Rutherford, J Psychol Psychother 2013, 3:4
DOI: 10.4172/2161-0487.1000125

Journal of Psychology & Psychotherapy
ISSN: 2161-0487

Research Article Open Access

Social Attention is Measurably and Increasingly Atypical Across the First Six Months in the Broader Autism Phenotype

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Abstract

Children with autism spectrum disorders (ASD) are different from those without ASD with respect to some aspects of social attention. This difference may have developmental implications, as attention to social information supports both social and cognitive development. This longitudinal study measures early social attention in infants, based on infants' gaze direction in response to faces, eyes, and animate motion, and compares a group of infants who have a sibling with ASD to a control group. Infant siblings show social preferences significantly less strongly than the control group as early as six months of age. Furthermore, results reveal diverging developmental trajectories, as group differences increase over the first half of the first year of life.

Keywords: Broader autism phenotype; Infant siblings; Social orienting; Eye tracking

Introduction

Autism spectrum disorders (ASD) are a pervasive and sometimes severe continuum of disorders characterised by atypical social cognitive and communicative development and repetitive behaviours. When first describing autism, Kanner suggested that autism is present in the first few months of life [1]. Although researchers have had some success in describing and characterizing the development of ASD in the first year of life [2,3], early autistic development has until recently been difficult to study, since young children are not commonly diagnosed until three years of age or later [4]. The current strategy for conducting controlled laboratory investigations of the development of ASD in infants is to recruit infants who have a close relative with ASD [5-7].

Several groups have now used eye-tracking technology to compare gaze behaviour in infants at risk for ASD to control infants. Six-month-old at-risk infants were found to be more likely compared to control infants to look at their own mothers during a still-face procedure [8]. However, this early preference for mouths did not predict a later ASD diagnosis, although it did predict higher expressive language scores at 2 years of age [9]. Overall, eye gaze behaviour in the first year has not yet been found to be reliably predictive of later ASD diagnosis [5-7].

In addition, researchers have compared neural activity in infants with siblings with ASD to a control group, while these infants viewed eyes and faces. Although one group found no group differences in neural response to familiar versus unfamiliar faces [10], another group found group differences in the latency of the neural responses to eye gaze: the neural response was slower in the ASD group [11].

Typical and autistic attention to social information

The social orienting view [12-14] suggests that for children developing with ASD an early failure to orient normally to social stimuli leads to the development of autistic symptoms. Children with ASD may not have as strong a preference for speech over other sounds, as typically developing children do [15], and children with ASD are less likely than controls to orient to social stimuli such as a name or clapping hands [12].

The current investigation focuses on social attention in three areas: orienting to faces, a preference for orienting to eyes relative to the mouth in face displays, and attention to chase displays. Each of these areas has been investigated in typical and autistic development, as described below.

Attention to faces

Very young children orient preferentially to faces as early as 2 months of age [16]. However, behavioural and neuroimaging studies suggest that individuals with ASD show atypical face processing from early in life [17,18]. Those with ASD use face information differently, showing deficits in face recognition [19,20] and in the perception of emotional facial expressions [21-23]. Because children with ASD show relatively less social orienting than controls, they may look less at faces.

Attention to eyes and mouth

Young children are particular likely to look toward the eyes when scanning a still or static image of a face [24]. Research using eye tracking technology has revealed that adults with ASD are less likely than typical observers to scan the eyes region of the face in either static or dynamic presentations [25,26]. The strategy used by infants with and without a risk for developing with ASD has begun to be revealed by eye-tracking research: while some work has suggested that infant siblings of children with ASD are much more likely than controls to show diminished eye gaze during a still face procedure [8], this abnormal gaze pattern has not proved to be predictive of an ASD diagnosis [9].

Attention to chasing

Adult viewers are sensitive to animate motion that suggests chasing, and perceive chasing even when viewing simple, featureless stimuli, such as dots on a screen [27,28]. Before they are six months old, infants can discriminate a chase display from inanimate motion that is matched with respect to speed and other motion characteristics: Three-month-

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Received June 24, 2013; **Accepted** August 29, 2013; **Published** September 05, 2013

Citation: Rutherford MD (2013) Social Attention is Measurably and Increasingly Atypical Across the First Six Months in the Broader Autism Phenotype. J Psychol Psychother 3: 125. doi: 10.4172/2161-0487.1000125

old infants prefer to watch the chasing scene over the non-social scene [29]. Recently, some authors have argued that the perception of chasing is a developmentally fundamental social perceptual skill, emerging early in development [30], However, recent research has shown that children with ASD are less likely than controls to spontaneously see such displays as animate [31].

ASD in the first year of life

It may be reasonable to expect that there are measureable signs of ASD in infancy. Kanner suggested that autism is already present early in the first year [1], and many parents report that their child was "different" long before getting an ASD diagnosis [32]. A retrospective examination of first birthday party videotapes revealed that one-year-olds who were developing with ASD exhibited fewer social and joint attention behaviours, compared to typical one-year-olds [2]. One case study described the journals of a mother with twins, one of whom was eventually diagnosed with ASD. As early as the second half of the first year, there were differences in social development and language development between the two children recorded in the mother's journals [3]. In addition, parent-reported behaviours are significant predictors of later ASD diagnoses as early as 14 months of age [33].

One fruitful strategy for exploring the early development of ASD is to recruit siblings of children with ASD and observe their early development [5,6,8,34]. ASD appears to be heritable, so children born with genetic relatives with ASD are more likely than the general population to develop an ASD diagnosis [35]. Thus recruiting infants who have close family members with ASD may allow researchers to observe ASD in its earliest development.

The broader autism phenotype

Even with selectively recruiting infants who have siblings with ASD, most participants will likely never have an ASD diagnosis. Nonetheless, these infant sibling are still of interest because close relatives of those with ASD who do not, themselves, have an ASD diagnosis, may display characteristics that are peculiar to that group [36-39], and these characteristics are known as the "Broader Autism Phenotype." The Broader Autism Phenotype (BAP) refers to both behavioural characteristics and brain differences that are found in people who do not have an ASD diagnosis, but are close genetic relatives of someone who does.

The BAP is thought to index increased genetic liability for ASD [40]. Relatives of those with ASD are more likely than the general population to have a verbal IQ that is 15 or more points lower than their own performance IQ [41]. There are speech and language deficits and social and emotional maldevelopment in the monozygotic twin of a proband with ASD [35]. In addition, family members of those with ASD may show some peculiar cognitive benefits: grandparents of children with ASD may be particularly good at intuitive math and engineering [42].

The current study

The purpose of this study is to describing and characterizing the social cognitive development of ASD and the broader autism phenotype in the first year of life. More specifically, the study was designed to test the hypotheses that while typical infants would be interested in looking at faces, eyes and chase scenarios, children at risk for developing with autism would show these preferences less than controls, and that group differences would increase in infancy. To this end, looking duration (the sum of durations of all fixations in a specific region of interest) in response to specific social visual stimuli was measured using eye-tracking technology. This was a longitudinal study in which infants who have a sibling with ASD, as well as control infants, were tested at 3 months and 6 months of age. A greater understanding of the early development of autism may aid in future screening and early detection of autistic development.

Method

Participants

Infants in this study belonged to one of two groups: the infant sibling group or the control group. Exclusion criteria for both groups were preterm birth, birth complications, twin or multiple birth, extremely low birth weight, or any diagnosed developmental disorder.

The infant sibling group was made up of children who have a full genetic sibling with an autism spectrum disorder (31, 18 male). The average ages were 3 months, 3.04 days (SD=15.05 days) at the first visit, and 6 months, 5.12 days (SD=21.12 days) at the second visit. They were recruited either when their older sibling participated in research in an ASD-related study, via public speaking in local forums on autism-related topics, or through advertisements in pediatrician's offices. The older sibling, in each case, had been given an autism spectrum diagnosis by a clinician using DSM-IV criteria. Each older siblings' inclusion in was confirmed independently by the author using the ADOS [43] (average score for subscales A (Communication) and B (Reciprocal Social Interaction) was 12.25, range: 5 to 21). Thus, the siblings of the infant group included those with classic autism, Aspergers, and PDD-NOS.

The control group was made up of infants who had no known family member with ASD (61, 35 male). This group was recruited from an existing database that comprises children whose mothers were approached in hospital after giving birth and asked to participate in a research database. Their eligibility for this group was established through the parent by 1) explaining to the parent on the telephone during initial intake that we were inviting the baby to participate in a group that had no known ASD in the family 2) verbally asking the parent on their first visit "Does your baby have any relatives with autism spectrum disorders?" and 3) following a negative answer with "None at all"? The average ages were 3 months, 4.16 days (SD=17.22 days) at the first visit and 6 months, 6.68 days (SD=19.89 days) at the second visit. In addition, 7 participants were excluded from all analyses (3 from the infant siblings group, 4 from the control group) because the eye tracking signal was too weak to record.

Apparatus

Two of the three tasks (The face preference and the eye preference tasks, see description below) were presented on a 46 centimeter NEC monitor (26° of visual angle) with a resolution of 1024 by 768 and a refresh rate of 85 Hertz. The monitor was 100 cm from the baby's eyes when the baby's head rested on the back of the car seat.

Eye movements were tracked using the Eye-Trac 6000 ASL, which was controlled by an HP Intel Pentium M laptop and connected to a Sanyo auxiliary video display where the eye could be viewed by the experimenter while data were recorded. The eye-tracking camera was placed 85 centimeters from the infants' eyes and directly in front of the monitor. This camera focused on the left eye and used UV light reflected from the pupil and a corneal reflection obtained using infrared light to follow the infant's gaze.

An initial 3-point calibration procedure ensured that the machine could calculate the location on the computer screen that the infant was looking. The calibration procedure is that proscribed by the Eye

Tracker manufacturer. Specifically: three calibration points formed a triangle that spanned most of the screen, as calibration dot placement in a straight line is not thought to be valid. This allows the eye tracker to follow the infant's gaze throughout the experiment and reliably report where his or her gaze was directed on the screen. The calibration process could be visually verified throughout the session, as the eye tracker displayed a disk at the estimated point of foveation, superimposed onto the stimuli that drew the observers' gaze. Calibration happened once at the beginning of the 10 minute data collection period. The eye tracker sampled at 60 Hz, and had a published precision of .25° at this viewing distance, based on adult viewers.

The third task display (the chase preference task described below) was presented on two side-by-side monitors, each a 46 centimeter NEC monitor with a resolution of 1024 by 768 and a refresh rate of 85 Hertz. A video camera was placed between the two monitors.

Procedure

Infants were secured in a car seat. Younger infants had a cushion fitted around their heads to reduce movement. First, the face preference task and the eye preference task were administered via interleaved trials with the infant in front of an eye tracker. Infants watched displays that included the trials for each of the tasks randomly ordered. Each trail began with an initial sound and fixation video to capture the infant's attention and serve as a fixation target. In each trial, an image appeared on the screen for 5 seconds, followed by 3 seconds of grey screen. Following the face preference and eye preference tasks, infants participated in the chase preference task, described below.

Face Preference

The infant saw an image of a face and a foil image of the same size, matched for luminance and contrast. The images were 27 cm (15°) tall and 17 cm (10°) wide and side-by-side on the computer screen. The face image was a color photograph of a face, with hair combed or pulled off the face, and including the neck and some shoulders. The second image, the foil, was created by phase-scrambling the first image, a process that preserves the spatial frequency content of the image, while randomizing the phase. Specifically, the phase and amplitude components of the face images were separated, and the phase component replaced with the phase of a Gaussian white noise patch matched in size to the original image [44]. Because infants use more of the low end of the spatial frequency range to recognize faces and ignore the high spatial frequencies in face processing, care was taken to ensure that the foil and the face image had the same range of high, low and medium frequency components. Because the structure of images is largely carried by the phase information [45], the resulting foils were not face-like in appearance, despite the preservation of the spatial frequency content. An example is provided in Figure 1.

Each of 10 trials included an image of a different person, and each foil image was displayed with the image from which it was derived. The display remained on screen for 5 seconds. The amount of time the infant spent looking at the left or right half of the screen was measured.

Eyes preference task

In each of 10 trials, an infant was presented with a single, color photograph displaying a different face. The face image displayed was 22 cm (12.5°) tall and 16 cm (9°) wide, was centered on the computer screen and was presented on-screen for 5 seconds. The eye tracker measured whether an infant was looking into the "eyes" region of interest, which measured 3 cm (2°) tall and 8.5 cm (5°) wide, or the equally sized "mouth" region of interest. Figure 2 illustrates the regions of interest.

Chase Preference Task

Trials for the chase preference task were presented on two side-by-side monitors. Infants saw the displays described by Rochat et al. [29]. On one monitor, two dots moved about on the screen as if one were chasing the other. In the control display, the two dots moved about at comparable speeds, but without any apparent relationship (e.g. no chasing, no avoiding, etc.). Each or 2 trials was 90 seconds in duration.

A video camera was placed centrally in front of the infant so that looking direction could be coded from video. The measure of interest was the amount of time the infants spent looking at each of the two display monitors. Looking durations to the right or left of the midline were recorded from video by trained coders who were naïve to the infants group assignment as well as the trial type. After all tapes were coded, fifteen percent of them were re-coded by the other rater to ensure that inter-rater reliability was maintained. Individual observers' looking durations estimates did not differ significantly between raters, and inter class correlation analyses revealed acceptable inter-rater reliability: ρ^1=0.89.

Figure 1: An example of stimuli used in the face preference (FP) task. The two images were displayed simultaneously on the computer screen for a duration of 5 seconds. Each foil image was derived from the photo with which it was presented.

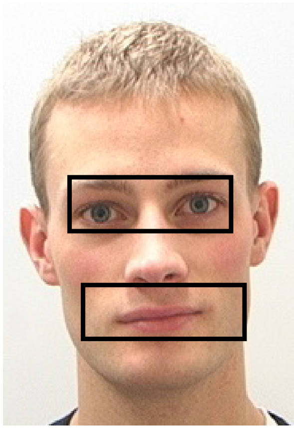

Figure 2: The regions of interest used in data analysis in the eyes preference task. The two regions of interest were of equal size, so chance performance would be equal looking duration in the two regions.

Results

Preliminary considerations

For each trial type, the point-of-regard is mapped onto a region of interest (ROI) that is specific to the task. For inclusion, infants needed to have measured fixations totalling 1 second of data for a trial to be included and in order for the point-of-regard to contribute to this fixation total, the infant had to look at the screen long enough for the eye tracker to detect gaze, so that saccade information was not included in point-of-regard data. Gender did not have a statistically significant effect on performance, so results were collapsed across gender it the following analyses.

For each task, looking duration to each of two regions of interest was summed across all trials for each infant and two regions of equal size were compared. The ratio used in analyses was the time spent looking at the social information divided by total looking duration. This ratio was the same measure used in the analyses of Young et al. [9].

Looking durations were first analyzed for violations of assumptions of the statistical procedures, and it was found that skewness and kurtosis were less than an absolute value of 1 so did not need to be corrected [46]. Variance was assessed by examining Levene's test for homogeneity of variance. For variables where Levene's test was significant, Fmax ratios were calculated. None of the Fmax ratios were greater than 4 and thus the data was considered to have met statistical assumptions [46].

Each of the three tasks was meant to measure gaze durations in tasks that were thought to index social perceptual development. Correlations amongst proportions of social attention for each task at each time point are presented for each group in Table 1.

Differences in attention to social information

With respect to the face preference task, a 2×2 mixed ANOVA was performed with age as a within-subject factor and group as a between-subject factor. The dependent measure was the time spent looking at the face divided by the time looking at both the entire display. This ANOVA revealed a significant main effect of group ($F(1,90)=12.88$, $p<0.001$, $\eta^2=0.14$) with the control group (M=0.73, SD=0.17) showing longer looking durations toward the face compared to control stimuli to a greater extent than the infant sibling group (M=.58, SD=0.23). In addition, there was a significant main effect for age ($F(1,90)=9.049$, $p=0.003$, $\eta^2=0.10$), revealing that the face preference increased with age overall (from 0.60, SD=0.27 to 0.71, SD=0.22). There was also a marginally significant age by group interaction ($F(1,90)=3.16$, $p=0.08$, $\eta^2=0.035$). Follow-up t tests revealed that the face preference was significantly stronger in the control group (0.81) than in the infant sibling group (0.61) at 6 months ($t(91)=5.68$, $p<0.001$, $d=59$). In contrast, the group difference (0.65 compared to 0.56) did not reach significance at 3 months ($t(91)=1.63$, $p=0.11$, $d=0.17$). Figure 3 illustrates these findings.

With respect to the eye preference task, a 2×2 mixed ANOVA was performed with age as a within-subject factor and group as a between-subject factor. The dependent measure was the time spent looking at the eyes region of interest divided by the time looking both the eyes and the mouth regions of interest, summed together. This ANOVA revealed a significant main effect of group ($F(1,90)=4.34$, $p=0.04$, $\eta^2=0.05$), with the control group (M=0.73, SD=0.25) showing a longer looking durations toward the eye stimuli compared to the mouth stimuli to a greater extent than the infant sibling group (M=0.58, SD=0.35). There was no significant main effect for age (0.64 at 3 months compared to 0.67 at 6 months; $F(1,90)=0.59$, $p=0.44$, $\eta^2=0.006$). The age by group interaction was not statistically significant ($F(1,90)=1.21$, $p=0.27$, $\eta^2=0.01$). Follow-up t tests revealed that the eye preference was significantly stronger in the control group (0.77) than in the infant sibling group (0.57) at 6 months ($t(91)=4.12$, $p<0.001$, $d=0.43$). In contrast, the group difference (0.68 compared to 0.60) did not reach significance at 3 months ($t(91)=1.08$, $p=0.28$, $d=0.11$). Figure 4 illustrates these findings.

With respect to the chase preference task, a 2×2 mixed ANOVA was performed with age as a within-subject factor and group as a between-subject factor. The dependent measure was the time spent looking at the half of the display showing the chase display divided by the time looking at the entire display. This ANOVA revealed a significant main effect of group ($F(1,90)=7.49$, $p=0.007$, $\eta^2=0.08$) with the control group (M=0.56, SD=0.11) showing a longer looking durations toward the chase stimuli compared to the independent motion stimuli to a greater extent than the infant sibling group (M=0.49, SD=0.18). There was no significant main effect for age (0.54 at 3 months compared to 0.50 at 6 months; $F(1,90)=1.79$, $p=0.18$, $\eta^2=0.02$). There was also no significant age by group interaction ($F(1,90)=0.028$, $p=0.87$, $\eta^2=0.003$). Follow-up t tests revealed that the chase preference was a significantly stronger in the control group (0.55) than in the infant sibling group (0.47) at 6 months ($t(91)=3.02$, $p<0.002$, d=0.32). In contrast, the group difference

Infant Sibling Group (n = 31)					
Task	Face at 3	Eye at 3	Chase at 3	Face at 6	Eye at 6
Eye at 3	0.20				
Chase at 3	0.30	-0.14			
Face at 6	0.18	0.17	0.01		
Eye at 6	0.03	**0.40	0.12	**0.33	
Chase at 6	0.07	*-0.39	0.07	0.30	*-0.39
Control Group (n = 61)					
Task	Face at 3	Eye at 3	Chase at 3	Face at 6	Eye at 6
Eye at 3	0.12				
Chase at 3	0.20	0.07			
Face at 6	0.11	*0.25	-0.14		
Eye at 6	-0.02	0.10	0.05	0.18	
Chase at 6	0.01	-0.09	-0.14	0.15	-0.02

Note: *p< .05, **p<.01, ***p<.001

Table 1: Correlations among proportions of social attention in infants at risk for autism and control infants.

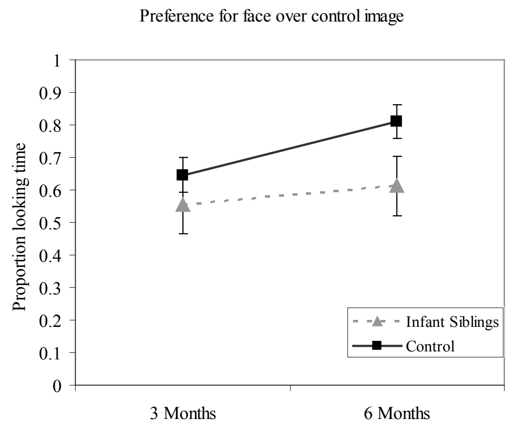

Figure 3: Average proportion of total looking duration that participants looked at the face during the face preference task, by group, across two test sessions. Error bars represent the standard error of the mean.

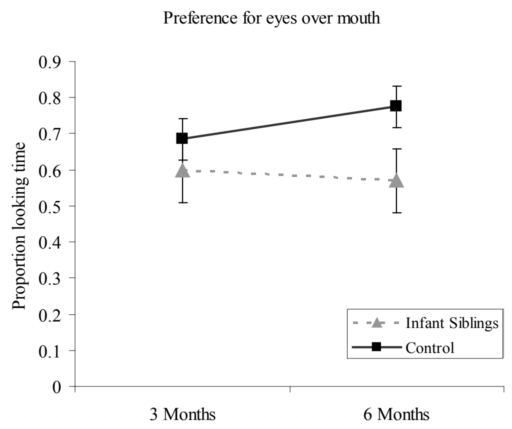

Figure 4: Average proportion of time spent looking at features that participants looked at the eyes during the eyes preference task, by group, across two test sessions. Error bars represent the standard error of the mean.

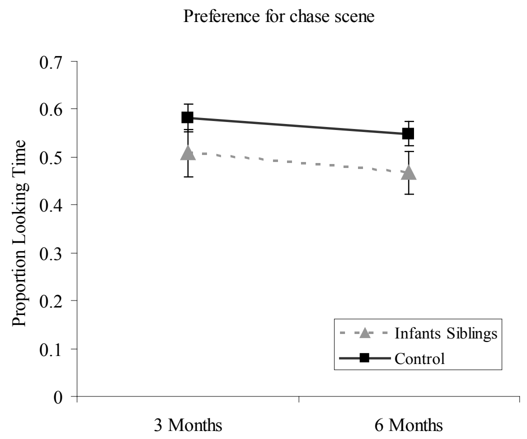

Figure 5: Average proportion of total looking duration that participants looked at the chase scene during the chase preference task, by group, across two test sessions. Error bars represent the standard error of the mean.

(0.58 compared to 0.51) was not significant at 3 months (t (91)=1.49, p=0.14, d=0.16). Figure 5 illustrates these findings.

Were social measures stable across time?

Of interest is the question of whether the three measures are related to each other, possibly reflecting common psychological processes. In order to test the extent to which each measure was predictive of performance on the same task across developmental time, relationships between performance at 3 months and performance at 6 months was tested for each task pooling the two groups together. The preference for face stimuli was correlated at 3 and 6 months (r(91)=0.18, p=0.04. The preference for eyes over mouth was correlated at 3 and 6 months (r(91)=0.48, p<0.001. And the preference for animate motion was marginally significant when 3 and 6 months performance was compared (r(91)=0.13, p=0.10.

Discussion

This study was designed to test the hypotheses that typical infants would be interested in looking at faces, eyes and chase scenarios, that children at risk for developing with autism would show these preferences less than controls, and that group differences would increase in infancy. Two findings emerge: First, there are significant group differences when infant siblings of children with ASD are compared to control infants. Those with no ASD in the family have a stronger preference for social stimuli than those with an affected sibling. Second, there is evidence of a developmental divergence, such that the group difference increases over the first half of the first year.

These results suggest that a group of infants who have a sibling with ASD are different from control infants on measures of social orienting early in the first year. The group difference is consistent with previous descriptions of the broader autism phenotype. Some of the cognitive characteristic of family members of those with ASD are similar to that of probands with ASD [36-38,47] including some deficits in interpreting social information in the eyes region of the face [48]. The results from the current study suggest that these BAP characteristics develop as early as the first year of life. It is possible that there may eventually be a way to screen for children developing with ASD much earlier than current practice.

Other studies have also found measurable differences in the first year between infants with siblings with ASD and control groups, including group differences in under- and over-responsivity to sensory information and smoothness of visual tracking at 12 (but not 6) months [5]. Some research revealing early evidence of BAP characteristics has used eye direction as measured [49] often employing an eye tracker as a sensitive method for measuring development [8,9].

One fundamental question is whether the three tasks measure a single developing social cognitive mechanism such as a preference for social information over non-social information, or rather, whether each task measures a specific developing social perceptual strategy. Correlational analyses suggest that one should not view the three tasks as measuring a unitary developing psychological process. The eyes and face preference tasks did show some relationship each with the other, and this relationship was significant for one pairing in each group. However, in the control group, there is a negative relationship between the chase preference task and the other tasks. This suggests that while each task may be measuring an aspect of social attention, these tasks are mediated by different psychological processes, perhaps with different developmental trajectories. That said, earlier findings suggest that the eyes versus mouth task may measure a specific developmental strategy: although very young infants prefer to look at the eyes over other facial features [24], among older infants, time spent looking at the mouth has been found to be related to development of expressive language, presumably because it aid in word segmentation and comprehension [9]. For example, recent evidence suggests that infants selectively attend to the mouth of a talking face when learning speech [50]. Thus, the infants' use of visual information in the mouth region may be part of a distinct visual strategy, specifically one associate with language learning.

It is interesting that the patterns of correlations among tasks differ between the two groups, primarily because more pairings reached significance in the infant sibling group. This is surprising given that the control group is larger. This difference is likely explained, in part, by the greater heterogeneity in the infant sibling group, which will ultimately include children with an ASD diagnosis, children who show the broader autism phenotype, and typically developing children. By comparison, the control group shows less variance in development and a stronger preference for social stimuli.

Also of interest is the finding that a group of infants who are siblings of children with ASD show a different developmental trajectory on a set of social perceptual tasks than does a control group of infants. This finding demonstrates a true developmental difference between the two groups. Whereas the control group shows an increase in interest in faces and for eyes between the ages of 3 and 6 months, the infants with siblings with ASD show essentially no increase. As a group, however, the infants siblings are more likely to look at social information than at the foil stimuli, which is not surprising since the group undoubtedly includes infants who are developing typically. Still, the groups are distinguishable, and increasingly so, indicating that on the whole the groups may have different developmental trajectories.

One caveat to keep in mind when considering the results of this study is that group-wise comparisons such as those offered here may not capture differences in developmental trajectories between subgroups of infants developing with autism. Some recent research has identified psychologically distinct subgroups in groups of adults with ASD [19] and in groups of infants at risk for ASD [8,9]. A group-wise comparison such as this will not detect clusters. That said, there could be similar levels of variance in the control group in terms of social cognitive development and a variety of developmental disorders. A longitudinal follow-up with these subjects will help clarify these issues.

The group differences found here may be consistent with the social orienting idea of autistic development. According to this view, social orienting is thought to be critically important to social and non-social cognitive development [13]. This study provides evidence consistent with the social orienting theory of ASD, since the control group and the infant sibling group differed on measures of early social orienting. That said, the study does not provide a strong test of the theory. The social orienting theory posits that early social perceptual deficits seen in this group are causally related to later social cognitive deficits as well as to a subsequent ASD diagnoses. Furthermore, recent work that reports the early development of infant siblings showed that early anomalies in development of infant siblings such as anomalous patterns of face scanning did not predict later autistic development [9]. The results reported here are part of a larger longitudinal study which will eventually offer a stronger test of the social orienting perspective.

Acknowledgement

The author would like to gratefully acknowledge the efforts of Brenda Lumsden-Johanson, Sandra Monteiro and Kristen Krysko for extensive work on scheduling participants and collecting data.

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