., 2008; Sigman & Ruskin, 1999), they are often not observed at an average age equal to or below 18 months (Morales et al., 2000; Mundy & Gomes, 1998). Relations between joint attention skills and language development appear to be moderated by an interplay between developmental level and autism (Morales et al., 2000; Mundy & Gomes, 1998; Mundy, Sigman & Kasari, 1990).

"Restrained" eye-tracking measures of RJA, which excluded from analysis infants who did not attend to objects, were unrelated to ESCS measures of RJA. However, 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. Thus, different eye-tracking measures of RJA may be related to interactive measures of RJA than are related to autistic symptomatology.

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 eye-tracking assessments of RJA yield lower rates of RJA than interactive eye-tracking assessments of RJA when assessed in the same population. More interactive eye-tracking assessments of RJA utilizing head mounted eye trackers 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. Future research should focus on delineating when concurrent relations between RJA and language become apparent for both eye-tracking and ESCS assessments of RJA, as well as potential longitudinal relationships 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 autism diagnosis.

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