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Own- and Other-Race Face Scanning in Infants: Implications for Perceptual Narrowing

ABSTRACT: *The present study investigated how 6- and 9-month-old Caucasian infants scan Caucasian and Chinese dynamic faces using eye-tracking methodology. Analyses of looking times revealed that with increased age, infants decreased their looking time to other-race noses, while maintaining their looking time for own-race noses. From 6 to 9 months, infants increased their looking time for the eyes of both races of faces. Analyses of scan paths showed that infants were no more likely to shift their fixation between the eyes of own-race faces than other-race faces. Similarity between participants' scan paths suggested that facial information was collected more efficiently for own- versus other-race faces at 9 months of age. Combined with previous eye-tracking studies of infants' face scanning (Liu et al. [2011] Journal of Experimental Child Psychology, 108, 180–189; Wheeler et al. [2011] PLoS ONE, 6, e18621. doi: 10.1371/journal.pone.0018621; Xiao et al. [2013] International Journal of Behavioral Development, 37, 100–105), the findings are interpreted in the context of perceptual narrowing and suggest differential contributions of visual experience, facial physiognomy, and culture in accounting for similarity and difference in infants scanning of own- and other-race faces.* Dev Psychobiol 56: 262–273, 2014.

Keywords: *face scanning; perceptual narrowing; eye-tracking; infancy*

INTRODUCTION

During the first year of life, infants' face recognition follows a developmental trajectory referred to as "perceptual narrowing" (Nelson, 2001; Scott, Pascalis, & Nelson, 2007; Slater et al., 2010). Three-month-olds discriminate between faces from within different ethnic groups; however, 9-month-olds can only do so with faces from their own ethnic group (Kelly et al., 2007, 2009). This phenomenon reflects the transition of infants' face recognition from broad discrimination abilities at an early age to more focal discrimination abilities at older ages of infancy. Evidence for perceptual narrowing has been robustly demonstrated for faces of different species and different races. However, there have been few efforts to investigate whether infants also show differential scanning of own- and other-race faces. The goal of the current study was to examine how perceptual narrowing might be manifested in the form of differential visual scanning patterns for own- versus other-race faces.

The other-race effect (ORE) refers to the finding that faces from other racial groups with which individuals have little experience are more difficult to recognize compared to own-race faces (for a review and discussion, see Hugenberg, Young, Bernstein, & Sacco, 2010; Meissner & Brigham, 2001). Research with adults has documented that face-specific behavioral effects commonly found with own-race faces are less evident for other-race faces; for example, the composite face effect (Michel, Caldara, & Rossion, 2006), the inversion effect (Balas & Nelson, 2010), and the part–whole effect (Tanaka, Kiefer, & Bukach, 2004). Using eye-tracking methodology, it has been shown that adults focus on different features of own- versus other-race faces (Fu, Hu, Wang, Quinn, & Lee, 2012).

Differential responding to own- versus other-race faces has been traced to infancy (Lee, Anzures, Quinn,

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Pascalis, & Slater, 2011; Quinn et al., 2013). Developmental changes in infants' abilities to recognize own- versus other-race faces have been examined using a visual paired-comparison (VPC) task. In a typical VPC study of face recognition, a single face is presented to infants until they have accumulated some amount of time viewing it. Then the infant is presented with two faces, one of which matches the first stimulus, the other of which is a new face belonging to the same category as the original stimulus. If longer looking is recorded for the novel face relative to the familiar face, it is inferred that infants are able to discriminate between the two individuals within this particular face category, whereas an absence of differential responding is consistent with a lack of discrimination ability. Using the VPC task, Sangrigoli and de Schonen (2004) demonstrated that 3-month-old Caucasian infants exhibited an ORE, although their ORE was rather fragile and was readily eliminated after infants were exposed to a few exemplars of other-race faces. Consistent with this finding, Kelly et al. (2007) have shown that the ORE may not be robust until 9 months of age. They showed that Caucasian 3-month-olds are able to discriminate and recognize faces from within own- and various other-race categories. Caucasian 6-month-olds exhibited an ORE for Pakistani and African faces, but not for Chinese faces. Caucasian 9-month-olds, however, consistently showed no evidence of discriminating even Chinese other-race faces, suggesting that the ORE is well developed by 9 months of age. A similar pattern of results has been found with Chinese infants (Kelly et al., 2009) for Chinese faces as opposed to Caucasian and African faces.

Although the ORE emerges early in life, recent studies have demonstrated that the ORE is readily modifiable given sufficient exposure to other-race faces during infancy. Exposing Caucasian infants to Chinese faces via picture books between 6 and 9 months of age is sufficient to preserve recognition abilities for Chinese faces at 9 months of age (Heron-Delaney et al., 2011). Several weeks of brief daily experiences with dynamic Chinese faces beginning at 8 months of age can even reverse the effects of perceptual narrowing in Caucasian infants, as indicated by improved recognition and encoding for Chinese faces after the daily exposures (Anzures et al., 2012). Thus, perceptual exposure, if it occurs prior to or even slightly after the tuning period for specialization, appears to be effective in preventing or even reversing the effects of perceptual narrowing.

Whereas these previous studies provide valuable insight into the development and remediation of perceptual narrowing, relatively little is known about how infants visually process own- and other-race faces, although one study suggests that Caucasian 8-month-olds process own-race faces holistically, but other-race faces featurally (Ferguson, Kulkofsky, Cashon, & Casasola, 2009). Moreover, unlike prior studies that have relied on global looking-time measures of infant performance, recent eye-tracking studies provide a more fine-grained understanding of the specific aspects of own- and other-race faces to which infants differentially attend (Gaither, Pauker, & Johnson, 2012; Liu et al., 2011; Wheeler et al., 2011; Xiao, Xiao, Quinn, Anzures, & Lee, 2013). For example, Wheeler et al. (2011) reported that during the period of perceptual narrowing, Caucasian infants developed different strategies for scanning own- versus other-race faces. Between 6 and 10 months, and consistent with the upper region processing bias (Quinn & Tanaka, 2009; Simion, Valenza, Cassia, Turati, & Umilta, 2002), their fixations on the eyes of own-race Caucasian faces increased, while fixations on the mouths of these faces decreased. In contrast, the amount of time spent fixating on these areas of other-race African faces did not change. Liu et al. (2011) examined how Chinese infants scanned own-race Chinese and other-race Caucasian faces and found that fixation time on the Chinese eyes and nose did not change, whereas fixation time on the Caucasian nose decreased with age in 4- to 9-month-olds. These results collectively suggest that the behavioral decline in face recognition ability for other-race faces in Chinese infants coincides with a decline in fixation on the center (i.e., the nose) of other-race faces (Liu et al., 2011), whereas advanced recognition ability for own-race faces in Caucasian infants occurs at the same time as increased fixation on the eyes of own-race faces (Wheeler et al., 2011; Xiao et al., 2013).

Infants' differential scanning patterns for own- versus other-race faces might relate to the role of experience in their developing face expertise. The growing evidence in perceptual narrowing converges to suggest that accumulating experience with a particular face type and a lack of experience with other face types result in different cross-race face processing abilities. This experientially based perceptual narrowing process is also observed in the language domain (Werker & Tees, 1999) and evidenced at the neural level via differential event-related potential responses to familiarized and novel monkey faces in 9-month-olds as opposed to familiarized and novel human faces (Scott, Shannon, & Nelson, 2006). In Valentine's face space account of the ORE, the face processing system is gradually tuning into the features that maximize discrimination of own-race faces, but not necessarily other-race faces (Valentine, 1991). With more experiences with own-race faces, infants' visual processing follows an optimization procedure of focusing on particular facial features that may contribute to more advanced recognition ability for those faces.

However, the existing evidence from infants is insufficient to draw a firm conclusion about the changes in scanning between 6 and 9 months that may underlie perceptual narrowing or that may be reinforced by the emergence of perceptual narrowing. This is because Liu et al. (2011) and Wheeler et al. (2011) used different own- and other-race faces (e.g., Caucasian and Chinese faces for Chinese infants vs. Caucasian and African faces for Caucasian infants). Presenting Caucasian and Chinese faces to Caucasian infants, which is currently lacking in the literature, would be comparable to the design of Liu et al. (2011). The present study aimed to fill this gap in the literature so as to achieve a better understanding about the possible relation between perceptual narrowing and infants' face scanning. We will also consider how the findings are relevant to understanding the differential contributions of culture, facial physiognomy, and visual experience to infant scanning patterns in accord with the rationale specified at the outset of the Discussion Section.

In the present study, we collected eye-tracking data from Caucasian 6- and 9-month-old infants while viewing own- and other-race Chinese dynamic faces. The procedure and stimuli were the same as in Liu et al. (2011) except that they tested Chinese infants between 4 and 9 months with age as a continuous variable. In the current study, there were two separate age groups in which the age ranges were relatively wide. A multi-method approach was used to analyze the eye-tracking data. The first approach used an area of interest (AOI) analysis to determine where infants look when presented with own- and other-race faces. Face stimuli were partitioned into AOIs which covered the main features including eyes, nose, and mouth. We specifically compared fixation durations for each featural AOI between own- and other-race faces at 6 and 9 months of age. The current data can be compared with previous research on infants' visual scanning of own- and other-race faces (Liu et al., 2011; Wheeler et al., 2011).

A second approach was the ScanPath analysis which focused on how infants shift their fixation between AOIs. We computed the frequency of eye movement shifts between the key features within each face, specifically, the scan paths between the eyes, the eyes and mouth, the eyes and nose, the nose and mouth, and the internal and external features. Then, the frequency of these scan paths were compared for own- versus other-race faces. While Gaither et al. (2012) reported that the number of visual transitions between the eye and mouth regions did not differ across face race (Caucasian vs. Chinese) in Caucasian and Asian infants at 3 months of age, Xiao et al. (2013) showed that 6- and 9-month-old Caucasian infants shifted between the eyes of own-race Caucasian faces more frequently than they did for other-race African faces. The current data would identify similarities and differences regarding the specific routes of fixation shifts between the facial features when 6- and 9-month-old Caucasian infants scan own- and other-race Chinese faces.

A third approach was the ScanMatch analysis that quantified similarities of scan paths between participants. According to Kato and Konishi (2013), the similarity of participants' scan paths provides a measure of how efficiently facial information is collected during eye movements. As participants' scan paths simplify to the most efficient path, it is reasonable to assume that their scan paths become more likely to resemble each other. Kato and Konishi (2013) found that scan paths for upright own-race faces were more similar between participants than for inverted own-race faces and such difference developed with increased age from 6 to 14 months of age. When comparing the path similarity of scanning own- and other-race faces, we hypothesized that the similarity index would be higher for own-race faces than for other-race faces with increased age.

METHOD

Participants

Participants included in the analyses consisted of 17 Caucasian 6-month-olds ($M = 169$ days, $SD = 27.80$, range: 131–210 days) and 20 Caucasian 9-month-olds ($M = 280$ days, $SD = 26.08$, range: 238–324 days). All were healthy and full-term infants, recruited through mailed letters sent to parents in the community. All parents reported that the infants had no regular exposure to Chinese individuals (i.e., parents did not have close family or friends of other ethnicities with whom their children had frequent contact). An additional 18 infants were excluded due to fussiness/crying ($n = 4$), failure to complete the whole session ($n = 2$), or because parents were non-Caucasian or mixed race ($n = 12$).

Stimuli

The stimuli consisted of six videos of female adult faces (three Caucasian and three Chinese faces), which were the same as those used in Liu et al. (2011). Female faces were used because previous studies have shown that infants tend to show greater responsiveness to female than to male faces, likely due to the fact that most primary caregivers are female (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). Each video featured an adult female looking directly into the camera with a neutral expression while counting upwards for 30 s. The video recordings presented were silent. Dynamic videos, as opposed to photo images, were shown because infants are more attentive to dynamic video images (Otsuka et al., 2009). The resolution for all videos was 640 × 480 pixels.

Procedure

Parents were informed of the purpose of the study prior to providing written consent for their child to participate. Infants were secured in a car seat that was placed in a three-quarter, semi-reclining position beneath a 21-in. monitor with an integrated Tobii 2150 eye tracker. The sampling rate of the eye tracker was 50 Hz and the screen resolution was 800 × 600. The eye-tracking screen was positioned at an angle parallel to the incline of the infant with a viewing distance of 60 cm. An experimenter sat behind the infant to adjust the position of the car seat during the calibration procedure.

Calibration trials occurred prior to viewing experimental stimuli for all infants. During the calibration, infants saw a cartoon character sequentially pop up at five locations across the screen: the four corners and the center. If insufficient data were collected during the initial calibration, then the same calibration procedure was repeated until successful, or for up to four failed attempts. After the calibration procedure, each infant saw two videos, one featuring an own-race face and the other featuring an other-race face. The particular face presented to participants was randomly selected from the three exemplars in each race category. The order of the two videos was counterbalanced across infants. Each video clip was 30 s in length.

Data Analysis

The eye-tracking data were collected using Tobii ClearView software. Fixations were defined as looking at a spot with a minimum radius of 30 pixels for at least 100 ms. We used a multi-method approach to analyze the eye-tracking data, including Areas of Interest (AOI), ScanPath, and ScanMatch analyses. In the AOI analysis, five AOIs were designated: left eye, right eye, nose, mouth, and the rest of the face area minus these facial features (see Fig. 1 for an example). Eyebrow was included into the eye AOI because it is known to be diagnostic of identity and important for face recognition (Sadr, Jarudi, & Sinha, 2003). The drawings of the AOIs on each face stimulus were identical across the current study and Liu et al. (2011). There were individual differences in terms of the size of each AOI across the three Caucasian and three Chinese faces. However, the mean pixels of the corresponding AOI were virtually identical between Caucasian and Chinese faces (Tab. 1). Proportional fixation duration for each area relative to the overall on-face looking time was calculated and compared across face race and age group. Since we aimed to test the effect of face race and age group on the fixation times within each AOI instead of comparing fixation times across AOIs, we did not adjust the proportion of looking time based on the relative size of each AOI.

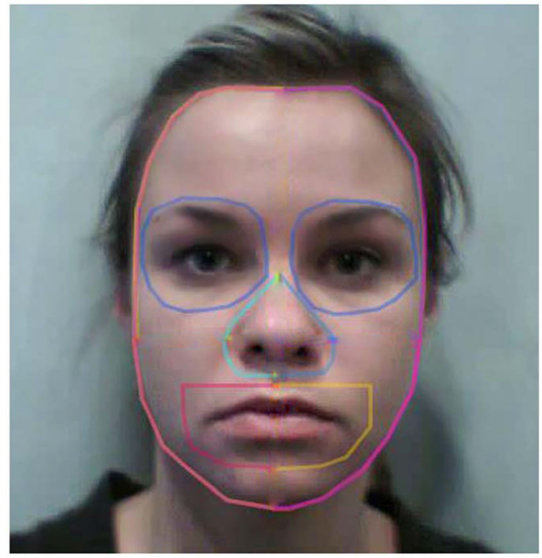

FIGURE 1 Example area of interest (AOI) plots.

The second analytic procedure was a ScanPath analysis that examined how frequently infants shifted their fixation between particular facial features. Fixation shifts were categorized into five different paths among the five AOIs. They consisted of shifts between the eyes, the eyes and nose, the eyes and mouth, the nose and mouth, and the internal features and external features. The number of times participants shifted from one AOI area to another was recorded for own- and other-race faces and then compared to examine any

Table 1. Mean Area in Pixels^2 and (SD) of Each AOI for Caucasian and Chinese Faces Used in the Current Study and in Liu et al. (2011)

	Mean Area (Pixels^2)	
AOI	Caucasian Faces	Chinese Faces
Whole face, hair, and neck	96147.17 (1577.39)	91986.67 (9475.7)
Eyes	15014.83 (694.24)	11620.83 (1525.64)
Left eye	7443.17 (261.53)	5936.00 (1033.64)
Right eye	7571.67 (473.80)	5684.83 (532.48)
Nose	5086.17 (262.22)	4078.67 (650.37)
Mouth	7448.17 (742.30)	5436.83 (614.90)
Hair and neck	28724.50 (2703.63)	40576.17 (12201.89)

potential similarities or differences during infants' scanning of the faces.

The third approach was a ScanMatch analysis which investigates the similarity between participants' scan paths (Cristino, Mathot, Theeuwes, & Gilchrist, 2010). ScanMatch bins a fixation sequence both spatially and temporally, and transforms this information into a sequence of letters that represent the location, duration, and order of the fixation. The letter sequences of two sets of eye movements are then compared to each other and a similarity score is calculated based on the Needleman–Wunsch algorithm that is commonly used to compare DNA sequences. After normalization, a similarity score close to 1.0 indicates that the two sequences of eye movements are highly similar spatially and temporally. The current study used ScanMatch analysis to compare each infant's eye movement sequence with the sequences of every other infant within the same age group. Since each infant had two fixation sequences that were collected during the presentation of Caucasian and Chinese faces, only sequences for viewing the same type of stimuli (Caucasian faces or Chinese faces) were matched between infants. In other words, our analysis produced average similarity scores as a function of age and face race.

RESULTS

Preliminary analyses revealed no significant effect of infants' gender or order of conditions on fixation patterns. Therefore, data from these two factors were collapsed for all subsequent analyses. We also reanalyzed Liu et al.'s (2011) data with Chinese infants and have reported the results in the following sections.

Total Fixation Duration

Table 2 shows the means and standard deviations of the total on-face looking time. Three participants whose total fixation duration were extreme values identified by the SPSS explore function (3 *SD*s above or below the mean) were deleted for the following analyses. The on-face fixations only included fixations on the face; the hair and neck were excluded.[1] In Table 2, infants' looking time was less than the stimulus presentation time (30 s) because infants either looked away or looked at the screen but not on the face, or their fixation duration did not reach the 100 ms threshold and therefore could not be counted as a fixation. Although there was an apparent difference in overall fixation duration between the Caucasian infants in the current study and the Chinese infants in Liu et al. (2011), we do not view this difference as problematic for further data interpretation because we are not performing direct comparisons of the data obtained in the two studies. We are interested primarily in comparing and contrasting patterns of fixation in each study.

Table 2. Mean and (SD) of Total On-Face Time in Seconds for Caucasian and Chinese Faces

	Caucasian Faces	Chinese Faces
Caucasian infants (current study)		
6 Months	10.75 (9.09)	8.65 (6.38)
9 Months	8.93 (4.71)	7.58 (4.18)
Chinese infants (Liu et al., 2011)		
6 Months	17.72 (6.62)	15.27 (7.53)
9 Months	14.45 (8.45)	14.88 (5.73)

Note: Fixations on the hair and neck were excluded for the calculation of total on-face looking time.

Analyses of variance were first conducted to determine whether there were differences in overall preference for either face type. A repeated measures 2 (stimulus race: own vs. other) $\times$ 2 (age group: 6 months vs. 9 months) ANOVA was performed with stimulus race as a within-subject variable, age group as a between-subject variable, and total on-face duration in seconds as the dependent variable. No significant main effects or interaction were found when analyzing the data of Caucasian infants or reanalyzing the data of Chinese infants in Liu et al. (2011). Overall, both 6-month-olds and 9-month-olds spent similar amounts of time scanning the whole Caucasian and Chinese faces.

Proportional Fixations on Individual AOIs

Proportional fixation times within each AOI relative to the total on-face fixation times were calculated for each condition. Since infants attended to the faces for different lengths of time, proportions were used to determine the relative amount of attention that infants paid to the different parts of the faces. Table 3 shows the means and standard deviations of the proportions of fixation time on each of the major AOIs relative to the fixation time on the whole face with hair and neck excluded.

First, we examined Caucasian infants' visual attention to the three major face features, specifically, the eyes (left eye and right eye), nose, and mouth. Multiple

[1] The mean total looking time on the face stimuli with hair and neck included was virtually identical to the on-face looking time, indicating that infants mainly fixated on the face area and not on the hairline and external contour of the faces. The means and standard deviations of the proportions of fixation time on each of the major AOIs relative to the fixation time on the whole face with hair and neck included are reported in Appendix A.

Table 3. Mean and (SD) Proportional Fixation Duration on Each AOI for Caucasian and Chinese Faces in the Current Study and in Liu et al. (2011)

	6 Months		9 Months	
AOI	Caucasian Faces	Chinese Faces	Caucasian Faces	Chinese Faces
Caucasian infants (current study)				
Eyes	.22 (.18)	.25 (.12)	.43 (.24)	.49 (.30)
Left eye	.12 (.11)	.11 (.10)	.20 (.19)	.26 (.22)
Right eye	.10 (.12)	.14 (.15)	.23 (.14)	.23 (.19)
Nose	.17 (.12)	.22 (.16)	.11 (.14)	.08 (.10)
Mouth	.23 (.21)	.22 (.17)	.14 (.14)	.15 (.21)
Chinese infants (Liu et al., 2011)				
Eyes	.35 (.20)	.31 (.26)	.25 (.15)	.18 (.17)
Nose	.25 (.15)	.16 (.20)	.12 (.10)	.31 (.17)
Mouth	.12 (.17)	.08 (.15)	.13 (.16)	.12 (.21)

Note: The proportional fixation duration on each AOI was calculated based on the absolute original size of the area without adjustment. Fixations on the hair and neck were excluded for the calculation of proportion.

2 (face type: Caucasian vs. Chinese) × 2 (age group: 6 months vs. 9 months) repeated measure ANOVAs were conducted for the fixation duration in each AOI based on the total on-face fixation times.

The ANOVA results for the left eye and right eye separately revealed no significant main effects of face race or age group or their interaction. We collapsed the fixation duration on the left eye and right eye and found a significant main effect of age group, $F(1, 29) = 7.74$, $p = .009$, partial $\eta^2 = .21$. Caucasian 9-month-olds spent a significantly greater amount of time on the eyes of both Caucasian and Chinese faces than Caucasian 6-month-olds ($M = .46$, $SD = .26$; $M = .23$, $SD = .17$, respectively).

For the proportion of fixation time on the nose, we found a significant interaction between face race and age group, $F(1, 30) = 4.78$, $p = .037$, partial $\eta^2 = .14$. To explain this interaction, two independent *t*-tests were conducted to compare the age differences in fixation time on the Caucasian nose and Chinese nose. With increased age, Caucasian infants became less inclined to look at the Chinese nose ($t[31] = 2.84$, $p = .008$), whereas their fixation time on the Caucasian nose remained unchanged ($t[33] = -.12$, $p = .908$).

The analysis of the proportional fixation time on the mouth revealed no significant main effects of face race or age group or their interaction.

Second, we applied the same analytical procedure to the data of Chinese infants from Liu et al. (2011). The results revealed a significant interaction between face race and age group for the proportion of fixation time on the nose, $F(1, 21) = 14.61$, $p = .001$, partial $\eta^2 = .41$. With increased age, Chinese infants became less inclined to look at the Caucasian nose ($t[21] = 2.18$, $p = .041$), whereas their fixation time on the Chinese nose remained unchanged ($t[21] = -1.81$, $p = .084$). There were no significant main effects of face race or age group or their interaction for the proportional fixation time on the eyes and mouth with Chinese infants.

ScanPath Analysis

We analyzed five types of fixation paths: between eyes, eyes–nose, eyes–mouth, nose–mouth, and internal–external. Internal–external categorized the scan paths between any one of the internal features (eyes, nose, and mouth) and other face areas not including the features (i.e., chin, forehead, and jaw). Mean frequencies for each path type are shown in Table 4. A generalized linear model approach was used to test our research questions because the observed data were counts and the distributions were not normalized. To examine the effects of face race (own vs. other) and age (6 months vs. 9 months) on all types of scan paths, five generalized linear models were tested with face race and age as predictors and the counts for each defined fixation path as the dependent variable. A Poisson regression model was used. All analyses were performed using SPSS Statistic 20.

The results from the Caucasian infants revealed no significant effects of face race and age for scan paths between the eyes or between eyes and mouth. For the scan paths between eyes and nose, we found a significant main effect of age, $\chi^2(1) = 7.66$, $p = .006$. With increased age, infants scanned more frequently between eyes and nose for both own- and other-race faces. For the scan path between nose and mouth, the main effect of age was significant, $\chi^2(1) = 41.47$, $p < .01$. In contrast with the scan paths between eyes and nose, the scan paths between nose and mouth were more frequent in 6-month-olds than in 9-month-olds.

Table 4. Mean Frequency and (SD) of Scan Paths Between AOIs of Caucasian and Chinese Faces in 6-Month-Olds and 9-Month-Olds in the Current Study and in Liu et al. (2011)

	6 Months		9 Months	
Category	Caucasian Faces	Chinese Faces	Caucasian Faces	Chinese Faces
Caucasian infants (current study)				
Between eyes	1.35 (2.34)	1.19 (2.93)	1.30 (2.18)	.90 (1.12)
Eyes–nose	.76 (1.15)	1.31 (1.74)	2.10 (2.34)	1.55 (2.44)
Eyes–mouth	1.29 (1.99)	1.31 (1.49)	1.60 (1.73)	1.80 (2.40)
Nose–mouth	2.88 (5.16)	2.00 (3.41)	.50 (1.05)	.35 (.57)
Internal–external	11.59 (11.44)	12.69 (9.22)	8.35 (6.07)	5.55 (4.80)
Chinese infants (Liu et al., 2011)				
Between eyes	1.00 (1.24)	.93 (1.14)	.22 (.44)	.11 (.33)
Eyes–nose	4.00 (3.92)	1.07 (1.07)	.67 (1.12)	1.11 (1.27)
Eyes–mouth	1.64 (2.10)	.71 (1.49)	1.56 (1.88)	.11 (.33)
Nose–mouth	3.21 (3.98)	.57 (.85)	1.00 (1.66)	1.11 (2.09)
Internal–external	9.86 (4.80)	10.21 (7.85)	10.22 (8.42)	7.00 (4.18)

For the scan paths between internal and external features, we found a significant main effect of age, $\chi^2(1) = 53.32$, $p < .001$, a significant main effect of face race, $\chi^2(1) = 4.04$, $p = .044$, and a reliable interaction between face race and age, $\chi^2(1) = 9.96$, $p = .002$. With increased age, Caucasian infants decreased their fixation shifts between internal and external more for other-race faces than for own-race faces.

The analysis of Chinese infants' ScanPath patterns from Liu et al. (2011) revealed a significant main effect of age for scan paths between the eyes, $\chi^2(1) = 7.98$, $p = .005$. Chinese 6-month-olds were more likely to shift their fixation between the eyes than Chinese 9-month-olds. For the scan paths between eyes and nose, we found a significant main effect of age, $\chi^2(1) = 8.77$, $p = .003$, and a significant interaction between face race and age, $\chi^2(1) = 9.52$, $p = .002$. With increased age, Chinese infants decreased fixation shifts between eyes and nose when scanning Caucasian faces, but maintained the same frequency of scan paths between eyes and nose when scanning Chinese faces. There was a significant main effect of face race for the scan path between eyes and mouth, $\chi^2(1) = 9.91$, $p = .002$. Chinese infants had more frequent fixation shifts between eyes and mouth when scanning Caucasian faces than Chinese faces. For the scan path between nose and mouth, we found a significant main effect of age, $\chi^2(1) = 7.34$, $p = .007$, and a significant interaction between face race and age, $\chi^2(1) = 9.37$, $p = .002$. With increased age, Chinese infants increased their fixation shifts between nose and mouth for Chinese faces, but deceased their fixation shifts between nose and mouth for Caucasian faces. For the scan paths between internal and external features, there was a significant interaction between face race and age, $\chi^2(1) = 4.19$, $p = .041$. Chinese infants' scan paths between internal and external features decreased significantly when scanning Chinese faces with increased age, but remained the same for Caucasian faces.

ScanMatch Analysis

We used ScanMatch Matlab toolbox (Cristino et al., 2010) to investigate scan path similarities between participants when they were scanning own- and other-race faces. First, the spatial and temporal information of one participant's saccade sequence is recoded to a string of letters representing fixation location, duration, and time order. We set the temporal sampling rate to 100 msec. The image is divided into 16×12 bins (400×400 pixels in each bin) and the fixation located in each region is coded by two letters. Second, the Needleman–Wunsch algorithm is used to calculate how similar two eye movement sequences are. The basic idea of this algorithm is that it uses local optimal alignment of sub-sequences to generate the best overall alignment. In this algorithm, the higher the score, the more likely it is that the two sequences are similar. In the present study, we calculated the averaged similarity scores among all the participant combinations within each group (Fig. 2). If the mean value in one group is larger than that in another group, it suggests that the scan paths among that group are more similar than in the other group.

To examine whether the similarity of scan path changed as a function of face race and age for the Caucasian infants, a 2 (face type: Caucasian vs. Chinese) $\times$ 2 (age group: 6 months vs. 9 months) repeated measures ANOVA was conducted with similarity scores in each group as the dependent variable. There was a significant main effect for age, $F(1, 293) = 20.93$, $p < .001$, partial $\eta^2 = .07$, and there was

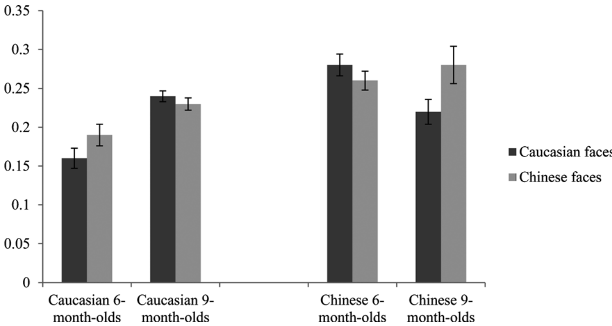

FIGURE 2 Mean similarity index of scan paths within each group as a function of face race and participant age. Error bars represent standard error of the mean.

also a significant interaction between face race and participant age, $F(1, 293) = 12.97$, $p < .001$, partial $\eta^2 = .04$. The similarity between participants' scan paths increased with age. To explain the interaction, simple main effect tests revealed that Caucasian 6-month-olds had a higher similarity score when viewing other-race faces versus own-race faces, $t(104) = 3.05$, $p = .003$. However, the scan path similarity of viewing own-race faces was higher than that for viewing other-race faces in 9-month-olds, $t(189) = 2.25$, $p = .025$.

For the analysis of Chinese infants from Liu et al. (2011), we found a significant interaction between face race and participant age, $F(1, 125) = 7.52$, $p = .007$, partial $\eta^2 = .06$. Simple main effect tests showed that there was no difference between viewing other-race faces and viewing own-race faces in scan path similarity with 6-month-olds, $t(90) = 1.47$, $p = .145$. However, the scan path similarity of viewing own-race faces was significantly higher than that for viewing other-race faces in 9-month-olds, $t(35) = 2.27$, $p = .029$. The results from both the Caucasian and Chinese infants indicate that the scan paths for own-race faces became more similar from one participant to another than participants' scan paths of other-race faces with increased age.

Stimulus Saliency Analysis

Where and how infants scan a face is influenced by both top-down cognitive operations and bottom-up sensory factors. The bottom-up factors refer to saliency effects such as local contrast, color, and orientation. As defined by Koch and Ullman (1985), saliency at a given location is determined by how different this location is from its surroundings in color, orientation, motion, depth, etc. Thus the saliency map provides a global measure of conspicuity with the assumption that highly salient areas automatically attract an observer's attention. To examine whether infants' differential scanning of the own- and other-race faces was driven by different perceptual saliency of the stimuli, we used the Matlab Saliency Toolbox (Walther & Koch, 2006) to compute and compare the saliency of the own- and other-race faces. The Saliency Toolbox calculates saliency for each area in a photo based on a psychologically plausible neural network model of visual attention to proto-objects in natural scenes. We generated 30 face images from each face video (one frame each second) and used them as input for Saliency Matlab analysis. Each face photo was divided into 30×40 grids and the saliency scores of each area were spatially averaged for Caucasian and Chinese faces.

To compare the saliency between Caucasian and Chinese faces, a "gene mattest" procedure (independent *t*-test) was tested and type I error was corrected by the FDR method. These analyses revealed that the Caucasian faces were significantly more salient in the eyes (mainly the left eye) than the Chinese faces (Fig. 3, the third panel, for all t values $>$ 2.96, $n = 180$, FDR corrected), whereas the Chinese faces were significantly more salient in the mouth than the Caucasian faces (for all t values < -2.96, $n = 180$, FDR corrected).

DISCUSSION

The present study aimed to document the development of scanning of own- versus other-race faces with an eye-tracking methodology in order to move towards a deeper understanding of the implications for perceptual narrowing. Six- and 9-month-old Caucasian infants' visual scanning patterns of Caucasian own-race faces and Chinese other-race faces were analyzed.

Regarding the factors that contribute to differential scanning patterns in own- versus other-race faces, the existing literature has raised three nonmutually exclusive possibilities: culture, facial physiognomy, and visual experience. According to the cultural account, eye movements in face scanning are affected by culture as individuals of different ethnic backgrounds adopt different scanning strategies. Caucasian adults and children scan faces based on a triangular pattern between the eyes and mouth, whereas Asian adults and children fixate centrally towards the nose (Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Kelly et al., 2011). According to the facial physiognomy account, different physiognomic features between own- versus other-race faces might drive infants to focus on those different specific features when scanning faces. According to the experiential account, differential experiences with own-versus other-race faces contribute to face scanning in

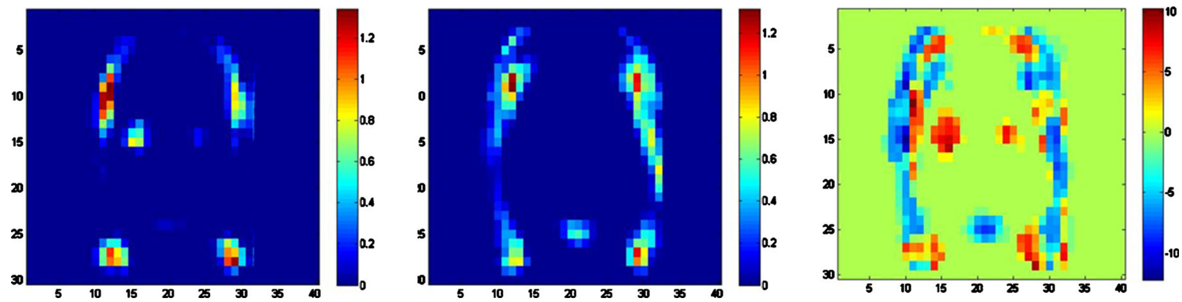

FIGURE 3 Mean saliency maps for the Caucasian (left panel) and Chinese (center panel), and the significant *t*-maps (Caucasian face saliency vs. Chinese face saliency, right panel). The colors on the two temperature bars of the left and center graphs refer to the mean saliency scores of the Caucasian or Chinese faces, with warm colors denoting high salience and cold colors denoting low salience. The colors on the right temperature bar refer to the t value of the difference in salience between the Caucasian and Chinese faces, with warm color denoting positive t values (Caucasian faces more salient than Chinese faces) and cold colors denoting negative t values (Chinese faces more salient than Caucasian faces). Note that the significant critical t value should be ± 2.96 for $\alpha = .05$ after FDR correction.

that infants would scan more familiar own-race faces differentially from less familiar other-race faces.

The AOI analysis showed that with increased age, Caucasian infants looked significantly less at the Chinese nose, while their attention to the Caucasian nose remained unchanged. This finding is exactly the opposite of what Liu et al. (2011) found. Using the same Caucasian and Chinese female face stimuli with Chinese infant participants, Liu et al. (2011) reported that looking time on the Caucasian noses decreased with age, whereas looking time on the Chinese noses remained unchanged. In other words, both studies demonstrated a decrement in fixation time on the nose of other-race faces (i.e., Chinese faces for Caucasian infants, Caucasian faces for Chinese infants) and a maintenance of fixation time on the nose of own-race faces. The combined findings from Liu et al.'s (2011) study with Chinese infants and the current study with Caucasian infants suggest that visual experience may play an important role in differential fixations on own- and other-race noses. These results lead to the speculation that fixation on the nose might facilitate infants' identification of own-race individuals.

Moreover, we found that both 6- and 9-month-old Caucasian infants spent a considerable proportion of time fixating on the eyes of own- and other-race faces. With increased age, Caucasian infants' fixation duration on the eyes increased, regardless of face race, while Chinese infants' looking time to the eyes of both race faces did not change with increased age. The looking pattern of Caucasian infants might be explained by the facial physiognomy and experience accounts. In support of facial physiognomy hypothesis, our analysis of the perceptual saliency in Caucasian and Chinese faces showed that Caucasian eyes are indeed more salient than Chinese eyes. It is likely that Caucasian infants might have discovered the eye region as a diagnostic feature which differentiates individual Caucasian faces and generalize this learned bias to Chinese faces. By contrast, Chinese infants did not show a similar scanning pattern on the eyes due to lack of such learned experience given that Chinese eyes are less diagnostic for individual face discrimination (Le, Farkas, Ngim, Levin, & Forrest, 2002). Also, the age-related increase in attention toward the eyes in Caucasian infants and the lack of age-related changes in Chinese infants is consistent with the enculturation hypothesis (Blais et al., 2008; Fu et al., 2012). As suggested by this hypothesis, infants might already have been socialized through their face-to-face interactions with parents to learn about the cultural norms of eye contact (Kisilevsky et al., 1998), with Caucasian, but not Chinese, infants, being increasingly socialized to attend to the eyes.

The comparisons of scan path frequencies between the eyes in Caucasian and Chinese infants further shed light on the cultural and visual experience perspectives. The scan paths between the eyes of both races of faces did not change with increased age in Caucasian infants in the current study, but decreased significantly in Chinese infants in Liu et al. (2011). The scan paths between the eyes could have functional significance from the perspective that more frequent shifts among internal features may be associated with a greater likelihood of processing the second-order relations which some have argued to be important in face processing (Maurer, LeGrand, & Mondloch, 2002). Furthermore, a previous study has found that Caucasian infants are sensitive to configural changes of the eyes in Caucasian faces (Quinn & Tanaka, 2009). On the one hand, the age-related decrease in fixation shifts between the eyes in Chinese infants and lack of age-related change in Caucasian infants support the enculturation hypothesis. Chinese infants become less likely to attend to the eye information due to the cultural norm of avoiding direct eye contact. On the other hand, the size of the eyes contains less variance across individual Chinese faces (Le et al., 2002), which might make it less useful for face identification. Therefore, with more visual experience with Chinese faces, Chinese infants gradually decrease their attention to the second-order information between the eyes of faces.

Our visual fixation results not only revealed differential patterns in infants' scanning of own- and other-race faces, but also similarity in scanning faces from both races. In terms of similarities in face race scanning, there was no overall fixation duration difference for same- and other-race faces on the whole face stimuli. Also, for both Caucasian and Chinese faces, the proportion of time fixating the eyes increased from 6 to 9 months in Caucasian infants. In addition, our results showed no differences in the frequency of scanning between eyes across face race with Caucasian infants. This is inconsistent with previous observations that Caucasian infants shifted their attention more frequently between the eyes of own-race Caucasian faces than between the eyes of the African other-race faces (Xiao et al., 2013). The differential findings between Xiao et al. (2013) and the current study might be due to the use of different other-race faces, suggesting that facial physiognomic differences between different own- and other-race face classes may affect infants' fixation shifts between face features.

Taken together with the previously discussed visual fixation findings, the scan path results suggest that when examining infants' fixation patterns for own- and other-race faces, we must consider the contributions of culture, facial physiognomy, and visual experience. It is also possible that the differential contributions of these factors to infants' visual fixation of the face may vary from one feature to another (i.e., nose vs. eyes). To further evaluate this possibility, future research needs to test Chinese infants with Chinese and African faces, and African infants with Caucasian, African, and Chinese faces. Only through this systematic approach will we be able to better ascertain the differential roles of experience, culture, and face morphology on infants' scan shifts between the features of own- and other-race faces.

Other than comparing scan paths among specific features, the current study also used a ScanMatch analysis to examine the spatial and temporal similarity of fixation shifts when infants scan the whole faces. We found that path similarity was higher or not different for other- versus own-race faces in 6-month-olds, but it became higher for own- versus other-race faces in 9-month-olds. The fact that scan paths began to resemble each other with increased age only for own-race faces suggests that infants become able to collect information from own-race faces more efficiently than other-race faces (Kato & Konishi, 2013). Such efficient facial information collection with increased age for own-race faces may reflect differential experience and possibly greater top-down control of scanning. For example, the difference between the similarity indices for upright and inverted own-race faces was significant but small during infancy and large for adults (Kato & Konishi, 2013). Since own-race faces and upright faces are more familiar than other-race faces and inverted faces, the increase of scan path similarity in own-race faces and upright faces converges to suggest that the face processing system is gradually tuned to more experienced faces. Although this is not necessarily a new conclusion, what is noteworthy about the present report is that the similarity in scanning for own-race faces increased greatly from 6 to 9 months of age, which coincides with the behavioral findings of perceptual narrowing in face recognition (Kelly et al., 2007, 2009) and categorization (Anzures, Quinn, Pascalis, Slater, & Lee, 2010).

Indeed, the parallel developmental trajectories of differential scanning patterns may be associated with infants' behaviorally assessed preference (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005), recognition (Kelly et al., 2007), categorization (Anzures et al., 2010), and holistic versus featural processing (Ferguson et al., 2009) of own- and other-race faces. In particular, the age-related changes in visual scanning of own- and other-race faces found in the present and previous studies (Liu et al., 2011; Wheeler et al., 2011; Xiao et al., 2013) may be related to the perceptual narrowing phenomenon observed in own- and other-race face recognition using conventional infant testing methods (Anzures et al., 2010; Bar-Haim et al., 2006; Ferguson et al., 2009; Kelly et al., 2005, 2007). In other words, with increased age, infants not only scan own- and other-race faces differently, but also discriminate and recognize own-race faces better than other-race faces. It is reasonable to assume that differential scanning patterns could lead to differential recognition abilities. However, it is equally possible that the relation could be the other way around. More advanced skills in individuating or categorizing a particular type of face might enhance the pattern of scanning so as to optimally extract identity or category information from an individual's face. These possibilities need to be verified by specifically designed investigations as no studies have directly examined infants' eye movement patterns and their differential processing (discrimination, recognition, or categorization) of own- and other-race faces except for Gaither et al. (2012), who tested younger infants. They found a positive correlation in 3-month-olds between the visual transitions between the top (eye region) and bottom (mouth region) halves of faces and the degree of discrimination ability for own-race faces, but not for other-race faces. Whether this significant finding can be extended to older infants awaits further investigation.

In conclusion, the findings from the present and existing eye-tracking studies with infants taken together shed light on the roles of culture, facial physiognomy, and visual experience in the development of own-race and other-race face scanning and the perceptual narrowing phenomenon. First, the present evidence combined with that from Liu et al. (2011) suggests that visual experience may play an important role in the age-related changes in infants' visual scanning of own- and other-race faces with respect to the nose. Second, the current data in combination with those of Liu et al. (2011) suggest that facial physiognomy, experience, and enculturation may play important roles in age-related changes in infants' visual scanning of own- and other-race faces with respect to the eyes. Third, when comparing the current data with those of Wheeler et al. (2011) and Xiao et al. (2013), the findings suggest that Caucasian infants respond differentially to different classes of other-race faces (i.e., Chinese vs. African), an outcome consistent with face physiognomic differences. The existing and current findings additionally suggest that to better understand the perceptual narrowing phenomenon in terms of own- and other-race face scanning, we must use not only well-established behavioral methods, but also emerging eye-tracking techniques. Only through such multi-method and multi-factor research approaches can we gain deeper insights about the perceptual narrowing phenomenon in face processing in general and own- and other-race face scanning in particular.

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APPENDIX A

Mean and (SD) Fixation Time on Each AOI for Caucasian and Chinese Faces With Hair and Neck Included

	6 Months		9 Months	
AOI	Caucasian Faces	Chinese Faces	Caucasian Faces	Chinese Faces
Whole face, hair, and neck fixation duration	12.22 (8.81)	11.20 (7.88)	9.39 (4.67)	8.29 (4.36)
Eyes	.21 (.18)	.29 (.12)	.41 (.24)	.45 (.30)
Left eye	.07 (.07)	.09 (.09)	.19 (.22)	.24 (.24)
Right eye	.13 (.17)	.20 (.19)	.22 (.18)	.21 (.23)
Nose	.13 (.12)	.17 (.15)	.13 (.17)	.07 (.10)
Mouth	.16 (.12)	.16 (.16)	.13 (.13)	.15 (.20)
Hair and neck	.02 (.03)	.10 (.17)	.03 (.04)	.09 (.19)

Note: The proportional fixation duration on each AOI was calculated based on the overall looking time on the face, hair, and neck.