DISTRIBUTION OF VISUAL ATTENTION WHEN COMPARING PAIRED FACES IN TYPICALLY DEVELOPING INFANTS AND INFANTS AT RISK FOR DEVELOPING AUTISM

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Infant eye tracking research has assessed the visual scanning of static and dynamic singularly presented faces. Yet, little is know about how infants visually compare paired faces. The current study characterizes the distribution of visual attention to paired faces for infants who where later diagnosed as being typically developing (TD), non-typically developing (NT), or having an autism spectrum disorder (ASD). The study sample was comprised of infant siblings of children with ASD (high-risk infants; HR) and infant siblings of typically developing children (low-risk infants; LR). Eye tracking data were collected at 11 months of age while all infants completed a visual paired comparison task. Stimuli were six face pairs, displayed for eight seconds each, created from twelve colored photographs of naturalistic female faces equivalent in facial expression. Participants were then asked to return at 24, 36, and/or 48 months of age for follow-up diagnostic assessment at which point they were categorized into the TD, NT, or ASD groups. When viewing paired faces, all three groups demonstrated a greater proportion of time looking to the bottom than the top half of the faces. Only the typically developing group looked longer to the right side of the face than the left; that is, demonstrated a left visual field (LVF) bias. The NT group spent significantly less time looking to the mouth regions than did the TD and ASD groups. With respect to paired face comparisons, there were no significant group differences in

the overall number of congruent saccades. However, there were group differences in the proportion of congruent mouth-to-mouth saccades. Infants with ASD made the largest number of mouth-to-mouth comparisons, followed by the TD group, and the NT group. Group differences were also found in the proportion of scans that went from a non-internal facial feature of one pair member to a non-internal feature of the other pair member. Essentially, NT developing infants made more extraneous comparisons than did TD infants.

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1.0 INTRODUCTION

Face perception, defined as the processes by which we extract and represent information from faces, is a crucial ability to master. Human faces are one of the most plentiful and salient features in our everyday environment. The ability to quickly and efficiently determine an individual's identity, age, and emotion is central to successful social interaction and social development. While it is certainly important to be able to perceive and remember information about a single face, rarely do we encounter faces in isolation. Indeed, this is reflected in many of the infant paradigms of face perception that require the infant to compare faces that vary on either novelty, or perceptual aspects such as emotion, gender, and attractiveness. Nevertheless, there is little understanding of the role played by visual attention distribution in the development of these competences.

Gains in the ability to processes faces throughout infancy and beyond may reflect a number of underlying processes. First, increases in face perception capabilities may reflect a maturational process that allows for the creation and maintenance of increasingly detailed mental representations of face characteristics and configuration. Second, as infants gain more experiences with faces they may develop more efficient and effective methods of distributing visual attention; thereby, attending to the areas or features of the face that provide the most valuable information depending on the task at hand. While the two are not mutually exclusive, the following study aims to explore the latter.

In the current study we aim to quantify the distribution of visual attention during face comparison tasks in the first year of life using eye-tracking technologies. Despite a large literature based in infant looking preference, little is known about how infants visually compare and discriminate faces. The few studies (Dundas et al., 2012; Guo et al., 2009) that do include more sophisticated eye tracking measures describe the scanning of single faces exclusively. In addition to exploring the distribution of attention of typically developing infants, we also purpose to examine these patterns in infants at high genetic risk of developing an autism spectrum disorder (as defined by having an older sibling with a confirmed autism diagnosis).

Autism spectrum disorders (ASDs) are a group of neurodevelopmental disorders characterized by deficits in social cognition and communication accompanied by repetitive, stereotyped behaviors. While individuals on the autism spectrum share a number of core symptoms, there is pronounced heterogeneity in symptom onset, severity, and presentation. The CDC estimates that ASD currently affects approximately 1 in 88 children and 1 in 54 boys aged 8 years (Baio, 2012). Individuals with an ASD show marked deficits in face processing capabilities (for review, see Sasson, 2006; Weigelt, Koldewyn, & Kanwisher, 2012). Recent research on the infant siblings of children diagnosed with an ASD supports the claim that these observed and reported deficits in face processing begin early in development and persist throughout the life course (McCleery, Akshoomoff, Dobkins, & Carver, 2009). In particular, inefficient attention distribution has been frequently implicated as an underlying mechanism resulting in poorer behavioral performance during face processing (Klin et al. 2002; Pelphrey et al. 2002, Trepagnier, Sebrechts, & Peterson, 2002) although this remains controversial (Dundas, Gastgeb, & Strauss, 2012; Fletcher-Watson et al. 2009; Bar-Haim, Shulman, Lamy, & Reuveni, 2006). By studying the visual scan patterns of infants at a higher genetic risk of developing ASD we may gain greater insight into the observed deficits in both attention and perception associated with autism.

1.1 DEVELOPMENTAL THEORY OF FACE PERCEPTION

By the time we reach adulthood, the majority of us have become human face processing experts (Carey, 1992). This is evident in our ability to more quickly and accurately recognize faces of our own species (Pascalis & Bachevalier, 1998) and race (Malpass & Kravitz, 1969), upright as opposed to inverted faces (Yin, 1969), and whole faces as compared their isolated parts (Tanaka & Farah, 1993). As adults, we complete these tasks automatically and effortlessly. But how does such an expertise develop?

A prominent theory claiming experience influences the development of expertise in face perception is that of perceptual narrowing (Nelson, 1993). Originating in the field of speech perception, perceptual narrowing posits that as individuals gain experience within a category their ability to perceive familiar forms of stimuli improves while their ability to perceive inexperienced stimuli declines. In addition to its observation behaviorally, this phenomena is believed to reflect a process of cortical specialization. In a study by Werker and Tees' (1984) English infants were tested with two non-English phonemic distinctions, the Thompson /k^i/-/q'i/ contrast and the Hindi /ṭa/-/ta/ contrast. Results suggest that while infants 6-8 months of age maintain the ability to distinguish between the non-English phonemes infants 10-12 months of age do not. While this seems to reflect a loss of ability, in actuality, it is indicative of a growing expertise in the native language.

Two effects observed in face perception that highlight the role of perceptual narrowing are the other-species effect (OSE) and the other-race effect (ORE). The OSE describes the phenomena in which individuals are more accurate in differentiating and recognizing members of their own species (Pascalis & Bachevalier, 1998; Scott & Monesson, 2009). As predicted by evidence of perceptual narrowing in speech perception, there is a distinct developmental trend associated with the OSE. Scott and Monesson (2009) using a visual paired-comparison task found that while at 6 months of age infants could discriminate between both human pairs and macaque pairs of faces; when the same infants were tested at 9 months of age they could not. Importantly, this effect could be negated through the use of a training procedure. When children at 6 months of age were sent home with a book of macaque faces and name labels to read over the three-month period with their parents, they maintained their ability to discriminate both own species faces and macaque faces at 9 months of age. Analogously, the ORE describes the phenomena in which individuals can more accurately discriminate between and recognize members of their own ethnicity (Kelly et al., 2007; Malpass & Kravitz, 1969). The ORE follows the same developmental trajectory as the OSE. When testing infants of Caucasian decent with a visual paired-comparison task, 3-month-olds are able to discriminate between all ethnicities (African, Asian, Middle Eastern, and Caucasian were tested), while 6-month-olds are only able to discriminate between two (Asian & Caucasian) and 9-month-olds are only able to discriminate between faces of their own race (Kelly et al., 2007).

These changes brought on by the process of perceptual narrowing accompany a greater shift from feature based to global strategies of face processing. As opposed to many types of object recognition, face recognition relies on the ability to perceive a whole from the integration of its individual features. Furthermore, the integrated whole is more than that of its combined parts. This is known as holistic processing and is achieved through a distinctive developmental trajectory in which infants first rely on the outer contours and features of the face, then the internal features, and finally the spatial configuration of features for identification (Mauer & Salapatek, 1976). The ability to detect changes in internal features of the face (such as the eyes) is evident shortly after birth (Simon et al., 2002). In comparison, the ability to integrate features into a gestalt is not evident until approximately 7 months of age (Cohen & Cashon, 2001) and even then, it is unstable (Cashon & Cohen, 2004). By 10 years of age children continue to make more errors than adults in conditions where stimuli only vary by spacing of the eyes and mouth (Mondloch, Grand, & Maurer, 2002). The development of holistic face processing is also evidenced in studies demonstrating that, in contrast to non-face objects, upright faces are perceived significantly better than upside down faces. Fittingly, this has been deemed the inversion effect (Yin, 1969). Presumably, this effect is due to a disruption of configural processing by the inversion of the face. Research with infants shows that this advantage for upright faces emerges by the end of the first year of life (Halit, de Haan, & Johnson 2003; Valentine, 1988).

1.2 FACE PERCEPTION AND ATTENTION DISTRIBUTION: TYPICALLY DEVELOPING INFANTS

At birth, infants show a clear attentional preference for faces and face like-stimuli (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991). Early on, infant visual attention is focused on areas of high contrast within the face such as the hairline and outer contours of the jaw. As visual acuity and contrast sensitivity improves, around two-months of age infants shift this attentional focus to the inner features of the face such as the eyes, nose, and mouth (Haith, Bergman, & Moore, 1977; Mauer & Salapatek, 1976). Typically developing infants also show increased looking to the eye as compared to mouth regions (Batki et al. 2000; Cassia, Turati & Simion, 2004). Presumably, this is due to the increased importance of the eyes in determining socially relevant cues, such as bids for joint attention (Langton, Watt & Bruce, 2000), emotion identification (Ekman, & Friesen, 2003), and gender categorization (Best, Minshew & Strauss, 2010). However, during periods of language learning this preference may shift with infants allocating increased attention to the mouth (Lewkowicz & Hansen-Tift, 2012).

Infants also show a differential distribution of visual attention for own-race and other-race faces following the typical period of perceptual narrowing (Liu et al. 2011; Wheeler et al. 2011). In a study by Liu and colleagues, it was found that while at 4 months of age infants fixated for equal duration on the internal features of both own- and other-race face stimuli, by 9 months of age this duration decreased for other-race faces but not own-race faces. Additionally, the decrease in fixation time on the internal features of the other race stimuli was most prominent for the nose. In a similar study conducted by Wheeler and colleagues (2011), it was found that, with increased aged, infants showed an increase in looking to the eyes and a decrease in looking to the mouth of own-race faces. These changes in attention distribution coincide with behavioral observations of reduced recognition memory and online differentiation between other-race faces by 9 months of age.

Finally, between the ages of 6 and 11 months of age, infants preferentially attend to the left side of the face, known as the left visual field bias (Dundas, Gastgeb, & Strauss, 2012; Wheeler, 2010). This phenomenon is fairly robust and does not appear to be disrupted during the viewing of other-race faces (Liu et al. 2011). Moreover, the left visual field bias extends into adulthood (Guo et al. 2009). While the exact implications of this finding are unknown, this is likely another indicator of emergent configural processing in infancy and the further attunement of the face perception system. These findings from the viewing of single faces can inform predictions of how infants visually compare pairs of faces.

1.3 FACE PERCEPTION AND ATTENTION DISTRIBUTION: INFANTS AT RISK FOR AUTISM

Although ASDs are neurodevelopmental disorders present from birth, symptom profiles cannot be identified until around 18 months of age at the earliest (Zwaigenbaum et al. 2005). This relatively late point of identification and diagnosis has led to the study of infants at a higher biological risk of developing an ASD relative to the general population. Infants who have an older sibling diagnosed with an ASD (high-risk; HR) are over 18% more likely to develop an ASD themselves as compared to infants without a relative diagnosed with an ASD (low-risk; LR) (Ozonoff et al., 2011). The study of HR infants allows for the examination of early developmental trajectories of infants that later go on to receive an ASD diagnosis. The hope is that this will provide insight into the etiology and early behavioral manifestations of the disorder and ultimately lead to early identification and intervention.

While there are few studies of high-risk infant siblings, there is a slightly broader literature of face processing in children diagnosed with autism. Overall, the literature suggests that both children diagnosed with autism and HR infants demonstrate less orientation and overall attention to faces (Merin, Young, Ozonoff & Rogers, 2007; Klin, 2002). However, it is unclear as to whether this is stimulus dependent or a broader characteristic of the visual attention system

(Ibanez et al. 2008; van der Geest, Kemner, Verbaten & Engeland, 2002; Zwaigenbaum et al. 2005). The lack of a finding of a left visual field bias in HR infants (Dundas, Gastgeb, & Strauss, 2012) suggests that the differences in face processing found in this population are not strictly limited to a divergence in the broader attention system. But rather, there may be deficits in the ability to utilize or fully develop configural processing. This is further supported by findings that, at 9 and 11 years of age, children diagnosed with high functioning autism showed impairments in holistic face processing and the greatest disadvantage when task performance relied on the eyes only (Joseph & Tanaka, 2003).

Some preliminary evidence suggests that at 6 months of age HR infants show decreased looking toward the eyes as compared to their LR counterparts (Merin, Young, Ozonoff & Rogers, 2007). However, upon follow up at 2 years of age, reduced gaze to the eyes was not predictive of diagnostic outcome (Young, Merin, Rogers, & Ozonoff, 2009). Interestingly, increased gaze to their mother's mouth during interactive periods did predict higher levels of expressive language at 2 years of age. The mixed finding in the face scanning literature for children diagnosed with autism and HR infants necessitate further investigation in the processes underlying the development of face perception in this population. Apparent deficits at an early stage in development that are later corrected may indicate the utilization of alternative face processing strategies.

1.4 EYE TRACKING IN INFANCY

Although the majority of research in the field of infant face perception has relied on traditional methods of experimenter recorded visual preference, there is a growing literature of infant eye tracking. As opposed to basic familiarization and habituation paradigms, eye tracking allows for the analysis of the “microstructure” of looking time and preference (Aslin, 2007). Previously, experimenters were limited to describing findings in terms of global looking time. Eye tracking provides additional measures such as number and duration of fixations or saccadic movements. While direction of gaze is not perfectly correlated with the absorption of visual information (Aslin & McMurray, 2004), attentional shifts are reflected in saccades (Gottleib, Kusunoki & Goldberg, 1998) and fixations (Corbetta, 1998). This allows researchers to ask questions of attentional processes as opposed to only visual preference (Oakes, 2012). It is important to note, however, that the design and implementation of the visual task plays an inextricable role in the interpretation of eye movements (Hayhoe, 2004). As are all measures of looking preference, eye tracking is well suited to the constraints and demands on infancy research. It requires no overt response on behalf of the participants, only natural looking.

1.5 THE CURRENT STUDY

Previous infant eye tracking research has assessed the visual scanning of static (Guo et al. 2009; Dundas et al. 2012) and dynamic (Liu et al. 2011; Xiao et al. 2014) singularly presented faces. While it is certainly important to perceive and remember information about a single face, infants are often exposed to more than one individual face at a time. In fact, many infant paradigms of face perception and memory require the infant to compare faces that vary on either novelty, or perceptual aspects such as emotion, gender, and attractiveness. This occurrence both necessitates and highlights the development of efficient face comparison strategies. Yet, little is known about how infants visually compare paired faces. Using eye tracking technologies, the current study hopes to add to the literature on the development of face expertise by first characterizing how typically developing infants distribute visual attention during a paired face comparison task. This will provide us with a baseline for future group comparisons.

Second, we aim to compare the face scanning patterns in HR and LR infants. This will provide a valuable first step towards identifying an early developmental trajectory of face comparison strategies for typically developing infants and high-risk infants that later do or do not go on to receive an ASD diagnosis. Any discrepancies observed between the two groups may predict later diagnostic outcome as well as later face perception abilities or social functioning. Overall, we predict that the HR group will show less organized patterns of attention distribution. This may either be reflected in an inability to develop a predictable and efficient strategy of face scanning or by a general tendency to fixate on task irrelevant features.

Finally, we aim to identify any early disparities in the distribution of visual attention between infants that go on to receive an ASD diagnosis, developmental delays, and those that are typically developing in early childhood. By further categorizing the infant eye tracking data based on early childhood outcome, we aim to eliminate, to an extent, the heterogeneity typically found in infant sibling research. We predict that the patterns of attention distribution for the ASD group will mirror those of the previous defined HR group but to a more pronounced degree.

2.0 METHOD

2.1 PARTICIPANTS

The study sample was comprised of infant siblings of children with ASD (high-risk infants; HR) and infant siblings of typically developing children (low-risk infants; LR). HR participants had at least one older sibling with a confirmed ASD diagnosis and LR participants had an older sibling or siblings who had not been diagnosed with ASD as well as no first or second degree relatives diagnosed with ASD. For the HR group, ASD diagnosis of the older sibling was confirmed using the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord et al., 2000) and the Autism Diagnostic Interview-Revised (ADI-R; Lord et al., 1994). Additional exclusion criteria for all participants were a birth weight less than 2500 grams, problems with pregnancy, labor or delivery, traumatic brain injury, prenatal illicit drug or alcohol use, and/or birth defects. All participants were drawn from a larger study conducted by the Center for Infant and Toddler Development and recruited by the Autism Center for Excellence (ACE) at the University of Pittsburgh.

Infants were recruited at 6 months of age and followed longitudinally up to 48 months of age. Participants were seen at the Infant and Toddler Development Center at 6, 11, and 16 months of age to partake in a number of eye-tracking tasks and a developmental assessment, the Mullen Scales of Early Learning (MSEL; Mullen, 1995), at every time point. The MSEL is a standardized measure of language and cognitive functioning that is divided into four subscales: visual reception, fine motor, receptive language, and expressive language (Mullen, 1995). Participants were then asked to return at 24, 36, and 48 months of age for follow-up developmental evaluations using the MSEL (Mullen, 1995) and ASD evaluations using the Autism Diagnostic Outcome Schedule-Generic (ADOS-G; Lord et al., 2000)

Based on the above assessments and clinical judgment, participants were categorized into one of three possible outcome groups: ASD, non-typically developing (NT), or typically developing (TD). To receive a diagnosis of ASD, children had to meet spectrum cut-offs on all three ADOS-G total scores, which were then reviewed and approved by a clinical psychologist. The NT group of children showed developmental delays in at least one of the following categories: global developmental delay, language delay, and/or social concerns. Global developmental delay was identified as having Visual Reception and Receptive Language MSEL (1995) scores greater than 1.5 standard deviations below the normative mean and a clinical opinion confirming the status by a licensed psychologist. Language delay was identified as a Receptive Language and/or Expressive Language MSEL (1995) score greater than 1.5 standard deviations below the mean and again a clinical confirmation. Children could also be included in the language delay group if they had a Words Produced score below the 10^{th} percentile on the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al., 2007). Social concerns were identified by clinical opinion or if children met at least spectrum cutoffs on only the ADOS-G Social Interaction total or scored within 2 points of spectrum cutoffs on the combined Communication and Social Interaction Total. Children included in the TD group did not meet any of the above criteria.

The following study limits its analyses to the data from the eye-tracking visit at 11 months of age and subsequent follow-up evaluative time points. Fifty HR infants and 34 LR infants participated at 11 months of age. Of the total 84 infants included in the initial sample, 63 participants returned and completed follow-up assessments for at least one of the 24, 36, and 48 months of age time points. Seven of these children received a diagnosis of ASD, another seven were categorized as non-typically developing, and the remaining 49 were categorized as typically developing (see Table 1 for a summary of participant demographics).

Table 1: Participants' demographic characteristics

	HR (N = 50)		LR (N = 34)	
	M	*SD*	*M*	*SD*
Age (in days)	353.36	19.13	354.15	14.17
Gender (M/F)	(30/20)		(19/15)	
Ethnicity	43 Caucasian, 1 Black, 5 Hispanic White, 1 More than one race		33 Caucasian, 1 Black	

2.2 STIMULI

During the 11-month visit, infants participated in a visual paired comparison (VPC) task, the Identity Comparison Task (ICT). Stimuli were six face pairs created from twelve colored photographs of naturalistic female faces equivalent in emotional expression (see Figure 1). The entire screen spanned approximately 33 x 26 degrees of visual angle while each face was approximately 10 x 13 degrees of visual angle.

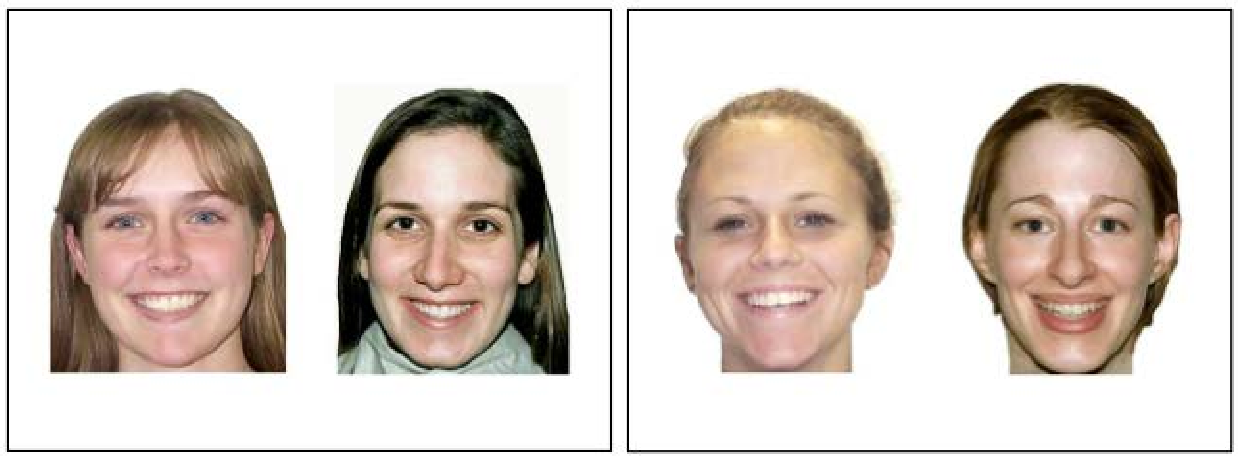

Figure 1: Example face pairs from the Identity Comparison Task

2.3 APPARATUS

Testing was conducted in a dark, quiet room that resembles a small movie theater. Each infant was seated in a highchair approximately 162cm in front of a large (69 x 91cm) projection screen with their guardian seated directly behind them. Guardians were directed not to talk about or point toward the images on the screen but encouraged to comfort the infant if necessary. A stand-alone eye-tracker that does not require attachment to the participant in any way was positioned on a table in between the infant and the projection screen. Using Tobii Studio software (Version 2.0.6.), the stimuli was rear-projected onto the screen and the infant's eye movements were recorded at a sampling rate of 60 Hz, accuracy of 0.5 degrees of visual angle, special resolution of 0.2 degrees, and drift of 0.3 degrees.

2.4 PROCEDURE

Once the infant and guardian were seated comfortably, a cartoon was played to orient the child toward the screen and maintain his or her attention. When the infant was quiet and attending to the screen, the cartoon was turned off and the eye-tracking calibration period began. During calibration, infants were visually prompted by a moving target to orient their gaze to a total of five predetermined locations on the screen. These targets were small, brightly colored objects that simultaneously produced a slight motion (jitter or oscillation) and corresponding sound. Once the experimenter determined that the infant was attending to the current location, they manually advanced the target to the next location. The experimenter had a number of calibration stimuli to choose from in order to optimize infant interest and gaze compliance. Calibration stimuli were adjusted as deemed necessary.

After the calibration period was complete, the participants engaged in the Individual Comparison Task. Infants were shown six different face pairs each for eight seconds. The left versus right positioning of each face as well as the presentation order of the face pairs was counterbalanced across participants. Between each stimulus presentation, a small cartoon appeared to either maintain the infant's direction of gaze or to reorient the infant's gaze to the center of the screen.

2.5 DATA REDUCTION

Trials in which the infants failed to fixate on each face in the pairing a minimum of once (non-comparison trials) were eliminated from analyses (approximately 19%).

2.5.1 Visual Attention Distribution

The amount of time infants spent looking to specific regions within the faces was determined by computing the total fixation duration for each of 20 areas of interest (AOIs). Eight spatial AOIs split each face into four equal quadrants (see Figure 2). These quadrants were then used to determine proportion of time infants looked to the left half of the face from vertical midline (left visual field or right side of the face) as well as lower half from vertical midline for each face. The proportion of time looking to the left visual field was calculated by taking the amount of time that the infant looked to the left quadrants of each face divided by the total amount of time the infants looked to both the left and the right quadrants, averaged across all twelve face stimuli. The proportion of time looking to the lower half of the faces was calculated by taking the amount of time that the infant looked to the lower quadrants of each face divided by the total amount of time the infants looked to both the lower and upper quadrants, averaged across all twelve face stimuli. Twelve featural AOIs were identified as right face oval (the right face of the trials pair), left face oval (the left face of the trial pair), and an eye, nose, mouth, and hair region of each face and the entire screen that included both faces. The eye AOIs included the area ranging from the top of the eyebrows to the top of the orbital bone. The mouth AOIs included the area extending from halfway between the bottom of the nose and the mouth to an equal distance below the mouth. The nose AOIs included the area extending from the outer edge of each nostril from halfway between the bottom of the nose and the mouth to the top of the orbital bone. Hair AOIs closely followed the outline of the face oval to the interior and the hairline to the exterior (see Figure 3). These featural AOIs were then used to determine proportion of time looking to the face region (defined as the addition of the face oval and hair AOIs), to individual features (eyes, nose and mouth) and to the internal features as a whole (as defined as the addition of the eye, nose, and mouth AOIs). The proportion of time looking to the face region was calculated by taking the amount of time that the infant looked to the face region of each face divided by the total amount of time the infants looked to the whole screen, averaged across all six trials. The proportion of time looking to an individual feature was calculated by taking the amount of time that the infant looked to the feature (i.e. eyes) divided by the total amount of time the infants looked to the face oval, averaged across all twelve face stimuli. The proportion of time looking to the internal features was calculated by taking the amount of time that the infant looked to the internal features (eye AOI, nose AOI, mouth AOI) of each face divided by the amount of time the infants looked to the face oval, averaged across all twelve face stimuli.

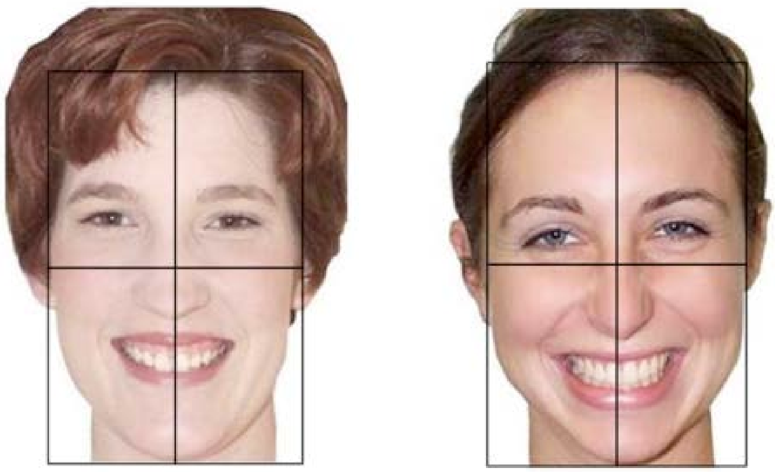

Figure 2: Example spatial areas of interest (AOIs) depicting the upper left, upper right, lower left, and lower right quadrants designated for each face

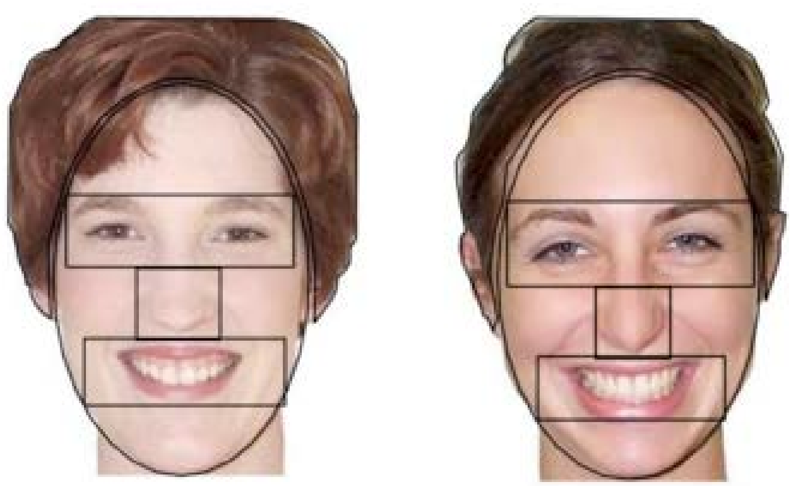

Figure 3: Example featural areas of interest (AOIs) depicting the right face oval (the right face of the trial pair), left face oval (the left face of the trial pair), eye, nose, mouth, and hair regions

2.5.2 Face Comparison Congruency

The sequence of fixations between and within the paired faces was determined using the aforementioned AOIs for eyes, nose, mouth, and hairline as well as an AOI that collapsed across the remaining within-face regions of non-interest such as the chin, cheek, and forehead (extraneous features). The extraneous features AOI was calculated by taking the amount of time that the infant looked to the face oval and subtracting the internal features (eye, nose, and mouth). Once the AOIs were identified, a team of trained coders manually scored each between-face saccade as either congruent or incongruent. Congruent between-face saccades were defined as those that involve fixations between corresponding AOIs in each face pair (i.e. mouth AOI of the left face to the mouth AOI of the right face). These coding measures were then used to calculate the proportion of congruent saccades, the proportion of congruent internal feature saccades, and the proportion of congruent saccades for each feature individually (eyes, nose, mouth, hair, and extraneous features). The proportion of congruent saccades was calculated per participant as the number of congruent between-face saccades divided by the total number of between face saccades, averaged across all comparison trials. The proportion of congruent internal saccades was calculated per participant as the number of congruent between-face saccades in the eye, nose, and mouth areas divided by the total number of between-face saccades, averaged across all comparison trials. Finally, the proportion of congruent saccades for each internal feature area was calculated per participant as the total number of congruent between-face saccades to that region divided by the total number of between face saccades, averaged across all comparison trials.

3.0 RESULTS

3.1 VISUAL ATTENTION DISTRIBUTION

All one-way ANOVAs and independent samples t-tests report comparisons of proportions that have undergone arcsine square root transformation. All means reported and one-sample t-tests reflect the non-transformed proportion values. Two participants (one LR, one HR) were excluded for failing to look to both faces during at least one paired comparison trial.

3.1.1 Typically Developing Infants

The first aim of the study was to characterize how typically developing infants distribute visual attention during a paired face comparison task. In order to achieve this, the first set of analyses examined only those participants in the TD group. An analysis was conducted to determine whether the infants spent a greater proportion of time attending to the lower as opposed to the upper half of the face. To test this a one-sample t-test of the total looking duration to the lower half of the face was conducted. This revealed a greater proportion of looking to the lower half of the faces (t (46) = 6.57, p <. 00) compared to 50%. Another analysis was conducted to determine whether infants looked longer to the right side of the face than the left; that is, whether or not they demonstrated a visual field (LVF) bias. Again, a one-sample t-test of the total looking duration to the right side of the face was conducted. This reveled a greater proportion of looking to the left LVF (t (46) = 1.98, p = .05) compared to 50% (see Table 2). Descriptive statistics also revealed that 79% of typically developing infants' total looking time was spend looking at the face (*M* = .79, *SD* = .15) during the paired face comparison task. Of this proportion of time looking to the face, 57% was directed toward the internal features (*M* = .57, *SD* = .16). This percentage can be further divided among the facial features with the greatest amount of attention being directed toward the mouth (*M* = .22, *SD* = .19). See Table 2 for a complete summary of the descriptive statistics results.

Table 2: Summary of visual attention distribution for typically developing infants

	Mean Proportion of Fixation Duration	
	N = 47	
	M	*SD*
Bottom Half of Face	.75***	.26
Right Side of Face	.55*	.18
Face Oval	.79	.15
Eyes	.17	.19
Nose	.18	.14
Mouth	.22	.19

* p < .05; *** p < .001

3.1.2 Risk Status Analyses

The second aim of the study was to identify any early disparities in the distribution of visual attention during a paired face comparison task between HR and LR infants. A one-way ANOVA of total fixation duration revealed that, overall, the HR group showed a significantly greater amount of looking (*M* = 24.47 seconds, *SD* = 10.10), as indexed by looking to the whole screen, compared to the LR group (*M* = 19.87, *SD* = 11.36) (F (1,82) = 3.80, p = .06). This finding necessitated that all following comparisons between the groups use proportions as a means of controlling for overall differences in gaze duration. One-way ANOVAs were conducted to compare whether the LR and HR infants differed in the proportion of time they spent looking at each of the AOIs (e.g. spatial and featural). None of these ANOVAs indicated any significant differences in looking between the HR and LR infants (see Table 3). However, one-sample t-tests revealed that both the HR (t (48) = 8.08, $p < .00$) and the LR (t (32) = 3.93, $p < .00$) groups spent a significantly greater proportion of time looking to the lower half of the faces compared to 50%. There was not a significant LVF finding for analyses by risk status.

Table 3: Summary of visual attention distribution by risk status

	F	*p*
Whole Screen	3.80	.06
Bottom Half of Face	.62	.43
Right Side of Face	.16	.70
Face Oval	1.75	.19
Eyes	.80	.37
Nose	.041	.84
Mouth	.402	.53

3.1.3 Outcome Group Analyses

The third aim of the study was to identify any disparities in the distribution of visual attention during a paired face comparison task between infants that go on to receive an ASD diagnosis, a NT diagnosis, and TD infants. The following analyses were conducted with an awareness of the large discrepancy in group sizes, and therefore, should be considered preliminary at best. A one-way ANOVA revealed significant group differences in the proportion of time spent looking to the mouth (F (2, 58) = 3.63, p = .03) (see Figure 4). Follow-up independent samples t-tests indicated there was a significant difference between the NT group (M = .09, SD = .14) and the TD group (M = .22, SD = .19) (t (52) = 1.99, p = .05) as well as between the NT group and the ASD group (M = .34, SD = .21) (t (12) = 2.86, p = .01). Both the ASD (M = .90, SD = .14) (t (6) = 7.47, p <. 00) and NT (M = .76, SD = .16) (t (6) = 4.37, p = .005) groups spent a significantly greater proportion of time looking to the lower half of the faces compared to 50% as revealed by one-sample t-tests. While the TD group demonstrated a significant LVF bias, as reported above, this was not observed in the ASD and NT groups. See Table 4 for a complete summary of the descriptive statistics results by outcome.

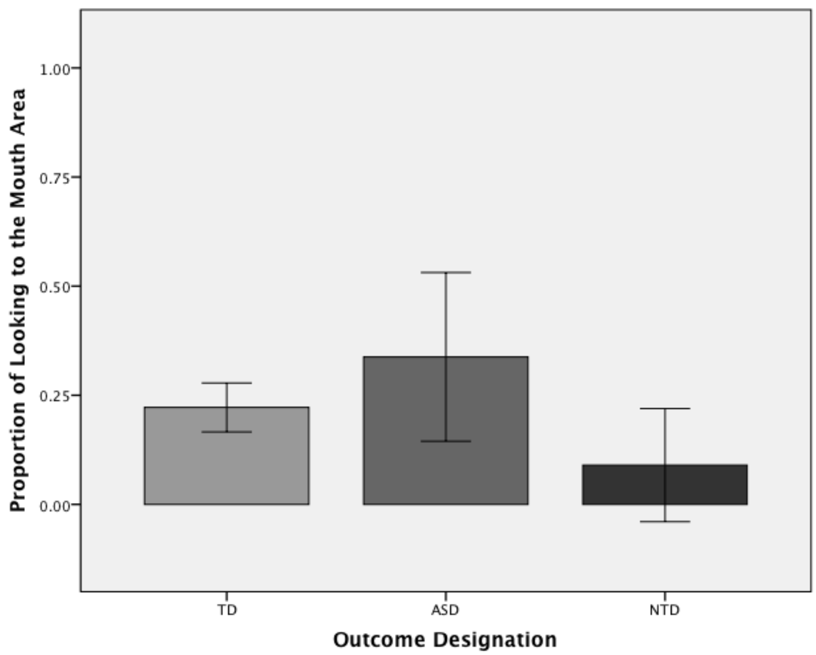

Figure 4: Mean proportion of looking to the mouth by outcome designation

Table 4: Summary of visual attention distribution by outcome designation

	Mean Proportion of Fixation Duration					
	TD (N = 49)		ASD (N = 7)		NT (N = 7)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Bottom Half of Face	.75	.26	.90	.14	.76	.16
Right Side of Face	.55	.18	.47	.06	.53	.34
Face Oval	.79	.15	.79	.12	.80	.14
Eyes	.17	.19	.05	.09	.14	.13
Nose	.18	.14	.18	.10	.15	.12
Mouth*	.22	.19	.34	.21	.09	.14

* $p < .05$

3.2 FACE COMPARISON CONGRUENCY MEASURES

All one-way ANOVAs and independent samples t-tests report comparisons of proportions that have undergone arcsine square root transformation. All means reported and one-sample t-tests reflect the non-transformed proportion values. Two participants (one LR, one HR) were excluded for failing to look to both faces during at least one paired comparison trial.

3.2.1 Typically Developing Infants

As with the previous set of analyses, the first step in characterizing the sequence of fixations between and within the paired faces is to describe how typically developing infants scan and compare paired faces. When presented with two visually paired faces, typically developing infants make congruent between-face saccades 30% of the time (*M* = .30, *SD* = .20). Nineteen percent of those congruent between-face saccades involved congruent looks between features (*M* = .19, *SD* = .19) and of that 19%, almost 11% were congruent eye AOI to eye AOI saccades (*M* = .11, *SD* = .18). See Table 5 for a complete summary of the descriptive statistics results.

Table 5: Summary of congruency measures for typically developing infants

	Mean Proportion of Congruent Saccades N = 47	
	M	*SD*
Face to Face	.30	.03
Eye to Eye	.11	.03
Nose to Nose	.03	.01
Mouth to Mouth	.06	.01
Extraneous Face to Extraneous Face	.08	.02

3.2.2 Gender

An analysis of gender (including all study participants) revealed a significant difference in the proportion of congruent mouth-to-mouth saccades between males (*M* = .05, *SD* = .08) and females (*M* = .09, *SD* = .13) (F (1, 80) = 3.88, p = .05) with females making proportionately more.

3.2.3 Risk Status Analyses

One-way ANOVAs were conducted to compare whether the LR and HR infants differed in the proportion of congruent saccades they made between each of the AOI pairs (i.e. between corresponding regions on each face). None of these ANOVAs indicated any significant differences in looking between the HR and LR infants (see Table 6**)**.

Table 6: Summary of congruency measures by risk status

	Mean Proportion of Congruent Saccades			
	HR (N = 49)		LR (N = 33)	
	M	*SD*	*M*	*SD*
Face to Face	.34	.18	.31	.22
Eye to Eye	.11	.16	.11	.20
Nose to Nose	.03	.05	.03	.05
Mouth to Mouth	.08	.11	.04	.07
Extraneous Face to Extraneous Face	.10	.14	.12	.19

3.2.4 Outcome Group Analyses

Again, the following analyses were conducted with an awareness of the large discrepancy in group sizes, and therefore, should be considered preliminary at best. A one-way ANOVA revealed significant group differences in the proportion of congruent mouth-to-mouth saccades (F (2, 58) = 6.71, p < .00) (see Figure 5). Follow-up independent samples t-tests showed a significant difference between all three of the outcome groups. The TD group made significantly more congruent mouth-to-mouth saccades (*M* = .06, *SD* = .09) compared to the NT group (*M* = .00, *SD* = .00) (*t* (46) = 4.89, *p* <. 00). The ASD group made significantly more congruent mouth-to-mouth saccades (*M* = .17, *SD* = .14) compared to the TD group (*M* =. 06, *SD* = .09) (*t* (52) = 2.75, *p* < .00). Consequentially, the NT group made significantly fewer congruent mouth-to-mouth saccades (*M* = .00, *SD* = .00) compared to the ASD group (*M* = .17, *SD* = .14) (t (12) = -4.49, *p* < .00). A second one-way ANOVA showed another significant group difference in the proportion of congruent extraneous feature to extraneous feature between face saccades (*F* (2, 58) = 4.93, *p* = .01) (see Figure 6). Follow-up independent samples t-tests revealed a significant difference between the TD and NT groups with the TD group making significantly less congruent extraneous feature to extraneous feature between face saccades (*M* = .22, *SD* = .20) compared to the NT group (*M* = .47, *SD* = .27) (*t* (52) = -2.950, p < .00). See Table 7 for a complete summary of group comparisons by outcome.

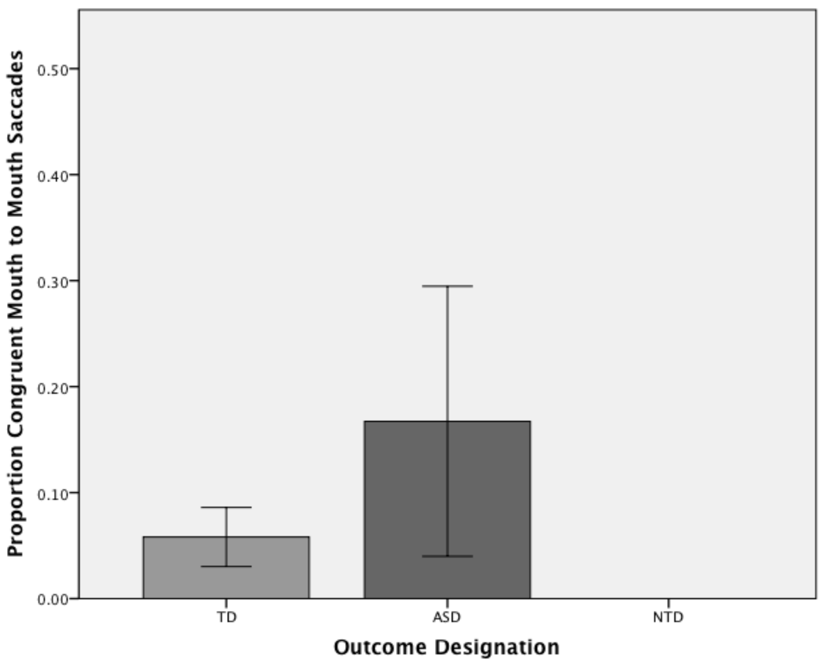

Figure 5: Mean proportion of congruent mouth-to-mouth saccades by outcome designation

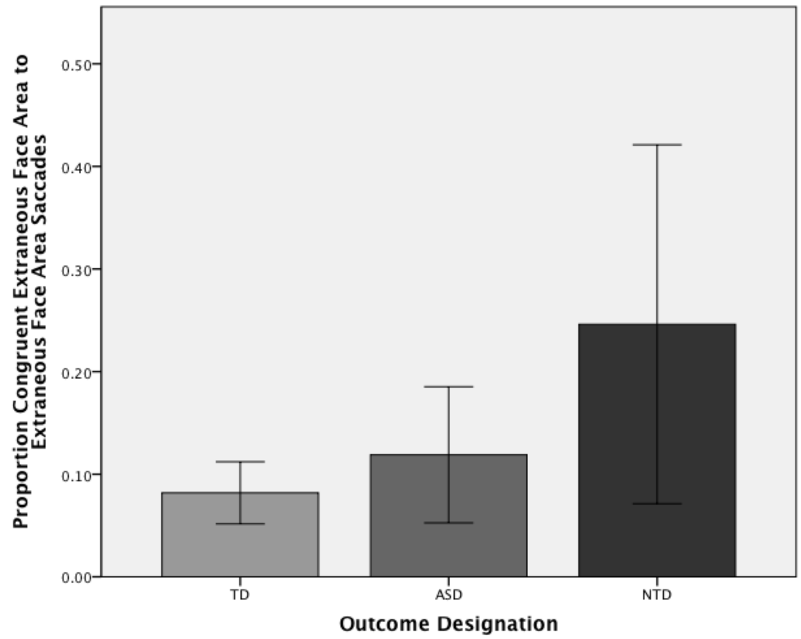

Figure 6: Mean proportion of congruent extraneous face to extraneous face saccades by outcome designation

Table 7: Summary of congruency measures by outcome designation

	Mean Proportion of Congruent Saccades					
	TD (N = 49)		ASD (N = 7)		NT (N = 7)	
	M	*SD*	*M*	*SD*	*M*	*SD*
Face to Face	.30	.03	.37	.03	.39	.05
Eye to Eye	.11	.03	.02	.01	.13	.05
Nose to Nose	.03	.01	.06	.03	.01	.01
Mouth to Mouth**	.06	.01	.17	.05	.00	.00
Extraneous Face to Extraneous Face *	.08	.02	.12	.03	.25	.07

* p < .05 and **p < .005

4.0 DISCUSSION

The present study is the first to characterize how infants visually compare paired faces using eye tracking technology. As the first of its kind, a primary aim was to establish the way in which typically developing infants distribute visual attention while viewing face pairs. This was then used as a baseline for future comparisons. While previous work has suggested that fixation to the upper half of the face may play an integral role in the processing of single faces (Cassia et al., 2004), the current study observed greater looking to the bottom half of the face. This was reflected in both the comparative and descriptive data. In broadly characterizing the way in which typically developing infants allocate their visual attention, it was found that 22% of the total time looking to the face was directed to the mouth. These findings in combination tentatively suggest that the features of the bottom half of the face (the mouth in particular) may be central to face comparison processes in infancy. When comparing faces, the mouth is a large and easily distinguished feature and hence may be particularly prominent when infants are trying to compare two faces. Alternatively, as posited by Lewkowicz and Hansen-Tift (2012), it is possible that these patterns of fixation may more broadly be reflective of the emphasis placed on language learning during this developmental time point. In order to tease apart these two possibilities, future research should aim to describe the developmental changes in the distribution of visual attention to paired faces over the first year of life and beyond.

In line with previous studies of infant visual attention to single faces (Dundas et al., 2012; Liu et al., Xiao et al., 2014; Wheeler, 2010), typically developing infants spent a greater proportion of time looking to the right side of the face than to the left. This suggests that the LVF bias observed during the viewing of singularly presented faces remains intact during the scanning of face pairs at 11 months of age. Previous work suggests that the LVF bias arises from a right hemispheric advantage for face processing (Yovel et al., 2008). By preferentially looking to the right side of a face, the LVF, more visual information is transmitted to the right hemisphere of the brain. It is reasonable to believe that this increased engagement of the right hemisphere during the processing of single faces is also advantageous when comparing face pairs.

Continuing the characterization of face pair comparison in typically developing infants, analyses of face comparison congruency measures found that when 11-month-old infants make between face saccades approximately 30% of those are congruent (i.e. between corresponding regions on each face). This suggests that at this point in development, infants are relying heavily on featural processing strategies. With each congruent saccade, infants are presumably comparing a target feature of one face to the same feature of the other. This raises the question of what our congruency measure is truly indexing. Does a high degree of congruency reflect a more mature or an undeveloped face processing strategy? Unfortunately, with this being the first study of its kind, we have no baseline for what congruency measures would constitute a mature, adult-like scanning strategy. However, based on evidence of single face studies (Mondloch, Grand, & Maurer, 2002) it is likely that the mature face processing system would rely on a more holistic scanning strategy. Rather than comparing pairs of faces feature by feature, adults may look at one face, abstract a mental representation, and then shift to the other face to engage in mental comparison. This process of abstraction and mental comparison would likely be reflective of fewer congruent saccades. By the end of the first year of life, infants have made great strides in the development of face processing expertise. By observing infants at 11 months of age, we may be examining a transition period from a featural to holistic approach to processing faces. This possibility is reflected in the high levels of variability observed within our congruency measure. An important next step for this line of research is to take a developmental approach to this question and characterize face comparison strategies across the lifespan.

In addition to characterizing how typically developing infants compare paired faces, this study aimed to identify any early disparities in distribution of visual attention between HR and LR infants. Interestingly, aside from a discrepancy in overall fixation duration to the screen, no differences between the two groups were observed. This is likely due to the high levels of heterogeneity in both the LR and HR populations. While studies of HR infant siblings increase the likelihood of observing infants that will later go on to receive an ASD diagnosis, only a small percentage do so. Inevitably our HR group not only represents infants that will go on to receive an ASD diagnosis or other developmental delays later in childhood but also infants that will go on to be typically developing children. A lack of findings between these two groups reaffirms popular sentiment that infant sibling ASD research must focus on outcome diagnostic categorization in addition to risk status. While looking at risk is an important first step in understanding early signs and symptoms of ASD as well as the broader ASD endophenotype, the most predictive data will likely come from examining childhood diagnostic outcome.

Although this study did not identify any differences in the distribution of visual attention to paired faces in our HR and LR groups, a significant difference in the proportion of time spent looking to the mouth was found among our outcome groups. While the ASD and TD groups did not differ from one another in the proportion of time they spent looking to the mouth, they both significantly differed from the NT group. While the ASD group and TD group each spent an average of 34% and 22% respectively, the NT group only spent 9% of the time looking to the mouth. Significant differences in looking to the mouth area were also reflected in the congruency measure where all three groups differed significantly. The ASD group made the greatest proportion of congruent mouth-to-mouth saccades with 17%; the TD group was in the middle with 6% and the NT made the least with 0%. Although the NT group failed to make congruent mouth-to-mouth- saccades, they made significantly more congruent saccades between extraneous face regions than the TD group.

Not a single infant that later went on to receive NT diagnostic outcome made a congruent mouth-to-mouth saccade. This may not be surprising considering that the majority of infants in the NT group displayed a language delay. Again, this follows the proposition of Lewkowicz and Hansen-Tift (2012). The children that are failing to make congruent mouth-to-mouth saccades, potentially an indication of typical language development, are showing language delays. Based on this relationship, it is possible that a lack of looking to the mouth may be specific to language delay as opposed to other categories of non-typical development recorded in the study. However, due to the large discrepancy in group sizes, it is noted that all results based on outcome categorization should be considered preliminary at best. Future work would benefit from the recruitment of a larger sample in the hopes of more precisely isolating the scanning strategies of infants that later go on to receive ASD and NT diagnoses.

While the data reported here from a single age has yielded scientifically important information, it is also recognized that the question at hand must be addressed using a developmental perspective. The ability to quickly and accurately process faces continues to develop throughout childhood and into adulthood. It is only reasonable to believe that the strategies used to complete this task continue to develop as well. By examining only a single point in development, we are missing the larger developmental trajectory. The strategies employed during the first year of life will likely vary greatly from those used during adulthood. Unfortunately, as the first study to address the scanning of face pairs, it is not yet known how adults visually compare faces. Therefore, there is no mature standard against which to compare the strategies used in infancy. Follow-up analyses examining these processes in both older infants and adults are currently in process to help clarify these results. In addition to taking a developmental perspective, future research should also examine this phenomenon across a number of different tasks that present a variety of processing demands (i.e. gender identification, familiarity identification and emotion recognition). Face comparison strategies may vary depending on the task participants are prompted to complete. While the bottom half of the face seems to be influential for identity comparison tasks, it may be that the upper half of the face is prominent during emotion comparison tasks. Future work should strive to span face processing domains.

Despite its limitations, the current study has taken a first step in the direction of understanding the processes underlying face comparison. As the first study to characterize both visual attention distribution and gaze scan patterns during a paired face comparison task, it has provided insights into the processing strategies of both typically and non-typically developing infants at 11 months of age. First, by examining the scanning strategies of typically developing infants it was found that the lower region of the face, the mouth in particular, plays a primary role in the face comparison process as does looking to the left visual field. Second, while there were no attention distribution differences found between infants at high and low risk of developing ASD, differences found in visual attention distribution and saccade congruency were predictive of diagnostic outcome in early childhood. Most importantly, this study serves as a starting point of understanding how individuals compare faces and whether these processes will provide insight into aberrant face processing development in disorders such as ASD.

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