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Visual input to the left versus right eye yields differences in face preferences in 3-month-old infants

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Abstract

From birth, infants prefer looking at faces over scrambled faces. This face input is important for the development of face processing: individuals who experienced early visual deprivation due to congenital cataracts have long-lasting face processing deficits. Interestingly, the deficits are eye-specific such that left eye cataracts disrupt the development of face processing, whereas right eye cataracts do not. This raises the question of whether infant face preferences are driven primarily by faces observed through the left eye. To investigate this, we presented 3-month-old infants with intact faces paired with scrambled faces. Infants viewed the moving stimuli binocularly, only with their left eye, or only with their right eye. Infants viewing stimuli binocularly or with only the left eye spent significantly more time looking at intact faces than scrambled faces, but this effect was equivocal in infants viewing stimuli through only their right eye. Infants in the binocular group had the greatest preference for faces, and this preference was greater than the right eye group's preference for faces. The left eye group's preference for faces was not statistically different from the other two groups' preference for faces, but additional analyses revealed a correlation between preference for faces and age for the right eye group only, indicating that preference for faces seen with the right eye increase from 3 to 4 months of age. These results indicate that the left eye plays a special role in face processing at, or before 3 months of age, but a preference for faces through the right eye emerges soon after.

KEYWORDS
development, face preference, hemispheric specialization, infants, looking behavior, monocular viewing

1 | INTRODUCTION

Infants show an interest in faces very early in life. Newborn infants, averaging only nine-minutes-old, rotate their head and eyes further to track faces than scrambled faces or blank paddles (Goren, Sarty, & Wu, 1975). A similar preference has been found for infants with a mean age of 37 min (Johnson, Dziurawiec, Ellis, & Morton, 1991), and this finding has since been replicated several times with other age groups (Farroni et al., 2005; Frank, Vul, & Johnson, 2010; Macchi Cassia, Turati, & Simion, 2004; Simion, Macchi Cassia, Turati, & Valenza, 2001; Valenza, Simion, Macchi Cassia, & Umiltà, 1996). This preference allows infants to harvest rich information from faces, and this early experience with faces appears to be important for the development of typical face processing (Le Grand, Mondloch, Maurer, & Brent, 2001, 2003, 2004; Ostrovsky, Andalman, & Sinha, 2006).

Individuals born with dense congenital cataracts that interfere with early patterned visual information have long-lasting face processing deficits even when the cataracts were treated in the first months of life (Le Grand, Mondloch, Maurer, & Brent, 2003; Roder, Ley, Shenoy, Kekunnaya, & Bottari, 2013). These impairments were present despite having normal or corrected-to-normal vision and being tested at least 8 years post-surgery. Interestingly, one study showed that deficits were present in individuals who had bilateral cataracts or unilateral left eye cataracts, but not individuals who had unilateral right eye cataracts (Le Grand et al., 2003). A follow-up study found evidence that this effect is specific to faces: none of the individuals had difficulty with a matched object task, regardless of which eye was affected (Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010).

Why might left eye cataracts have long-lasting effects on face processing while right eye cataracts do not? One proposal is that this difference results from two purported features of visual development (Le Grand et al., 2003). According to this proposal, although the adult visual system sends information from each eye to both hemispheres of the brain, in the first 6 months of life information may be sent primarily to the contralateral hemisphere of the brain (Figure 1). One study supporting this claim used visual perimetry to show that sensitivity to stimuli in the temporal visual field develops before sensitivity to stimuli in the nasal visual field (Lewis & Maurer, 1992). The temporal visual fields are viewed by the nasal hemiretinas, which project to the contralateral side

Research highlights

- Previous studies show that visual deprivation from congenital cataracts on the left eye disrupts the development of face processing, but similar deprivation from right eye cataracts does not.
- Are early face preferences driven by left eye input? 3- to 4-months-olds viewed faces and scrambled faces with their left or right eye, or both.
- Infants viewing faces with both eyes, or with their left eye, preferred faces over scrambled faces, but infants using their right eye only did not.
- Face preference increased with age for right eye only. Thus, the left eye drives face preference early, but the right eye's contribution increases over time.

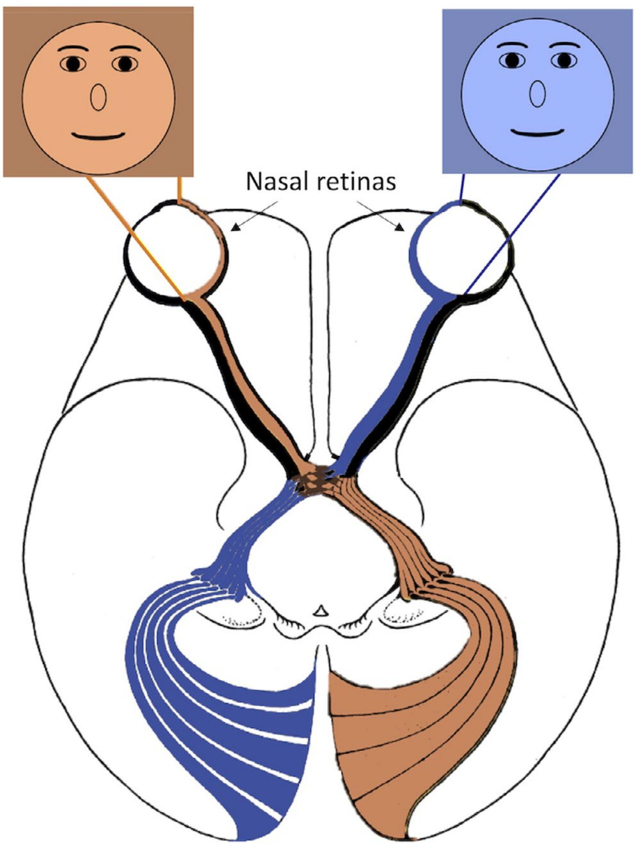

FIGURE 1 Schematic of the transfer of information in the infant visual system. If sensitivity to the temporal visual fields (viewed by the nasal retinas) develops earlier than sensitivity to the nasal visual fields (viewed by the temporal retinas) (Lewis & Maurer, 1992), information would be primarily sent from each eye to the contralateral hemisphere of the brain

of the brain. As a result, early in life information may travel predominantly from the left eye to the right hemisphere of the brain (which plays a special role in face processing, described below) and from the right eye to the left hemisphere of the brain. Ipsilateral transfer of information would develop later, when sensitivity to the nasal visual fields emerges. Secondly, the visual hemispheres may not share face information efficiently in the first 24 months of life (Adibpour, Dubois, & Dehaene-Lambertz, 2018; Deruelle & de Schonen, 1995; Liégeois, Bentejac, & de Schonen, 2000; Liégeois & de Schonen, 1997; de Schonen & Mathivet, 1990). For example, in one study, 4- to 10-month-old infants learned a face discrimination task in one visual hemifield before being tested in the other visual hemifield. There was a right hemispheric advantage for learning the task, but there was no hemispheric transfer of learning (de Schonen & Mathivet, 1990). In another study, 19- to 23-month-old infants shown schematic faces with either two matching eyes (e.g., two circles) or two different eyes (e.g. one circle and one triangle) were able to determine whether the eyes matched when the faces were presented unilaterally, in one visual hemifield, but not if they were presented bilaterally, spanning two visual hemifields (i.e., one eye appeared in each hemifield). In contrast, 24- to 28- month-old infants could successfully perform the task when the faces were presented unilaterally or bilaterally, indicating that they compared visual information received by two separate hemispheres of the brain (Liégeois et al., 2000). Thus, the proposal suggests that left eye cataracts may selectively impede the delivery of face information to the right hemisphere, and any information received by the left hemisphere may not be efficiently shared with the right hemisphere. In contrast, the right hemisphere in individuals with unilateral right eye cataracts may still receive face input through their intact left eye (Le Grand et al., 2003).

Why is input to the right hemisphere critical for face processing? Numerous studies using a variety of techniques have demonstrated that face processing is more dependent on the right cerebral hemisphere than the left in adulthood. For example, neuropsychological studies have demonstrated that prosopagnosia is far more likely to result from damage to the right hemisphere than the left hemisphere (Barton, Press, Keenan, & O'Connor, 2002; De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994; Rossion, 2008). Similarly, intracranial stimulation of right hemisphere face areas is more likely to disrupt face perception and recognition than stimulation of left hemisphere face areas (Rangarajan et al., 2014; Schalk et al., 2017). In healthy adults, functional Magnetic Resonance Imaging (fMRI) and electroencephalography (EEG) studies have shown stronger face selectivity in the right hemisphere than the left hemisphere (Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Truett, 1997; Rossion et al., 2000).

This right hemisphere superiority for face processing may be present very early in life. Behaviorally, 4- to 10-month-old infants show a left visual hemifield/right hemisphere advantage for discriminating faces (de Schonen, Gil De Diaz, & Mathivet, 1986; de Schonen & Mathivet, 1990). In addition, scalp recordings via event-related potentials (ERPs) have shown right-lateralized face-selective responses in 1- to 6-month-olds (Adibpour et al., 2018; de Heering & Rossion, 2015). A Positron Emission Tomography (PET) study of 2-month-old infants viewing unknown female faces found stronger right hemisphere brain activation in areas analogous to face processing areas typically seen in adults (Tzourio-Mazoyer et al., 2002). One Near-Infrared Spectroscopy (NIRS) study of 7- to 8-month-olds showed a right hemisphere advantage for intact faces over scrambled faces (Honda et al., 2010), while another NIRS study of 5- to 8-month-olds showed a right hemisphere advantage for upright over inverted faces (Otsuka et al., 2007). Even newborn infants (1 to 4 days old) viewing schematic face-like patterns show right lateralized neural responses that overlap with adult face processing areas (Buiatti et al., 2019) indicating that a right hemisphere dominance for face processing is present at birth.

Regardless of the mechanisms underlying the unilateral cataract findings, the findings raise the question of whether input from the left eye and right eye play different roles in face processing in the early months of life. Given the importance and strength of face preferences early in life, we chose to investigate this question by examining whether infants show a preference for intact over scrambled faces when they view them with the left eye versus the right eye. We recruited 3-month-old infants (3.00–3.98 months) to watch videos of high-contrast schematic faces paired with scrambled faces in a between-subjects design. We chose this age group because they are old enough to be alert and engaged, and their basic visual acuity and contrast sensitivity is sufficient for seeing large, high-contrast stimuli, but they may not yet have full sensitivity to information arriving at their temporal hemiretinas (Lewis & Maurer, 1992). One group of infants viewed the stimuli with both eyes, while the other two groups viewed the stimuli with either the left or right eye (Figure 2). To examine whether any effects are face-selective, infants also viewed moving schematic flowers paired with scrambled flowers. If the left eye plays a special role in early interest in faces, we predict that infants viewing the stimuli with both eyes or the left eye only will show a significant preference for faces over scrambled faces, but infants viewing the stimuli with the right eye only will not show this preference. If the effects are specific to faces, there should be no difference between groups with regard to preference for flowers versus scrambled flowers.

2 | METHOD

2.1 | Participants

One-hundred and sixty-seven 3-month-old infants (71 = female, mean age = 3.50 months, range 3.00–3.98) were recruited through the Infant Participant Pool at the Institute of Child Development at the University of Minnesota. To be eligible to participate, infants must have been born after at least 37 weeks gestation, weighed at least 2000 grams (4 lbs, 6 oz) at birth, have no known genetic, medical, or neurological condition that affected growth or development, have no first-degree relatives with autism spectrum disorders, psychosis, or schizophrenia, and have normal, or corrected-to-normal, vision and hearing. This study was approved by the Institutional Review Board at the University of Minnesota. Parental permission was provided for all infant participants. This study was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki).

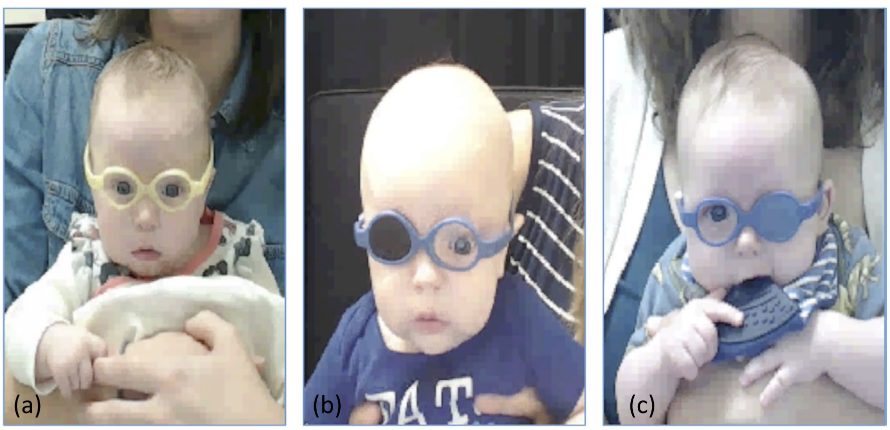

FIGURE 2 Different viewing conditions (Groups). (a) Binocular (BIN), (b) Left Eye Open (LEO), and c) Right Eye Open (REO)

2.2 | Design

Infants watched videos of high-contrast schematic faces and scrambled faces. These stimuli traveled up and down the screen simultaneously, but in opposite directions. In this between-subjects design, one group of infants viewed the stimuli binocularly (BIN, n = 48), while the other two groups viewed the stimuli with either the left eye open (LEO, n = 62) or the right eye open (REO, n = 57), Figure 2. To examine whether any effects are face selective, all infants also watched videos of schematic flowers paired with scrambled flowers.

2.3 | Stimuli

Our face stimuli were designed based on the stimuli used in the Goren et al. (1975) and Johnson et al. (1991) face-tracking studies. Specifically, we wanted to design high-contrast intact and scrambled faces to best match their experimental design. Stimuli consisted of a black-and-white schematic face paired with a scrambled version consisting of the same parts (Face condition, Figure 3a) or a black-and-white schematic flower, paired with a scrambled version of the same flower (Object condition, Figure 3b). The flowers were designed by taking the circular outline of the face and replacing the internal features with lines for petals. Faces and flowers were therefore matched in shape and size: circular and 8.4° in diameter when viewed from 60 cm. Stimuli were displayed on a light grey background.

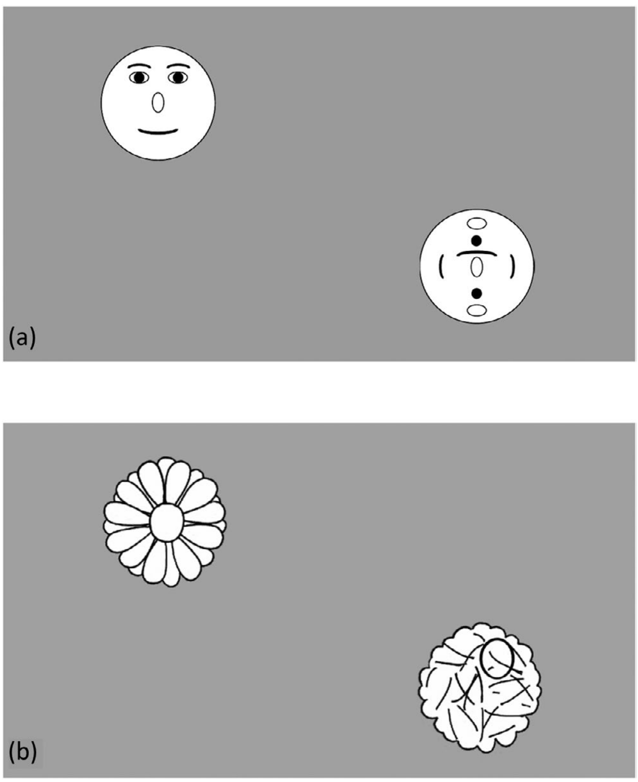

FIGURE 3 Stimuli. (a) Face condition: intact face paired with scrambled face. (b) Object condition: intact flower paired with scrambled flower

Trials consisted of the intact face (or flower) beginning in one corner of the screen such that the center of the stimulus was 14.3° horizontally and 4.2° vertically from the corner. The scrambled stimulus started in the corner of the screen that was diagonally opposite (e.g., a top-left intact face was paired with a bottom-right scrambled face). The stimuli were separated by 14.5° (horizontally) and moved simultaneously at the same speed in opposite directions. In each 5,200 ms trial, the stimuli traveled vertically to the opposite side of the screen and back to their starting positions (speed = 9.4°/s). The starting position of the stimuli was randomized and counterbalanced such that the intact face started in each of the four corners of the screen four times per block. Each trial was preceded by a moving, colorful, attention-grabbing stimulus displayed at center screen. These "attention-grabbers" stayed on screen until the experimenter judged that the infant was looking at the screen, at which point the next trial was initiated by keypress.

2.4 | Apparatus

Videos were displayed on a 27", 1,920 × 1,080 resolution ASUS computer screen with a 120 Hz refresh rate. Videos were played through Tobii Studio software (Tobii Technology AB, www.tobii.com), although eye gaze movement was not recorded[1]. Instead, infants' faces were recorded by a high-resolution screen-mounted camera for later coding by trained researchers (see Analyses, below).

2.5 | Procedure

2.5.1 | Set-up

Infants were randomly assigned to a viewing condition: Binocular (BIN), Left Eye Open (LEO), or Right Eye Open (REO) in a between-subjects design. Infants were seated on their parent's lap approximately 60 cm from the computer screen. Some infants were placed on pillows if they were too small to be recorded by the screen-mounted camera. Basic measures, such as weight, length, or head circumference, gestational age, age at time of testing, temperament, and household income, did not vary by Group (Table 1). The experimenter explained the task to the parent and instructed him or her not to point to or name anything on the screen throughout the testing session. The experimenter then fitted the infant with a pair of infant-sized glasses (Figure 2). The BIN infants wore a set of glasses that had no lenses in them. The LEO and REO infants had glasses with one opaque lens and one missing lens. For the LEO infants, the opaque lens covered their right eye, whereas for the REO infants the lens covered the left eye. We used glasses instead of an eye patch because pilot work revealed that the glasses stayed in place more securely. When the glasses were properly positioned, the experimenter started the first block of trials.

TABLE 1 Sample size, basic demographic information, physical measurements, and temperament scores (Infant Behavior Questionnaire - Revised, IBQ-R), by group

	Binocular	Left Eye Open	Right Eye Open
Sample size			
Tested	48	62	57
Final analysis	47	60	53
Demographic information			
Age at time of test (months)	3.49 (*SD* 0.28)	3.51 (*SD* 0.29)	3.49 (*SD* 0.30)
Weeks gestation	39.8 (*SD* 0.91)	39.9 (*SD* 1.00)	39.9 (*SD* 1.17)
Race (% Caucasian)	91.7%	88.7%	89.5%
Ethnicity (% Non-Hispanic)	97.9%	96.8%	100.0%
Household income:			
Range	<$25,000-over $200,000	$25,000-over $200,000	<$25,000-over $200,000
Mode	$100,000-150,000	$75,000-100,000	$100,000-$150,000
Physical Measurements at test			
Weight (lbs)	14.4 (*SD* 1.83)	15.2 (*SD* 1.75)	14.4 (*SD* 1.79)
Length (in)	24.7 (*SD* 1.57)	24.7 (*SD* 1.24)	24.5 (*SD* 1.21)
Head circumference (in)	16.4 (*SD* 0.54)	16.4 (*SD* 0.65)	16.3 (*SD* 0.66)
Temperament (IBQ-R)			
Positive emotionality	3.85 (*SD* 0.62)	3.91 (*SD* 0.72)	3.92 (*SD* 0.70)
Negative emotionality	3.45 (*SD* 0.47)	3.45 (*SD* 0.41)	3.53 (*SD* 0.38)
Regulatory capacity	4.90 (*SD* 0.48)	5.00 (*SD* 0.60)	4.95 (*SD* 0.57)

2.5.2 | Familiarization

Blocks began with a colorful swirling circle paired with an enticing noise appearing on the left side of the screen followed by several flashing red dots, and then the same colorful swirling circle on the right side of the screen followed by the same flashing red dots. This procedure was designed to attract the infants' attention to each side of the screen before the experimental stimuli appeared, in effort to reduce the tendency for infants to look at only one side of the screen throughout the task. Next, a familiarization phase began during which a single schematic face (or flower) appeared at center screen and moved up and then down, ending at center screen. This was followed by the scrambled face (or flower) that moved in the opposite trajectory. The face and scrambled face alternated for a total of four appearances. This portion of the task was introduced to familiarize the infants with the stimuli before they were paired in the main part of the experiment so that experimental trials would be more likely to reflect preference rather than exploration of the stimuli.

2.5.3 | Experimental trials

After the familiarization phase, the first attention-grabbing stimulus appeared at center screen until the experimenter judged that the infant was looking at the stimulus. The experimenter then initiated the first trial by key press. Experimental trials consisted of an intact face and scrambled face (or flower and scrambled flower) moving up and down in opposite directions on opposite sides of the screen. Each block consisted of 16 face trials or 16 flower trials with the intact and scrambled stimuli randomly alternating sides. Upbeat music with non-English (Basque) lyrics played in the background to help maintain the infants' interest. Experimenters attempted to show the infants two blocks of trials from each stimulus condition (i.e., two faces and two flowers), with the order alternating between conditions, but some infants did not complete all blocks due to fussiness or fatigue (see Quality Control, below). Each child was randomly assigned to start the task with either the face or flower condition (A-B-A-B or B-A-B-A). Each block took approximately 2 min and 30 s, depending on how long the attention-grabbing stimuli were on the screen, for a total task duration of about 10 min, plus transition time between blocks. Some infants took breaks between blocks if they needed to be changed or fed.

2.6 | Data processing

Video recordings were exported from Tobii Studio (Tobii Technology AB, www.tobii.com) with picture-in-picture showing the infant's face in the top corner and a screen recording of the stimuli in the main window (Figure 4). A researcher then cropped

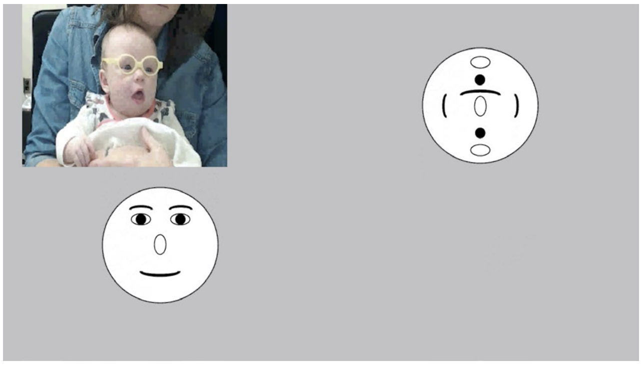

FIGURE 4 Example of picture-in-picture view of a trial. Prior to coding, videos were cropped around the infant so that the coder could not see the stimuli

the videos around the inset of the infant's face so that coders were blind to which stimulus was on which side of the screen during a given trial. The videos were cropped such that a small section of background from the stimulus screen was still visible so that the coder could determine when trials started and finished (the background changed color when the attention-grabbing stimuli were on the screen). Eight researchers coded the videos using Datavyu software (www.datavyu.org), marking timestamps when the infant was looking at the left or right side of the screen. Any look that was not clearly directed to the left or the right was not coded. Later, these "other" looks were calculated by subtracting time on the left and right of the screen from the total trial time. One of the researchers also watched the stimulus recordings and noted which stimulus appeared on which side of the screen on each trial. After the videos were coded, the time spent looking at the left and right side of the screen for each trial was integrated with location of the stimuli in Excel. This allowed us to generate a measure of time spent on each stimulus as a proportion of time spent on screen. All coders were compared to a criterion coder and had high intraclass correlations (all >0.900).

2.7 | Quality control

2.7.1 | Minimum time on stimuli per trial

We collected data from 167 infants (BIN = 48, LEO = 62, REO = 57). First, all looking times (ms) to intact face, scrambled face, intact flower, and scrambled flower were converted into proportions of looking time per trial. We then computed an average proportion of looking time per participant across all face trials (i.e., trials from Blocks 1 and 2 combined) and all flower trials, respectively. Using the averages from face trials, we computed the mean proportion of time on stimuli (face + scrambled face) for each group. We used a one-way ANOVA with factor of Group (BIN vs. LEO vs. REO) to determine whether the groups spent equivalent proportions of time looking at the stimuli. There was a main effect of Group, F (2, 159) = 24.93, $p < .001$, $\eta_p^2 = 0.19$. Planned group-wise comparisons revealed that the BIN group spent a significantly larger proportion of time looking at the stimuli (mean = 0.79, *SD* = 0.12) than the LEO (mean = 0.56, *SD* = 0.21) and REO (mean = 0.60, *SD* = 0.18), ps < 0.001. This was expected because the BIN infants were less distracted by their lens-free glasses than the other two groups, who had one eye occluded. The LEO and REO groups looked at the stimuli for comparable proportions of time (LEO vs. REO, p = .894). Because the LEO and REO groups were our primary groups of interest, we used mean proportion of time on stimuli from all LEO and REO participants combined to determine the minimum proportion of time on stimuli needed for a trial to be considered valid. The mean proportion of time on screen for LEO and REO participants was 0.58 (*SD* = 0.19). Using a cut off of 2 *SD* below the mean, we computed a minimum valid proportion of time on screen to be 0.20. This is the equivalent of 1,040 ms, a duration that allows infants to make approximately two eye movements and enough time for an infant to orient to, and process, stimulus information (Canfield et al., 1997).

2.7.2 | Minimum number of valid trials per block

Using the 0.20 minimum valid data criterion established above, we computed the number of valid trials per block for each infant. We then averaged Block 1 and Block 2 to generate an average number of valid trials per Block per Group. For infants who only completed one block, we used the number of valid trials from the completed block. We conducted a one-way ANOVA with factor of Group (BIN vs. LEO vs. REO) and found a significant main effect of Group, F (2, 159) = 15.7, $p < .001$, $\eta_p^2 = 0.14$. Bonferroni-corrected group-wise comparisons revealed that the BIN group had significantly more valid trials on average per block (mean = 15.2, *SD* = 1.4) than the LEO group (mean = 12.3, *SD* = 3.3) and the REO group (mean = 13.1, *SD* = 2.7), ps < 0.001. The LEO and REO groups did not differ from each other, p = .341. We therefore used the mean number of trials per block for the LEO and REO groups combined (mean = 12.7, *SD* = 3.1) to generate a minimum number of trials needed for a block to be considered valid. We first computed 2 *SD* below the mean (6.5 trials), but in effort to use as much data as possible, we established a minimum valid data criterion of 3 *SD* below the mean, which translates to 4 trials per block or 25% of the block. In the end, of the n = 48 BIN infants who participated in the study, n = 46 infants contributed data from two valid blocks of trials, n = 1 infant contributed data from one valid block, and n = 1 infant contributed insufficient valid data to be included in further analyses. A total of 3 blocks were invalid for this group. Of the n = 62 LEO infants who participated in the study, n = 42 contributed data from two valid blocks of trials, n = 60 contributed data from at least one valid block, and n = 2 infants contributed insufficient valid data to be included in further analyses. A total of 22 blocks were invalid for this group. Of the n = 57 REO infants who participated in the study, n = 48 contributed two valid blocks of trials, n = 53 contributed data from one valid block, and n = 4 contributed insufficient valid data to be included in further analyses. A total of 13 blocks were invalid for this group.

2.7.3 | Summary

See Figure 5 for a flow chart summarizing our quality control procedures. In implementing these quality control measures, our analyses were performed using mean proportions of looking time from valid trials only, defined as at least 20% of the total trial time (1,040 ms of 5,200 ms) spent looking at stimuli on the screen. Data from a block of trials were included if that block of 16 trials contained at least 4 valid trials. These criteria were generated using data from the Face condition, but the same criteria were applied to the data from the Flower condition. We also confirmed that basic characteristics, such as weight, length, head circumference, gestational age, age at time of test, temperament, and socioeconomic status, did not vary between groups (Table 1).

2.8 | Analytic plan

Before beginning our analyses using the valid data, we computed mean preference scores for each infant for each block of trials. These scores were computed by subtracting the proportion of time on the scrambled face (or scrambled flower) from the proportion of time on the intact face (or flower). A positive preference score therefore indicates a preference for the intact face (or flower), and a negative preference score indicates a preference for the scrambled face (or flower).

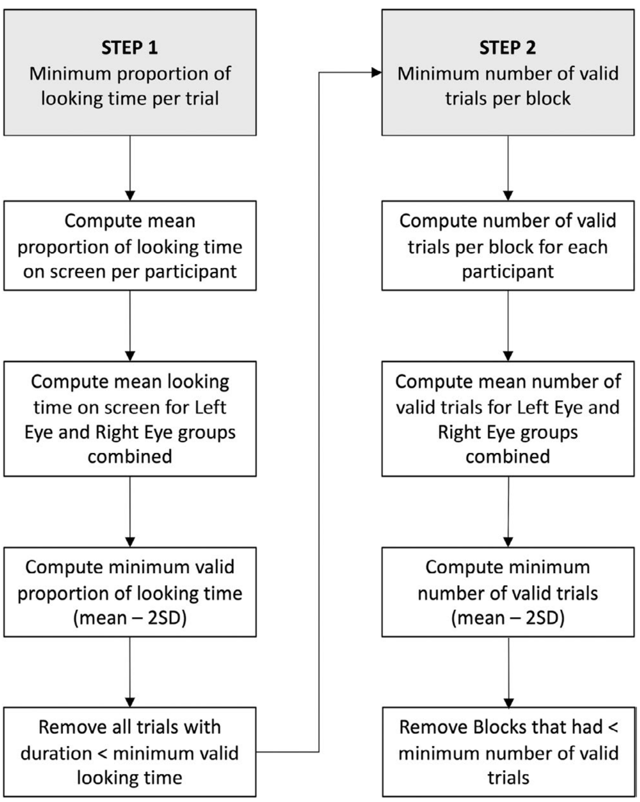

FIGURE 5 Data quality control procedures. *SD*, Standard Deviation

We explored looking behavior to intact versus scrambled faces and intact versus scrambled flowers separately using the following steps. We first explored whether there were differences between the Groups and whether there was a difference in preference scores from Block 1 to Block 2, which would indicate change in looking behavior over time. We did this by performing a 3x2 omnibus ANOVA with factors of Group (BIN vs. LEO vs. REO) and Block (Block 1 vs. Block 2), followed by Bonferroni-corrected comparisons to further investigate any main effects. Next, we explored whether each group's face preference score was different from chance (i.e., no preference), which would indicate a statistically significant preference for one stimulus over another (e.g., a preference for faces over scrambled faces). Because the omnibus ANOVA from our first analyses showed no main effect of Block, we collapsed across blocks and used one-sample *t* tests to compare each group's overall preference score to zero (i.e., chance). To account for multiple comparisons leading to possible family-wise Type I errors, we divided $\alpha = 0.05$ by 3, setting $\alpha = 0.017$.

3 | RESULTS

3.1 | Faces versus scrambled faces

Analyses were performed using face preference scores, which were computed by subtracting proportion of looking time on the scrambled face from proportion of looking time on the face. A positive preference score indicates a larger proportion of time spent looking at the face. Results are plotted in Figures 6 and 7.

One-hundred and thirty-six infants contributed data from two blocks of Face trials (BIN = 46, LEO = 42, REO = 48). Using data from these infants, we found a significant main effect of Group, F (2, 133) = 4.13, p = .018, η_p^2 = 0.06, but no main effect of Block, F (1,133) = 1.92, p = .168, η_p^2 = 0.02, and no Group by Block

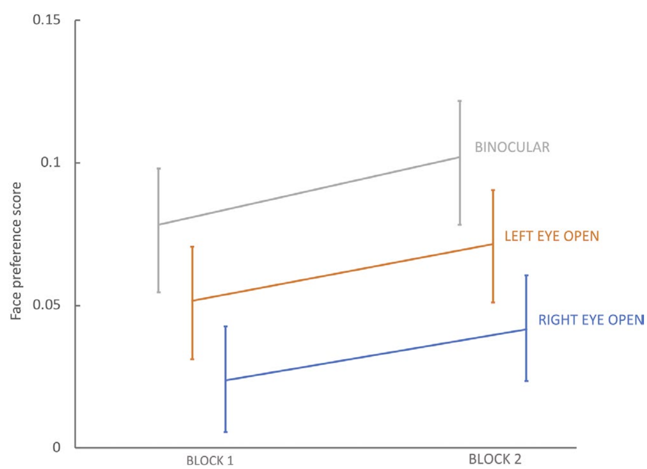

FIGURE 6 Face preference scores by Group and Block. Preference scores were computed by subtracting proportion of looking time on scrambled face from proportion of looking time on the intact face. A positive preference score indicates more time spent looking at the intact face. Error bars represent standard error

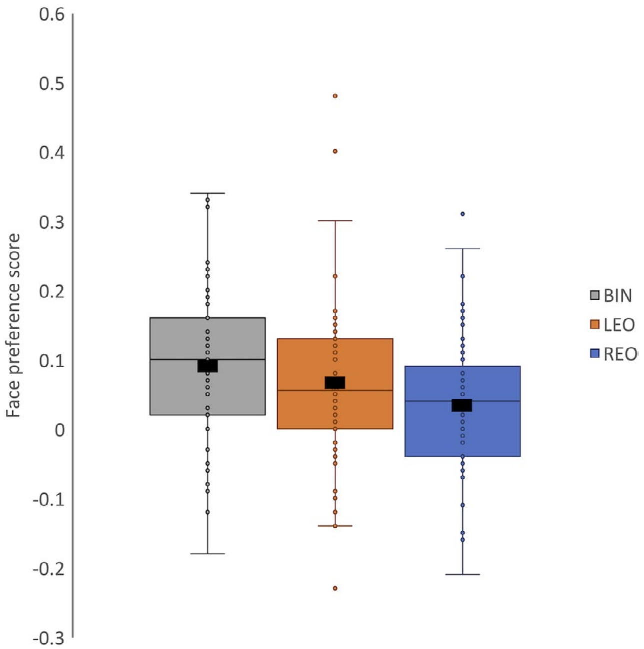

FIGURE 7 Individual face preference scores by Group. Boxes represent the interquartile range. Whiskers represent error, which is measured as 1.5 times the interquartile range. Horizontal lines within the boxes represent medians. Black rectangles represent the mean for each group. Each colored circle represents a different infant. Circles outside the whiskers represent outliers. Preference scores were computed by subtracting proportion of looking time on scrambled face from proportion of looking time on the intact face. A positive preference score indicates more time spent looking at the intact face

interaction, F (2,133) = 0.003, p = .997, η_p^2 = 0.00, see Figure 6. Because there was no main effect of Block and no Group by Block interaction, we ran a one-way ANOVA with factor of Group (BIN vs. LEO vs. REO). This allowed us to include data from an additional n = 24 infants who only contributed data from one block of trials. One hundred and sixty infants contributed at least one block of trials (BIN = 47, LEO = 60, REO = 53). Again, there was a significant main effect of Group F (2, 159) = 3.11, p = .047, η_p^2 = 0.04 (Figure 7). Bonferroni-corrected comparisons revealed that the BIN group had a larger overall preference score (i.e., larger preference for faces) than the REO group, p = .041, but did not differ from the LEO group, p = .583. The LEO group's overall preference score did not differ significantly from the REO group's overall preference score, p = .583. An additional analysis revealed the presence of a linear trend in the data such that face preference scores were highest for the BIN group, and lowest for the REO group, with the LEO group falling in between, F (1,159) = 6.22, p = .014, η_p^2 = 0.04. This trend is best observed in Figure 7.

The one-sample t tests (α = 0.017) comparing the mean face preference score from each group to chance (chance = 0.00) revealed that the BIN group had a significant preference for intact faces over scrambled faces, mean = 0.09, SD = 0.12; t (46) = 5.33, p < .001; d = 0.78, 95% CI [0.06–0.12]. Seventy-seven percent of BIN infants looked at the faces more than the scrambled faces. The LEO group also had a significant preference for faces over scrambled faces, mean = 0.06, SD = 0.12; t (59) = 3.93, p < .001; d = 0.51, 95% CI [0.03–0.09]. Seventy percent of LEO infants looked at the faces more than the scrambled faces. Using the corrected α = 0.017, the REO group did not have a significant preference for faces, mean = 0.03, SD = 0.10; t (52) = 2.37, p = .021, d = 0.33, 95% CI [0.01–0.06]. It is important to note, however, that this result would be considered statistically significant if the correction for multiple comparisons was not applied (i.e., if α = 0.05). Others have commented on the subjective nature of p-values (Ho, Tumkaya, Aryal, Choi, & Claridge-Chang, 2019; Wasserstein, Schirm, & Lazar, 2019) adding another level of complexity to this result. Overall, sixty-two percent of REO infants looked at the faces more than the scrambled faces.

In summary, the BIN group had the largest face preference score (0.09), followed by the LEO group (0.06). The BIN's preference score did not differ significantly from the LEO group's preference score, but was significantly greater than that of the REO group (0.03). This pattern was reflected by a significant linear trend. The LEO group's preference score did not differ significantly from the REO group's preference score. The BIN and LEO groups' preference for intact faces was significantly greater than chance, but the REO group's preference score was equivocal: the difference from chance was borderline.

3.2 | Flowers versus scrambled flowers

One-hundred and fifty-six infants contributed data from at least one block of Object trials (BIN = 47, LEO = 55, REO = 54). Results are plotted in Figure 8.

We performed a 3 × 2 omnibus ANOVA with factors of Group (BIN vs. LEO vs. REO) and Block (Block 1 vs. Block 2). There was

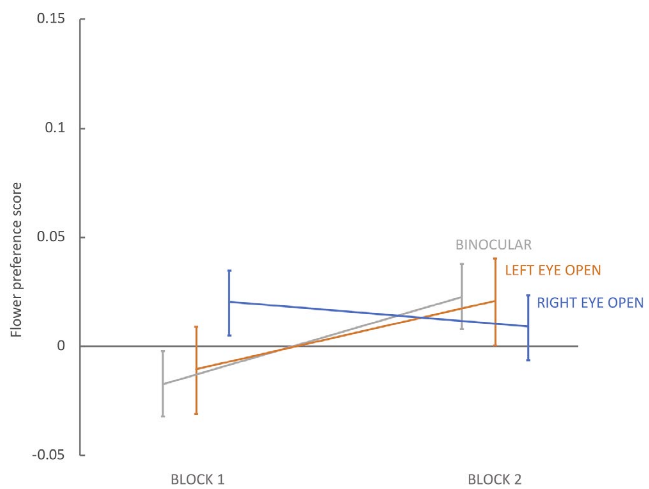

FIGURE 8 Flower preference scores by Group and Block. Preference scores were computed by subtracting proportion of looking time on scrambled flower from proportion of looking time on the intact flower. A positive preference score indicates more time spent looking at the intact flower. Error bars represent standard error

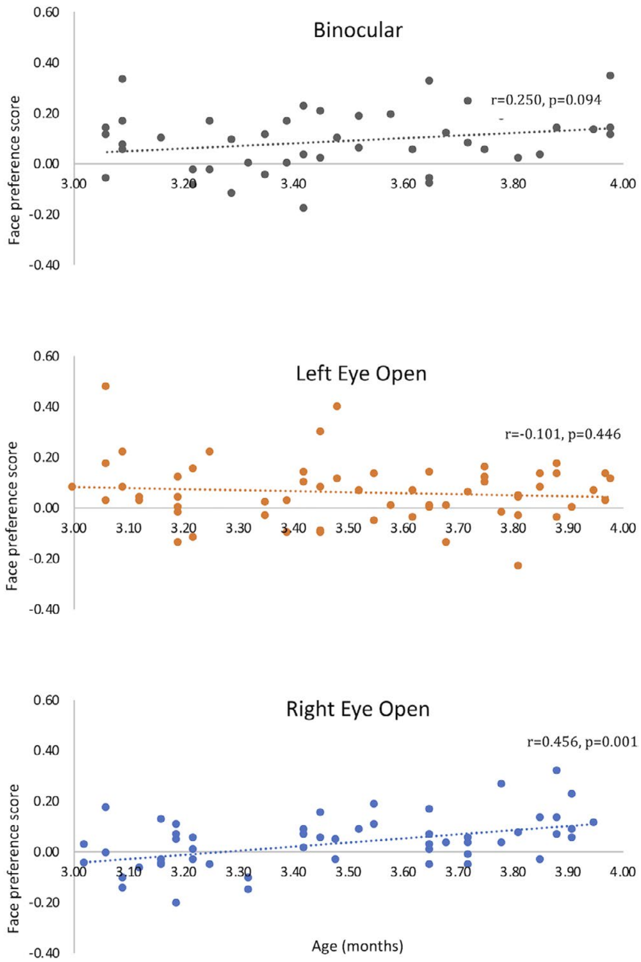

FIGURE 9 Correlations between face preference scores and age in months for each group, controlling for time on stimuli. Preference scores were computed by subtracting proportion of looking time on scrambled face from proportion of looking time on the intact face. A positive preference score indicates more time spent looking at the intact face

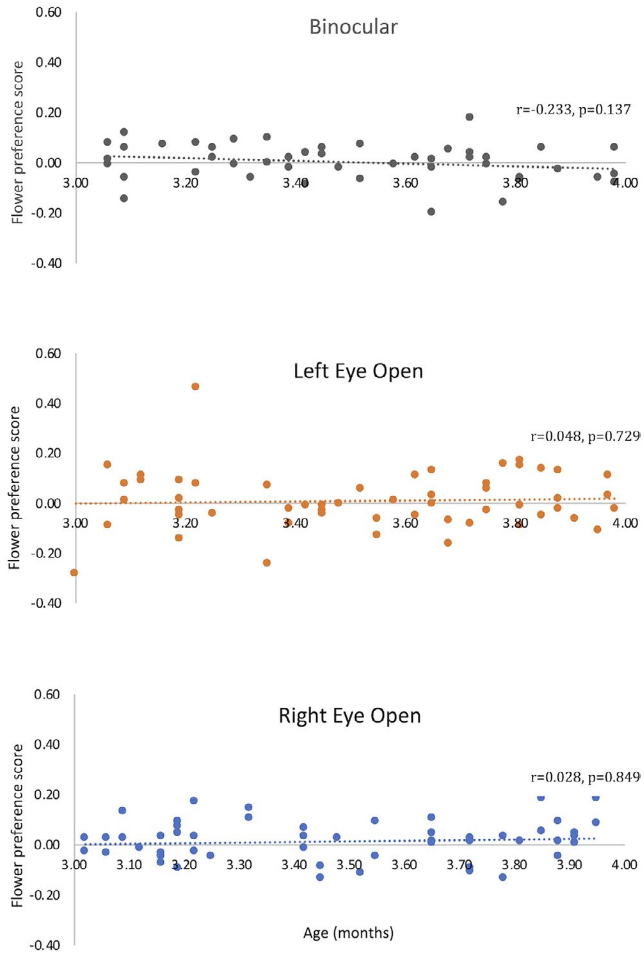

FIGURE 10 Correlations between flower preference scores and age in months for each group, controlling for time on stimuli. Preference scores were computed by subtracting proportion of looking time on scrambled flower from proportion of looking time on the intact flower. A positive preference score indicates more time spent looking at the intact flower

no main effect of Group ($p = .346$, $\eta_p^2 = 0.017$) or Block ($p = .053$, $\eta_p^2 = 0.031$) on flower preference scores, and no Group x Block interaction ($p = .057$, $\eta_p^2 = 0.046$).

One-sample *t* tests comparing the mean flower preference score from each group to chance ($\alpha = 0.017$) revealed that none of the groups preferred flowers over scrambled flowers, BIN mean = 0.00, $SD = 0.07$, $p = .798$, $d = 0.04$; LEO mean = 0.01, $SD = 0.11$, $p = .544$, $d = 0.08$; and REO mean = 0.01, $SD = 0.08$, $p = .226$, $d = 0.17$.

In summary, there were no differences between Groups or Blocks and no Group by Block interaction on flower trials. None of the groups showed a significant preference for intact flowers over scrambled flowers.

3.3 | Age effects

Given the gradual development of sensitivity to the nasal visual fields between 2 and 6 months of age (Lewis & Maurer, 1992), we investigated the relationship between face preference scores and age in our sample. Specifically, we were interested in examining whether the preference for faces in the right eye group increased with age, as older infants develop (or increase) the ipsilateral transfer of information from their right eye to their right hemisphere. We did not expect preference for faces to change with age for the left eye group who are already receiving contralateral input to their right hemisphere, but we reasoned that there may be an increase in preference for faces with age for the binocular group if there was an increase in information arriving from the right eye to the right hemisphere with age.

We first examined the relationship between preference for faces and age across all infants. We found a weak but significant positive correlation between face preference score and age, $r = .176$, $p = .026$, such that older infants had larger face preference scores than younger infants. This correlation was still significant when we performed a partial correlation, controlling for time spent on stimuli by setting Time On Stimuli as a covariate, $r = .173$, $p = .029$. This confirmed that the effect of age was not driven by older infants being more attentive to the stimuli in general. Next, we looked at the relationship between face preference score and age for each group. We again controlled for time on stimuli and found a moderate, significant positive correlation between face preference scores and age for the REO group, $r = .456$, $p = .001$, Figure 9. There was no relationship between preference for faces and age for the BIN group, $r = .250$, $p = .094$, or the LEO group, $r = -.101$, $p = .446$, and there was no relationship between preference for flowers and age for any of the groups: BIN $r = -.223$, $p = .137$; LEO, $r = .048$, $p = .729$; REO $r = .028$, $p = .849$ (see Figure 10).

To further investigate the relationship between age and face preference for our primary groups of interest (i.e., LEO and REO), we used age as a categorical variable and performed a 2 x 2 Group (LEO vs. REO) by Age (Younger vs. Older) ANOVA. “Younger” infants ($n = 57$) were 3.00- to 3.50-months-old, and “Older” infants ($n = 56$) were 3.51- to 3.99-month-old. We were specifically interested in determining whether there would be an interaction between Group and Age such that for Younger infants, the LEO group's face preference is significantly greater than that of the REO group, but for Older infants there is no difference between the LEO and REO groups’ face preference scores. Indeed, we found a significant Age by Group interaction, $F(3,112) = 8.15$, $p = .005$, $\eta_p^2 = 0.07$, but no main effect of Group, $F(1,112) = 1.60$, $p = .209$, $\eta_p^2 = 0.01$, or Age, $F(1,112) = 1.85$, $p = .117$, $\eta_p^2 = 0.02$ (see Figure 11). Independent samples *t*-tests confirmed that Younger LEO infants ($n = 29$) had significantly greater face preference scores than Younger REO infants ($n = 28$), $t(55) = 2.60$, $p = .012$, $d = 0.69$, but there was no difference between LEO infants ($n = 31$) and REO infants ($n = 25$) among the Older infants, $t(54) = -1.32$, $p = .193$, $d = 0.05$.

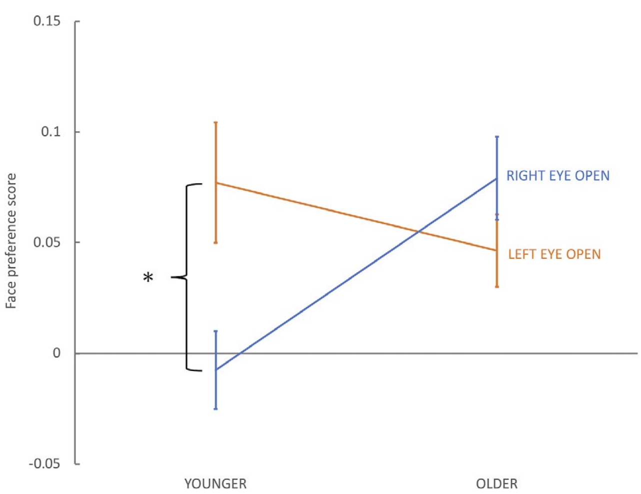

FIGURE 11 Face preference scores by Group and Age for the monocular viewing groups. Younger infants = 3.00 to 3.50 months; Older infants = 3.51 to 3.99 months. Preference scores were computed by subtracting proportion of looking time on scrambled face from proportion of looking time on the intact face. A positive preference score indicates more time spent looking at the intact face. Error bars represent standard error. $^*p < .015$

4 | DISCUSSION

Humans are born with a unique interest in faces. Individuals born with congenital cataracts on the left eye have been shown to have long-lasting face processing deficits, even when tested many years after the cataracts were removed, and with normal or corrected-to-normal vision (Le Grand et al., 2003). By contrast, individuals born with cataracts affecting the right eye only do not have face processing deficits. This points to the possibility that the left eye plays a special role in receiving visual information from faces early in life to promote the development of normal face processing. It also leads to a prediction that young infants viewing faces and scrambled faces through the left eye may prefer faces, while infants viewing these stimuli through the right eye only may not.

The authors of the unilateral cataract study (Le Grand et al., 2003) postulated that their results could be explained by the development of the visual system: because of the uneven development of sensitivity to the nasal versus temporal visual fields early in life (i.e., <6 months), visual information may enter each eye and go predominantly to the contralateral hemisphere of the brain (Lewis & Maurer, 1992), with underdeveloped crosstalk between visual hemispheres (Adibpour et al., 2018; Deruelle & de Schonen, 1995; Liégeois et al., 2000; Liégeois & de Schonen, 1997; de Schonen & Mathivet, 1990). Given that face processing is especially dependent on the right hemisphere (Barton et al., 2002; De Renzi et al., 1994; Kanwisher et al., 1997; McCarthy et al., 1997; Rangarajan et al., 2014; Rossion, 2008; Rossion et al., 2000; Schalk et al., 2017), the left eye would thus be critical to processing information about faces. Consistent with this hypothesis, the present study suggests that input to the left eye is sufficient to promote a face preference at an early age: infants using their left eye to view the stimuli, either binocularly or with their left eye only, preferred faces over scrambled faces. This preference was equivocal in infants using their right eye only.

Interpretation of our results is not straightforward. Although it is clear that the left eye alone is sufficient to support preferential looking at faces, there was no significant difference in mean face preference scores between infants viewing the stimuli with only their left eye and infants viewing the stimuli with only their right eye. Had this difference existed, we would have found compelling support for the hypothesis that the left eye plays a special role in face processing at 3 months of age. However, our additional analyses suggest that age may have obfuscated differences between groups. The Lewis and Maurer (1992) study showed steady development of sensitivity to the nasal visual fields from 2 to 6 months of age. These findings suggest that ipsilateral transfer of information from the eyes to the brain should increase with age. Applied to the present study, information about faces seen in the right eye only group should be more likely to reach the face-sensitive right hemisphere in older infants than younger infants. In support of this hypothesis, our age analyses revealed a positive relationship between preference for faces and age for infants viewing the stimuli with only their right eye, but not for infants viewing the stimuli with only their left eye or binocularly. In fact, when we looked exclusively at the younger half of the right eye group (3.00- to 3.50-months-old, n = 28), we found that less than half (46%) of these infants preferred faces over scrambled faces (i.e., face preference score >0). This is in contrast to 64% of the younger infants from the binocular group (n = 25) and 69% of the younger infants from the left eye open group (n = 29). When we compared younger infants viewing the stimuli with their left eye to younger infants viewing stimuli with their right eye, the infants viewing the stimuli with their left eye preferred faces significantly more than infants viewing the faces with their right eye – a finding that is consistent with our primary hypothesis. This difference disappeared when comparing older infants (i.e., 3.51- to 3.99-months-old) using their left eye to older infants using their right eye. Inspection of the means indicate that this difference disappeared because the face preference for the right eye group caught up to the face preference for the left eye group. Taken together, these analyses suggest an important effect of age for the right eye group only, possibly reflecting the addition (or strengthening) of ipsilateral signals from the right eye to the right hemisphere from 3 to 4 months of age. Future studies could follow up these findings in more depth by using a longitudinal design to test younger infants and measure change in looking behavior with development.

Our study is not the first to investigate monocular viewing of face stimuli in infancy. In a study of face processing in newborns, researchers presented infants (mean age 74 hr) with static face-like patterns and non-face patterns in either the temporal visual field or the nasal visual field (Simion, Valenza, Umiltà, & Dalla Barba, 1998). As in the current study, infants viewed the stimuli monocularly. Unlike the current study, the authors found no effect of eye. They did, however, find an interaction between stimulus and visual field such that infants were more likely to orient to the face-like patterns than non-face patterns when they were presented in the temporal visual field, but showed no such difference in the nasal visual field. The authors concluded that this supports the predominant role of a subcortical visual pathway early in life because the subcortical (retinotectal) system is thought to have greater input from the temporal visual field. This is consistent with the hypothesis that cortical visual processing emerges around 2 months of age (Johnson, 1990). Thus, the lack of effect of eye in newborns may be related to the lack of cortical input at this age.

Johnson, Farroni, Brockbank, and Simion (2000) repeated this experiment with 4- to 5-month-old infants using upright and inverted schematic faces. They too found no difference between infants viewing the stimuli with their left or right eye, but they also found no preference for the face over the inverted face in either visual field. Interestingly, they found a preference for the inverted faces in the nasal visual field. The authors suggest that by 4 months of age infants may develop a novelty preference that supersedes their face preference. In the present study, we may have hit that crucial period in development where visual processing is cortical, and infants still have a preference for faces over novel stimuli. In the future, we could test face preference monocularly in 3-month-olds, but present the stimuli to either the temporal or nasal visual fields, as in the Simion et al. (1998) and Johnson et al. (2000) studies. We would predict that infants viewing stimuli with their left eye would prefer the faces over the scrambled faces when those stimuli are shown in the temporal visual field, which is processed by the right hemisphere of the brain, but not the nasal visual field, which is processed by the left hemisphere. Based on the results of the present study, we would expect that infants viewing the stimuli with their right eye would not show a preference for faces regardless of visual field.

Our study was designed to test for differential contributions of the left eye and right eye in early face preferences, but it was not designed to test the mechanisms behind any differences. How could these mechanisms be tested more directly in future? One approach would involve showing infants intact faces and scrambled faces while they view the stimuli binocularly, with only their left eye, or with only their right eye, while recording event-related potentials (ERP). Previous research has found a negative component around 290 ms (N290) and a positive component around 400 ms (P400) in infants who respond in a special way to faces. One study found a differential response to human faces compared to monkey faces around 270 ms and a P400 that was larger for upright than inverted faces in 6-month-old infants (de Haan, Pascalis, Johnson, 2002). Gliga and Dehaene-Lambertz (2005) found increased amplitude of the P400 in response to intact compared to scrambled faces in 3-month-olds. This effect may vary by hemisphere: one study found a greater P400 response to unfamiliar than familiar faces in the right hemisphere of 9-month-olds (Scott, Shannon, & Nelson, 2006). These components could be investigated in young infants viewing faces and scrambled faces with the left eye or the right eye or both. If the left eye has a special role for interest in faces early in development, we would expect to see face-specific responses in the right hemisphere when stimuli are viewed binocularly or only with the left eye, but not when viewed with the right eye only.

In summary, the present study tested the prediction that young infants viewing intact faces and scrambled faces through the left eye will prefer intact faces, while infants viewing these stimuli through the right eye only will not. We found some support for this hypothesis: a group of 3-month-old infants viewing the stimuli with their left eye, either binocularly or with their left eye only, showed a significant preference for faces, but this preference was less clear in infants viewing the stimuli with their right eye. This suggests that the input to the left eye is sufficient to support a face preference. There was no significant difference in the magnitude of the face preference scores between infants viewing the stimuli through the left eye only versus the right eye only. However, age seemed to play a factor: although the preference for faces was consistent across age for infants viewing the stimuli with only their left eye or binocularly, the preference for faces in infants viewing stimuli through only their right eye increased with age. This may indicate that ipsilateral transfer of information from the right eye to the right hemisphere strengthens between 3 and 4 months of age. Future research could examine the role of each eye for face preferences longitudinally, in younger age groups, and/or use ERP to more directly evaluate the transfer of information from each eye to the visual hemispheres of the brain.

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CONFLICT OF INTEREST

The authors have no conflict of interest to report.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ENDNOTE

[1] This experiment was originally designed to be an eye-tracking study, but after numerous failed attempts to reliably record gaze position with different types of glasses, lenses, and eye patches, we decided to manually code screen-mounted video recordings.

REFERENCES

Adibpour, P., Dubois, J., & Dehaene-Lambertz, G. (2018). Right but not left hemispheric discrimination of faces in infancy. *Nature Human Behaviour*, *2*(1), 67–79. https://doi.org/10.1038/s41562-017-0249-4

Barton, J. J. S., Press, D. Z., Keenan, J. P., & O'Connor, M. (2002). Lesions of the fusiform face area impair perception of facial configuration in prosopagnosia. *Neurology*, *58*(1), 71–78. https://doi.org/10.1212/WNL.58.1.71

Buiatti, M., Di Giorgio, E., Piazza, M., Polloni, C., Menna, G., Taddei, F., … Vallortigara, G. (2019). Cortical route for facelike pattern processing in human newborns. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(10), 4625–4630. https://doi.org/10.1073/pnas.1812419116

de Heering, A., & Rossion, B. (2015). Rapid categorization of natural face images in the infant right hemisphere. *eLife*, *4*(JUNE), 1–14. https://doi.org/10.7554/eLife.06564

De Renzi, E., Perani, D., Carlesimo, G. A., Silveri, M. C., & Fazio, F. (1994). Prosopagnosia can be associated with damage confined to the right hemisphere-An MRI and PET study and a review of the literature. *Neuropsychologia*, *32*(8), 893–902. https://doi.org/10.1016/0028-3932(94)90041-8

de Schonen, S., Gil De Diaz, M., & Mathivet, E. (1986). Hemispheric asymmetry in face processing in infancy. In H. D. Ellis, M. A. Jeeves, F. Newcombe, & A. Young (Eds.). *Aspects of Face Processing. NATO ASI Series (Series D: Behavioural and Social Sciences)* (Volume *28*, pp. 199–209). Dordrecht: Spinger.

de Schonen, S., & Mathivet, E. (1990). Hemispheric Asymmetry in a Face Discrimination Task in Infants. *Child Development*, *61*(4), 1192–1205. https://doi.org/10.1111/j.1467-8624.1990.tb02853.x

Deruelle, C., & de Schonen, S. (1995). Pattern processing in infancy: Hemispheric differences in the processing of shape and location of visual components. *Infant Behavior and Development*, *18*(2), 123–132. https://doi.org/10.1016/0163-6383(95)90042-X

Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' preference for face-relevant stimuli: Effects of contrast polarity. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(47), 17245–17250. https://doi.org/10.1073/pnas.0502205102

Frank, M. C., Vul, E., & Johnson, S. P. (2010). Development of infants' attention to faces during the first year of life. *Cognition*, *110*(2), 160–170. https://doi.org/10.1016/j.cognition.2008.11.010.Development

Goren, C., Sarty, M., & Wu, P. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*, *56*(4), 544–549.

Ho, J., Tumkaya, T., Aryal, S., Choi, H., & Claridge-Chang, A. (2019). Moving beyond P values: Data analysis with estimation graphics. *Nature Methods*, *16*(7), 565–566. https://doi.org/10.1038/s41592-019-0470-3

Honda, Y., Nakato, E., Otsuka, Y., Kanazawa, S., Kojima, S., Yamaguchi, M. K., & Kakigi, R. (2010). How do infants perceive scrambled face?: A near-infrared spectroscopic study. *Brain Research*, *1308*, 137–146. https://doi.org/10.1016/j.brainres.2009.10.046

Johnson, M. (1990). Cortical maturation and the development of visual attention in early Infancy. *Journal of Cognitive Neuroscience*, *2*, 81–95. https://doi.org/10.1162/jocn.1990.2.2.81

Johnson, M., Dziurawiec, S., Ellis, H. D., & Morton, J. (1991). Newborn preferential tracking of faces and its subsequent decline. *Cognition*, *40*, 1–19. https://doi.org/10.1016/0010-0277(91)90045-6

Johnson, M., Farroni, T., Brockbank, M., & Simion, F. (2000). Preferential orienting to faces in 4-month-olds: Analysis of temporal-nasal visual field differences. *Developmental Science*, *3*(1), 41–45. https://doi.org/10.1111/1467-7687.00097

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience*, *17*(11), 4302–4311. Retrieved from http://f1000.com/717989828. https://doi.org/10.1523/JNEUROSCI.17-11-04302.1997

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2001). Early visual experience and face processing. *Nature*, *410*(6831), 890. https://doi.org/10.1038/35073749

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2003). Expert face processing requires visual input to the right hemisphere during infancy. *Nature Neuroscience*, *6*(10), 1108–1112. https://doi.org/10.1038/nn1121

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2004). Impairment in holistic face processing following early visual deprivation. *Psychological Science : A Journal of the American Psychological Society / APS*, *15*(11), 762–768. https://doi.org/10.1111/j.0956-7976.2004.00753.x

Lewis, T. L., & Maurer, D. (1992). The development of the temporal and nasal visual fields during infancy peripheral vision temporal nasal development static perimetry infants. *Vision Research*, *32*(5), 903–911. https://doi.org/10.1016/0042-6989(92)90033-F

Liégeois, F., Bentejac, L., & de Schonen, S. (2000). When does inter-hemispheric integration of visual events emerge in infancy? A developmental study on 19- to 28-month-old infants. *Neuropsychologia*, *38*(10), 1382–1389. https://doi.org/10.1016/S0028-3932(00)00041-5

Liégeois, F., & de Schonen, S. (1997). Simultaneous attention in the two visual hemifields and interhemispheric integration: A developmental study on 20- to 26-month-old infants. *Neuropsychologia*, *35*(3), 381–385. https://doi.org/10.1016/S0028-3932(96)00078-4

Macchi Cassia, V., Turati, C., & Simion, F. (2004). Can a nonspecific bias toward top-heavy patterns explain newborns' Face preference? *Psychological Science*, *15*(6), 379–383. https://doi.org/10.1111/j.0956-7976.2004.00688.x

McCarthy, G., Puce, A., Gore, J., & Truett, A. (1997). Face-specific processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, *9*(5), 605–610. https://doi.org/10.1162/jocn.1997.9.5.605

Ostrovsky, Y., Andalman, A., & Sinha, P. (2006). Vision following extended congenital blindness. *Psychological Science*, *17*(12), 1009–1014. https://doi.org/10.1111/j.1467-9280.2006.01827.x

Otsuka, Y., Nakato, E., Kanazawa, S., Yamaguchi, M. K., Watanabe, S., & Kakigi, R. (2007). Neural activation to upright and inverted faces in infants measured by near infrared spectroscopy. *NeuroImage*, *34*(1), 399–406. https://doi.org/10.1016/j.neuroimage.2006.08.013

Rangarajan, V., Hermes, D., Foster, B. L., Weiner, K. S., Jacques, X. C., Grill-Spector, K., & Parvizi, J. (2014). Electrical stimulation of the left and right human fusiform gyrus causes different effects in conscious face perception. *Journal of Neuroscience*, *34*(38), 12828–12836. https://doi.org/10.1523/JNEUROSCI.0527-14.2014

Robbins, R. A., Nishimura, M., Mondloch, C. J., Lewis, T. L., & Maurer, D. (2010). Deficits in sensitivity to spacing after early visual deprivation in humans: A comparison of human faces, monkey faces, and houses. *Developmental Psychobiology*, *52*(8), 775–781. https://doi.org/10.1002/dev.20473

Roder, B., Ley, P., Shenoy, B. H., Kekunnaya, R., & Bottari, D. (2013). Sensitive periods for the functional specialization of the neural system for human face processing. *Proceedings of the National Academy of Sciences*, *110*(42), 16760–16765. https://doi.org/10.1073/pnas.1309963110

Rossion, B. (2008). Constraining the cortical face network by neuroimaging studies of acquired prosopagnosia. *NeuroImage*, *40*(2), 423–426. https://doi.org/10.1016/j.neuroimage.2007.10.047

Rossion, B., Dricot, L., Devolder, A., Bodart, J.-M., Crommelinck, M., De Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience*, *12*(5), 793–802. https://doi.org/10.1162/089892900562606

Schalk, G., Kapeller, C., Guger, C., Ogawa, H., Hiroshima, S., Lafer-Sousa, R., … Kanwisher, N. (2017). Facephenes and rainbows: Causal evidence for functional and anatomical specificity of face and color processing in the human brain. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(46), 12285–12290. https://doi.org/10.1073/pnas.1713447114

Scott, L. S., Shannon, R. W., & Nelson, C. A. (2006). Neural correlates of human and monkey face processing in 9-month-old infants. *Infancy*, *10*(2), 171–186. https://doi.org/10.1207/s15327078in1002_4

Simion, F., Macchi Cassia, V., Turati, C., & Valenza, E. (2001). The Origins of Face Perception: Specific Versus Non-specific Mechanisms. *Infant and Child Development*, *10*(1–2), 59–65. https://doi.org/10.1002/icd.247

Simion, F., Valenza, E., Umiltà, C., & Dalla Barba, B. (1998). Preferential Orienting to Faces in Newborns: A Temporal-Nasal Asymmetry. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(5), 1399–1405. https://doi.org/10.1037/0096-1523.24.5.1399

Tzourio-Mazoyer, N., de Schonen, S., Crivello, F., Reutter, B., Aujard, Y., & Mazoyer, B. (2002). Neural correlates of woman face processing by 2-month-old infants. *NeuroImage*, *15*(2), 454–461. https://doi.org/10.1006/nimg.2001.0979

Valenza, E., Simion, F., Macchi Cassia, V., & Umiltà, C. (1996). Face Preference at Birth. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(4), 892–903. https://doi.org/10.1037/0096-1523.22.4.892

Wasserstein, R. L., Schirm, A. L., & Lazar, N. A. (2019). Moving to a World Beyond "p < 0.05". *American Statistician*, *73*(sup1), 1–19. https://doi.org/10.1080/00031305.2019.1583913

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