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Both children and adults scan faces of own and other races differently

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ABSTRACT

Extensive behavioral and neural evidence suggests that processing of own-race faces differs from that of other-race faces in both adults and infants. However, little research has examined whether and how children scan faces of own and other races differently for face recognition. In this eye-tracking study, Chinese children aged from 4 to 7 years and Chinese adults were asked to remember Chinese and Caucasian faces. None of the participants had any direct contact with foreign individuals. Multi-method analyses of eye-tracking data revealed that regardless of age group, proportional fixation duration on the eyes of Chinese faces was significantly lower than that on the eyes of Caucasian faces, whereas proportional fixation duration on the nose and mouth of Chinese faces was significantly higher than that on the nose and mouth of Caucasian faces. In addition, the amplitude of saccades on Chinese faces was significantly lower than that on Caucasian faces, potentially reflecting finer-grained processing for own-race faces. Moreover, adults' fixation duration/saccade numbers on the whole faces, proportional fixation percentage on the nose, proportional number of saccades between AOIs, and accuracy in recognizing faces were higher than those of children. These results together demonstrate that an abundance of visual experience with own-race faces and a lack of it with other-race faces may result in differential facial scanning in both children and adults. Furthermore, the increased experience of processing faces may result in a more holistic and advanced scanning strategy in Chinese adults.

1. Introduction

Processing of faces based on differential experience has attracted the interest of many researchers in psychology since the early 1900s (Feingold, 1914). One well established example is the differential processing of faces of own and other races (for a review, see Anzures et al., 2013). This phenomenon, which is commonly referred to as the Other-Race Effect (ORE), has been repeatedly demonstrated in studies with infants (Anzures, Ge, Wang, Itakura, & Lee, 2010; Ferguson, Kulkofsky, Cashon, & Casasola, 2009; Kelly et al., 2007; Kelly et al., 2009), children (Anzures et al., 2014), and adults (Caharel et al., 2011; Golby, Gabrieli, Chiao, & Eberhardt, 2001; Tanaka & Pierce, 2009). Recent evidence suggests that the behavioral Other-Race Effect also has a neural equivalent, or Neural Other-Race Effect (NORE) in infancy (Balas & Nelson, 2010), childhood (Ding et al., 2012), and adulthood (Golby et al., 2001; Hugenberg, Young, Bernstein, & Sacco, 2010; Meissner & Brigham, 2001; Natu, Raboy, & O'Toole, 2011; Sporer, 2001).

In spite of the growing behavioral and neural evidence, little is known about whether and how individuals scan faces of own and other races to extract information for face recognition. Faces form one of the most complex and information rich classes of stimuli in our visual environment. They contain a multitude of information such as identity, race, gender, age, and attractiveness as well as gaze and emotion (Lee, Anzures, Quinn, Pascalis, & Slater, 2011). For the task of face recognition, one must scan the face and actively search for identity relevant information to ensure accuracy. Given the existing evidence about the ORE and NORE, one can assume that our active visual scanning of faces of own and other races may also differ due to our differential experience with processing the two types of faces, as demonstrated in a previous eye-tracking study in which Chinese adults scanned Chinese and Caucasian faces with different strategies (Fu, Hu, Wang, Quinn, & Lee, 2012). In Fu et al. (2012), Chinese adults scanned own-race Chinese faces with a focus around the nasal region, whereas they scanned Caucasian faces with a focus on the eyes.

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Eye-tracking is the ideal methodology for studying scanning patterns during the processing of faces from own and other races. It records observers' fixations on various parts of the face in real time with high temporal and spatial resolution (Frank, Vul, & Johnson, 2009). Several recent studies have used eye-tracking to examine how individuals visually scan faces of own and other races. Some researchers have reported that even in infancy, the scanning strategies of Caucasian and Chinese infants vary for processing faces of different races (Gaither, Pauker, & Johnson, 2012; Liu et al., 2011; Wheeler et al., 2011; Xiao, Xiao, Quinn, Anzures, & Lee, 2013). For example, Wheeler et al. (2011) found that with age, Caucasian infants from 6 to 10 months increased their visual attention to the eye region of own-race faces but their fixations on the mouths of these faces decreased, consistent with an upper region processing bias (Quinn & Tanaka, 2009; Simion, Valenza, Macchi Cassia, Turati, & Umiltà, 2002); during the same time frame, visual attention to the eyes of other-race African faces did not change. In contrast, Liu et al. (2011) found that when viewing own-race Chinese and other-race Caucasian faces, Chinese infants' fixation duration on the Chinese nose had no significant change from 4 to 9 months of age, whereas their fixation duration on the Caucasian nose decreased significantly with age. It seems that Caucasian and Chinese infants have differential scanning patterns for faces of own and other races. Moreover, the development trajectory of scanning strategy for own-race faces seems to be different from that for other-race faces.

Consistent with the infant findings, a study of Chinese adults revealed that their scanning strategies for Caucasian faces and Chinese faces were different, with greater focus on the nose of Chinese faces and the eyes of Caucasian faces (Fu et al., 2012). However, little is known about young children's scanning strategies for faces of own and other races (Kelly et al., 2011). An abundance of research has been carried out to investigate face processing strategies in adults and children, using an array of techniques such as inversion, part-whole, and composite face methodologies (e.g., Brace et al., 2000; Diamond & Carey, 1986; Maurer, Grand, & Mondloch, 2002; Pellicano, Rhodes, & Peters, 2006; Tanaka, Kiefer, & Bukach, 2004; Young & Bion, 1981). Collectively, these studies have demonstrated that both children and adults process faces holistically, although children perform more poorly than adults (e.g., Pellicano & Rhodes, 2003). However, due to limitations of the behavioral paradigms, no detailed differences in processing strategy between children and adults were demonstrated. Furthermore, existing eye-tracking studies have mainly used the area of interest approach to focus on the fixation data and have not utilized the multiple sources of information afforded by eye-tracking technology.

To bridge this gap and obtain a more informed view of the developmental course of differential scanning of faces of own and other races, we conducted an eye-tracking investigation with native Chinese children from 4 to 7 years of age and native Chinese adults. The data during the learning and reviewing of target faces were analyzed. In this study, we took a multi-method approach to analyze the eye-tracking data. First, we used the traditional Area of Interest (AOI) approach. The AOI approach has the advantage of being easy to use and provides a default mode of analysis for most eye-trackers. With this approach, visual fixations on a predefined key area of the face are grouped together to reveal the amount of time that an observer spent on this area when encoding that face (Fig. 1).

The disadvantage of the AOI approach is that it groups fixations on a large area of the face together as if they are the same (e.g., fixations on the pupil, sclera, and eye lid are indiscriminately lumped together as fixations on the eyes). This approach thus fails to reveal potentially important differences in fixations on different parts within an AOI. Also, important fixation effects may sometimes occur at the borders of multiple AOIs, resulting in obscuration of the effects.

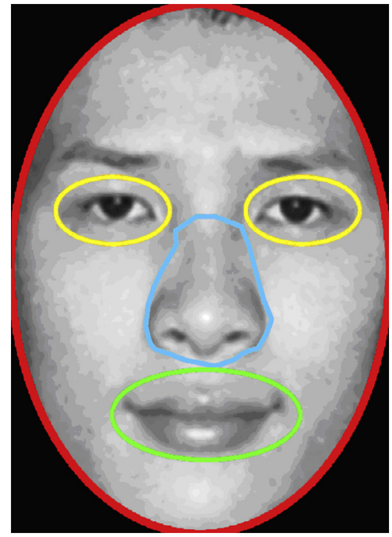

Fig. 1. An example face showing how the AOIs were defined in our study.

To compensate for these shortcomings of the AOI approach, we also took a pixel level data-driven approach. More specifically, we used a novel method that computes statistical fixation maps of eye movements (Caldara & Miellet, 2011). Unlike the above AOI analyses that amalgamate all fixation points that fall into a particular predetermined area of interest and perform statistical tests on the total fixations to the area between conditions, iMap allows for statistical testing of condition differences on any part of a stimulus without the restriction of the AOIs. Also, it allows for statistical testing of condition differences on a scale finer than the AOI analyses. Thus, iMap provides pixel level statistical maps about the fixation distribution differences between own- and other-race face scanning in each age group. This data-driven approach allows for direct comparisons of the differential scanning patterns between own- versus other-race faces across ages. By employing this approach, we aimed to reveal more subtle differences in the scanning patterns of faces of own and other races in children and adults.

We additionally used another novel approach, the scan path analysis, which has yet to be widely used to analyze scanning of faces. The scan path analysis capitalizes on the rich saccade data that are concurrently collected with the fixation data in an eye-tracking experiment, but often left unanalyzed. This analysis assesses specific fixation shifts between major internal face features, such as visual shifting between the eyes, between the eyes and the mouth, or between the eyes and the nose. Further, this analysis measures not only the frequency of saccades between key face areas but also saccade amplitudes. Saccade amplitude has been used to analyze adult eye-movement data since the 1970s (Baloh, Sills, Kumley, & Honrubia, 1975). It measures the length of saccades in degrees of visual angle, or in the distance between two successive fixations, which is determined by the visual angle if the distance from the viewer's eyes to the object is stable, which is the case in our study. Maw and Pomplun (2004) suggest that short saccades indicate fine-grained processing of local information, whereas long saccades often signify low information content or superficial scanning of local visual input.

Based on the existing eye-tracking studies, we hypothesized that both Chinese children and adults' proportional fixation duration on the eyes of Chinese faces would be less than on the eyes of Caucasian faces, and their proportional fixation duration on the nose and mouth of Chinese faces would be more than that on the nose and mouth of Caucasian faces, similar to what was reported in a previous study with Chinese adults (see Fu et al., 2012). The saccade pattern should also vary between the scanning of faces of own and other races with more scanning between the nose of the own-race Chinese faces and other face parts, and more scanning between the eyes of the other-race Caucasian faces. This expectation is based on findings suggesting that information from the eye region is more important for other-race Caucasian faces while information from the nose region is more important for own-race Chinese faces (see Fu et al., 2012; Liu et al., 2011; Wheeler et al., 2011). Also, we explored the effect of face race on saccade amplitude. We hypothesized that given the fact that the size of the behavioral other-race effects are comparable between children as young as preschoolers and adults (Anzures et al., 2014), the effect of face race on scanning in adults would be similar to that in children. However, adults' scanning would be more expert, especially for own-race faces, due to the increased experience of processing own-race faces.

2. Method

2.1. Participants

In total, 83 children participated in the study (49 males aged from 48 to 80 months, Mean age = 63.4 months, *SD* = 8.0 months). Also, thirty university students participated (15 males, aged from 19 years to 26 years, Mean age = 21 years, *SD* = 1.25 years). All participants were native Chinese in a rural area of P.R. China. Participants had no prior direct contact with Caucasian or other non-Chinese individuals. They all had normal vision. They were classified into three age groups: 48–62 months old, younger-child group ($N = 41$); 63–80 months old, older-child group ($N = 42$); 19–26 years old, adult group ($N = 30$). The children were separated into two groups to test whether a significant difference in scanning strategy existed between the younger and older groups. In particular, we wished to examine whether the time window between 48 months and 80 months is a key period for scanning strategy development.

The children were recruited from a kindergarten where their parents had given informed consent to participate in the study. Oral assent was also obtained from children prior to their participation. Informed consent was additionally obtained from the university students who were compensated for their participation. Both child and adult participants were from families of all walks of life, including farmers, merchants, teachers, and other professional occupations.

2.2. Material

Fourteen photos of Caucasian faces (12 female) and fourteen photos of Chinese faces (12 female) were used (width: 500 pixels, 13.5 cm, 12.7 degrees of visual angle, height: 700 pixels, 18.9 cm, 17.9 degrees of visual angle, resolution: 72 pixels per inch). A practice was conducted with the male face stimuli, whereas the real experiment involved female face stimuli, because we wanted to decrease the likelihood that experience with the particular practice faces would affect performance with the test faces. The use of female faces for the experimental trials was because children are known to be more familiar with female adult faces than male ones (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). They were all normalized to be the same shape and size. Also, their eyes, nose, and mouth positions were normalized to the locations of the eyes, nose, and mouth of an average face such that the major features of all the face stimuli were located in the same regions. All face images were emotionless, frontal view, and presented in greyscale to prevent any differences in skin tone between the Chinese and Caucasian faces from affecting participants' scanning of the faces. To control for hairstyle differences, all face images were overlaid with the same elliptical shape. The images were matched in overall brightness and luminance using Photoshop. Further, the faces were chosen according to the results of a prior experiment in which the Caucasian and Chinese faces were matched in terms of attractiveness and distinctiveness as judged by Chinese and Caucasian adults (Ge et al., 2009). We only selected faces that were judged similarly in terms of distinctiveness and attractiveness. This selection criterion controlled for potential confounds of facial distinctiveness and attractiveness on participants' recognition performance and scanning patterns.

A Tobii 1750 Eye tracker (±40 deg range of visual angle, 0.5 deg precision of visual angle, 50 Hz sample rate, 17 in., 5 fps per second, 1280×1024 pixels resolution) was used to record participants' fixations on the face images. The Tobii Studio program was used to control the stimulus presentation. The X, Y fixation position coordinates were averaged for both eyes, or reflected the values of one validly measured eye. Tobii fixation filters were used to group gaze data into meaningful fixations. The filter detects quick changes in the gaze point signal using sliding averaging. Changes beyond 35 pixels (i.e., the radius spatial domain on the Tobii screen) were defined as abrupt. If a segment of the signal is constant or slowly changing due to drift, and its duration is longer than 100 ms, then we defined it as a fixation. If there is an abrupt change, and the change is between two fixations, then we defined it as a saccade.

2.3. Procedure

The participants took part in the study individually in a darkened room with consistent ambient light. They were positioned 60 cm from the eye-tracker screen. Children's oral responses were recorded by an experimenter using a mouse connected to the computer running the Tobii Studio program, while the adults clicked the mouse by themselves. Because our pilot work with the procedure informed us that children may fixate at the mouse instead of the faces on the screen if instructed to click the mouse, we instructed the children to report their answers orally.

The procedure of the experiment is illustrated in Fig. 2. Participants took part first in a practice experiment. The practice experiment included a familiarization period and a testing period. At the beginning of the familiarization period, the experimenter instructed the participants as follows: "You will see some of my acquaintances' photos, please remember them!" Two target faces (1 male Caucasian and 1 male Chinese) were presented on the Tobii eye-tracker screen one by one, shown for 3 s each followed by a 3 cm square cartoon character portrait used as a mask (2 s). The cartoon character was a female sheep popular among Chinese children. We used the sheep stimulus to make the procedure more child-friendly. The visual cartoon character was presented as a static stimulus at the center of screen, functioning as a "fixation cross", and coinciding with the auditory announcement of "the next image".

After the familiarization period, the testing period began. The acquaintance faces were mixed with 2 new foil faces (again 1 male Caucasian and 1 male Chinese). The participants judged whether they were old or new faces. Once the experimenter clicked a mouse to record a participant's response, the judged face was replaced by a cartoon character that appeared for 2 s, announcing whether the face was indeed an old or new face to provide feedback to the participants (Feedback). If the preceding face was a target face, then the cartoon face appeared, announcing that the face was a familiarized face and would be shown again regardless of the participant's

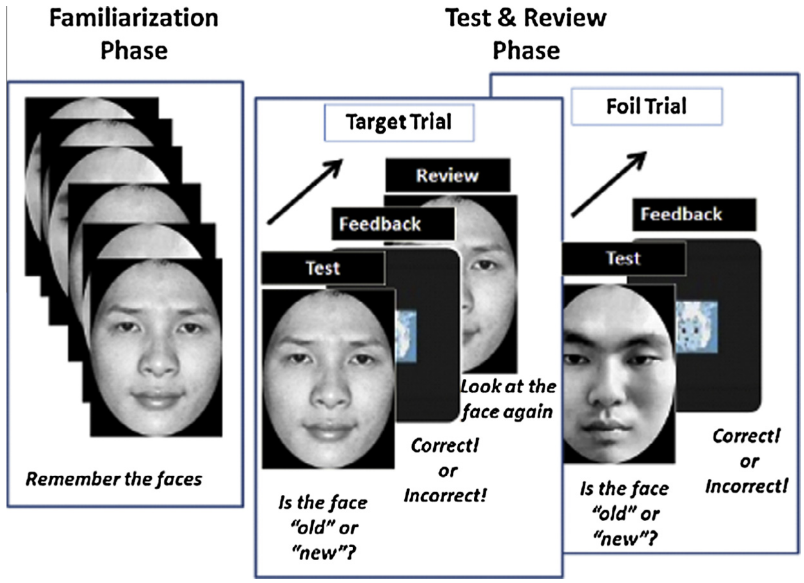

Fig. 2. Schematic illustration of the procedure used in the experiment.

correctness of response. This procedure ensured that participants would have another opportunity to re-scan the target face and remember it. We made this arrangement because the processing strategy in learning and reviewing faces is what we focused on. Then the target face just seen would be shown for 3 s for participants to review (Review). After the review, the cartoon character announced "the next image", after which a new trial began. If the preceding face was a new foil face, then regardless of the participant's correctness, the cartoon character appeared for 2 s, announcing that the face was not an acquaintance, and the foil face would not be shown again. We did not give the participant another opportunity to review this face because it was a foil face and would not appear again in the subsequent trials. Immediately, the cartoon character announced "the next image", after which a new trial began. This test-feedback-review (test-feedback) cycle would be repeated until the 2 target faces and 2 foil faces were shown (4 trials in total). The order of the target and foil faces was randomized between participants.

All participants understood the experimental task as evidenced by their perfect scores during the practice period. At the conclusion of the practice block, the formal experiment began. The formal experiment consisted of one familiarization block (Block 0) and three test blocks (Blocks 1–3). In the familiarization block, participants were shown 6 acquaintance faces (3 Chinese females and 3 Caucasian females). Target photos were labeled as "acquaintance" by experimenter. All participants learned the same "acquaintance" faces. After all "acquaintance" faces were presented, the familiarization period concluded and the testing period began. There were three tests altogether in the formal experiment. In each test, the 6 acquaintance faces were mixed with 6 new foil faces (3 Chinese females and 3 Caucasian females). The participants judged whether each face was an acquaintance or not. There were 12 trials altogether in a test.

Throughout these tests, the acquaintance faces were the same. The 18 foil faces were pre-allocated into three groups. Each group includes three Chinese female faces and three Caucasian female faces. The order of these groups was Latin matrix randomized between each participant, i.e. group1–group2–group3, group3–group1–group2, group2–group3–group1...

Before each familiarization and testing period, eye-movement measures of the participants were calibrated by a program provided by the Tobii eye-tracker. The calibration program asked participants to follow a bouncing red dot with their eyes as it moved around the screen. The diameter of the red dot changed from 0 to 1 in. If the participant's fixation was calculated to be more than 1 in. away from the center of the dot, a re-calibration was performed. Once the calibration was successful, the familiarization block (Block 0) of the experimental phase began. The results of the calibration were used to calculate the fixation points of the participants in the familiarization block. After each familiarization or testing period, participants were provided with a 1 min rest period.

3. Results

3.1. Behavioral performance

According to signal detection theory, discriminating ability (d') was calculated as the normalized Z value of the ratio of correctly recognized learned faces, Z(hit), minus the normalized Z value of the ratio of false judgments of unlearned faces, Z(false alarm). The normalized criterion was calculated as (Z(hit) + Z(false alarm))/2 * d'.

Combining the results from all three blocks, the means and standard deviations for response time (ms), accuracy (%), discriminating ability, and normalized criterion of the three different age groups for Chinese and Caucasian faces on all tests are presented in Table 1. For each age group's viewing of Chinese or Caucasian faces, one-sample t tests revealed that accuracy was significantly higher than 50% and discriminating ability was significantly higher than 0, all $t > 3.06$, all $p < 0.01$. No group's normalized criterion was significantly different from 0, all $p > 0.05$.

Repeated ANOVA analyses with participants' age group as a between-subjects variable and face race as a within-subject variable were conducted on response time, accuracy, discriminating ability, and normalized criterion, respectively. No significant race effect was found, all $p > 0.05$. An age effect was significant for response time, accuracy, and discriminating ability, respectively, $F(2,110) = 28.50$, $p < 0.001$, $\eta^2 = 0.34$; $F(2,110) = 61.89$, $p < 0.001$, $\eta^2 = 0.53$; $F(2,110) = 64.36$, $p < 0.001$, $\eta^2 = 0.54$. Scheffe post hoc tests revealed that response time of the adult group was significantly shorter than that of the other age groups, all $p < 0.001$. Response time of older children was significantly shorter than that

Table 1
Response time (ms), accuracy, discriminating ability, and normalized criterion for the different age groups.

AgeGroup	Rt_E	Rt_W	Acc_E	Acc_W	D_E	D_W	C_E	C_W
Younger children	4628.03 (2982.76)	4861.04 (2963.58)	58.6%** (12.7%)	55.9%** (12.2%)	.52** (.77)	.35** (.70)	.04 (.94)	.44 (3.14)
Older children	3498.04 (1352.76)	3572.36 (1336.24)	59.9%** (13.5%)	62.8%** (14.1%)	.57** (.80)	.76** (.86)	.08 (.57)	.30 (2.78)
Adults	1268.03 (333.16)	1328.71 (283.22)	80.2%** (9.8%)	82.8%** (12.0%)	1.81** (.65)	2.02** (.77)	−.01 (.31)	−.20 (.73)

Note: E = Chinese faces, W = Caucasian faces, RT = correct response time in milliseconds, Acc = accuracy, D = discriminating ability, C = normalized criterion c.
** Significantly higher than 0 or 50% at 0.01 level.

of younger children, $p = 0.019$. Other differences did not reach significance, all $p > 0.05$. Accuracy and discriminating ability of the adult group were significantly higher than those of younger and older children, all $p < 0.001$.

3.2. Fixations during learning and reviewing target faces

For every photo presentation, durations of fixations on each AOI were summed to provide a total fixation duration on each AOI for each participant. In addition, to control the influence of viewing time on the face in a photo presentation, we calculated the proportional fixation duration on the left eye, right eye, nose, and mouth, dividing their fixation duration by fixation duration on the whole face. Table 2 shows the means and standard deviations of the fixation duration on the whole face and the proportional ones on interior AOIs: left eye, right eye, nose, and mouth, for each age group.

3.2.1. Fixation duration on the whole face

An ANOVA with face race (Chinese, Caucasian) as a within-subject factor and age group (younger children, older children, adults) as a between-subjects factor was conducted on the fixation duration on the whole face. The effect of face race and its interaction with age group did not reach significance, $p > 0.05$. The age group effect was significant, $F(2,110) = 5.71$, $p = 0.004$, $\eta^2 = 0.093$. A Scheffe post hoc test revealed that adults' mean fixation duration was significantly higher than that of older children, $p = 0.005$.

3.2.2. Total proportional fixation duration on all AOIs (eyes plus nose plus mouth)

A face race by age group ANOVA was conducted on the proportional fixation duration on all AOIs (eyes plus nose plus mouth). The interaction between face race and age group was not significant, $p > 0.05$. A main effect of age group was significant, $F(2,110) = 6.34$, $p = 0.002$, $\eta^2 = 0.10$. A Scheffe post hoc test revealed that older children's proportional fixation duration on the three key AOIs ($M = 55.5\%$, $SD = 13.8\%$) was significantly lower than that of adults ($M = 66.2\%$, $SD = 12.7\%$), $p = 0.003$. A main effect of face race was also significant, $F(1,110) = 16.11$, $p < 0.001$, $\eta^2 = 0.13$. A paired-sample t test revealed that the total proportional fixation duration on the three key AOIs of Caucasian faces ($M = 62.8\%$, $SD = 15.1\%$) was significantly higher than that on Chinese faces ($M = 58.5\%$, $SD = 14.0\%$), $t(112) = 4.03$, $p < 0.001$.

3.2.3. Proportional fixation duration on each AOI (eyes, nose, and mouth, separately)

An ANOVA with AOI (left eye, right eye, nose, mouth) and face race (Chinese, Caucasian) as within-subject factors, and age group (younger children, older children, adults) as a between-subjects factor, was conducted on the proportional fixation duration on each AOI. The results showed that the interaction between AOI and age group was significant, $F(6,330) = 3.96$, $p = 0.001$, $\eta^2 = 0.067$. AOI's interaction with face race was also significant, $F(3,330) = 61.74$, $p < 0.001$, $\eta^2 = 0.36$. Other interactions did not reach significance, all $p > 0.05$.

To explore the effect of age group in the interaction between AOI and age group, the data of both races were merged. One way ANOVA tests with age group as a between-subjects factor were conducted on the proportional fixation duration on each AOI separately. The results showed that the age group effect was only significant for proportional fixation percentages on the nose, $F(2,110) = 13.20$, $p < 0.001$, $\eta^2 = 0.194$. The effect of age on other AOIs' proportional fixation percentages did not reach significance, all $p > 0.05$. A Scheffe post hoc test revealed that adults' proportional fixation percentage on the nose was significantly higher than that of younger and older children, all $p < 0.001$.

To explore the effect of face race in the interaction between AOI and face race, the data of all age groups were merged. Paired-sample t tests between faces of own and other races were conducted on the proportional fixation duration on each AOI separately. The results showed that fixation percentages on Caucasian eyes were

Table 2
Means and standard deviations of the fixation duration on whole face and the proportions on the eyes, nose, and mouth for the different age groups.

Group	Race	Face	Interiors	LE	RE	N	M
Younger children	E	2797.00 (294.21)	59.8% (12.9%)	11.0% (9.2%)	14.6% (10.9%)	19.6% (11.5%)	14.6% (12.4%)
	W	2826.69 (312.69)	64.0% (14.2%)	17.0% (10.4%)	21.6% (12.5%)	15.2% (8.2%)	10.2% (9.0%)
Older children	E	2524.80 (458.48)	53.5% (14.4%)	7.5% (8.2%)	11.9% (11.6%)	19.6% (11.9%)	14.5% (10.9%)
	W	2570.62 (415.33)	57.4% (15.6%)	12.0% (10.1%)	18.0% (13.7%)	15.8% (9.7%)	11.6% (9.2%)
Adults	E	2693.68 (294.44)	63.7% (13.0%)	9.3% (7.2%)	10.6% (9.8%)	29.8% (9.6%)	14.0% (9.7%)
	W	2711.64 (336.29)	68.7% (13.5%)	13.5% (8.1%)	16.0% (10.3%)	25.9% (7.9%)	13.2% (8.6%)

Note: W = Caucasian faces, E = Chinese faces, Interiors = eyes + nose + mouth, LE = left eye, RE = right eye, N = nose, M = mouth.

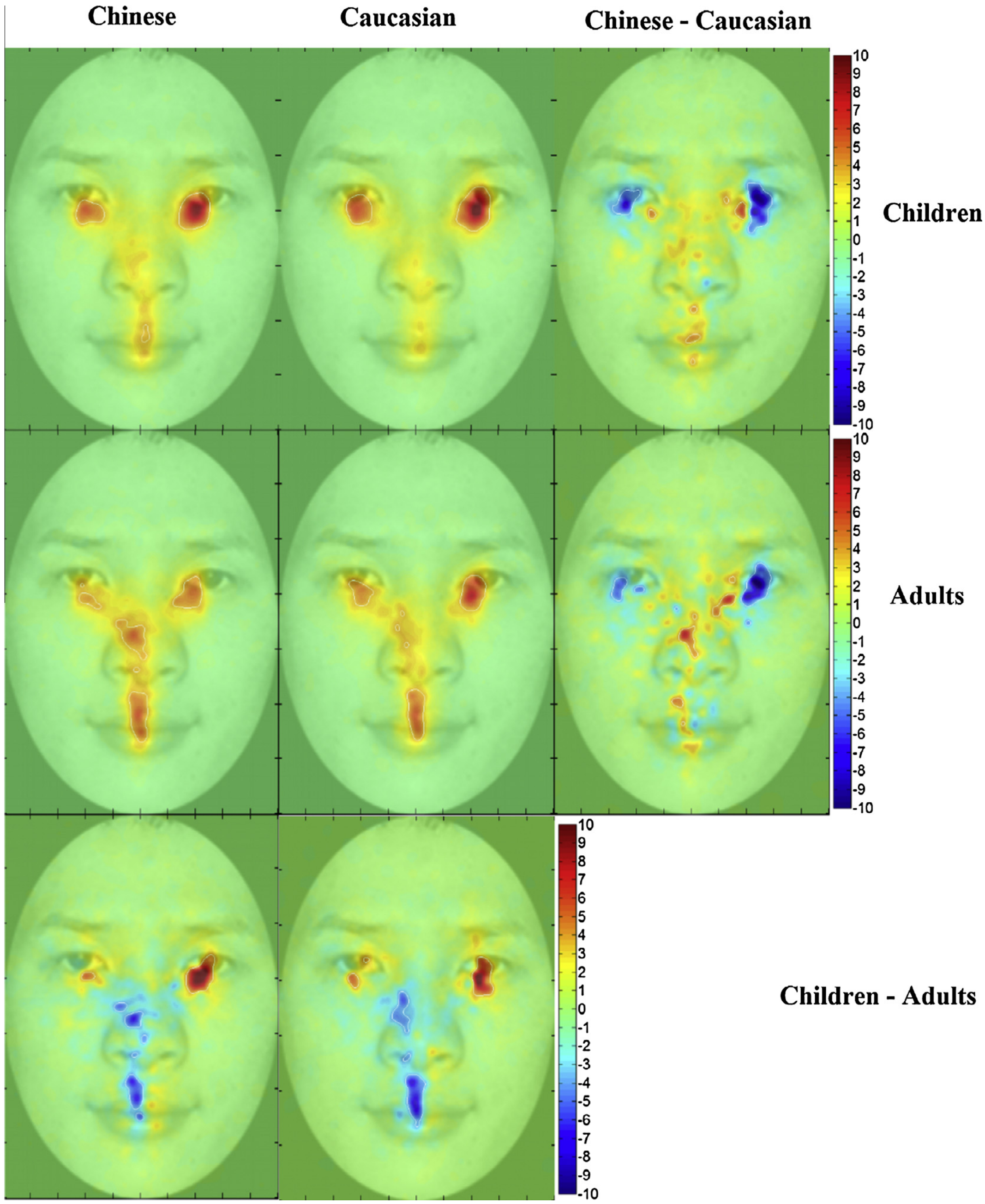

Fig. 3. iMap raw fixation maps of children and adults' fixation on Chinese and Caucasian faces and the difference maps.

significantly higher than those on Chinese eyes, all $t(112) > 9.64$, all $p < 0.001$. In addition, fixation percentages on the Caucasian nose and mouth were significantly lower than those on the Chinese nose and mouth, all $t(112) < -4.21$, all $p < 0.001$.

3.2.4. Raw fixation difference maps

To further investigate the fixation data for faces of own and other races, we used the iMap Matlab toolbox (Caldara & Miellet, 2011). In our study, fixation data from 60 of the 83 child participants (aged from 48 to 79 months) and all the adult participants were effectively recorded. The fixation coordinates on all of the Chinese and Caucasian target faces were analyzed with the iMap method, from which we obtained raw fixation maps (Fig. 3) in t values for both groups of children's fixations (first row), adults' fixations (second row), and children's versus adults' fixations (third row). Because there was no significant difference between the younger and older child groups, child fixation proportion on each AOI (eyes, nose, mouth) were combined into one child age group.

In addition, we showed separately the raw fixation maps for Chinese faces (first column) and for Caucasian faces (second column), and the raw fixation difference map in t values for Chinese faces versus Caucasian faces (third column). Areas showing a significant fixation difference are delimited by white borders ($p < .05$, corrected). In the third row of Fig. 3, hot colors (i.e., red[1]) denote greater fixations by children than adults, and cold colors (i.e., blue) denote greater fixations by adults than children, and values near 0 (or green color) indicate similar magnitude in fixation between children and adults. As shown, the red regions with white borders on the left eye and below both eyes indicate greater fixations

[1] For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

by children there. In addition, blue regions with white borders on the nose and mouth, and between the nose and mouth, indicate greater fixations by adults there.

In the third column of Fig. 3, hot colors (i.e., red) denote greater fixations on Chinese faces than Caucasian faces, and cold colors (i.e., blue) denote greater fixations on Caucasian faces than Chinese faces, with values near 0 (or green color) indicating similar magnitude in fixation between faces of own and other races. As shown, a red region with white border on the nose for adults indicates greater fixations on Chinese faces there; blue regions with white borders on the eyes for both children and adults indicate greater fixations on Caucasian faces there.

3.3. Saccade pattern during learning and reviewing target faces

Saccades were classified into ten groups according to their different combination of fixation regions: left eye–right eye, left eye–nose, left eye–mouth, left eye–other, right eye–nose, right eye–mouth, right eye–other, nose–mouth, nose–other, other–other, as shown in Fig. 4. Only the saccades between AOIs (left eye, right eye, nose, mouth) were analyzed in the following results.

3.3.1. Numbers of saccades within the whole face

These data are shown in the third column of Table 3. An ANOVA with face race (Chinese, Caucasian) as a within-subject factor, and age group (younger children, older children, adults) as a between-subjects factor was conducted on the saccade numbers within the whole face. The interaction of face race with age group did not reach significance, $p > 0.05$. The effect of face race was significant, $F(1,110) = 7.41$, $p = 0.008$, $\eta^2 = 0.063$. The number of saccades executed on Chinese faces ($M = 5.81$, $SD = 1.57$) was significantly lower than that on Caucasian faces ($M = 6.01$, $SD = 1.61$). The effect of age group was also significant, $F(2,110) = 46.93$, $p < 0.001$, $\eta^2 = 0.46$. A Scheffe post hoc test revealed that adults' saccade numbers were significantly greater than those of younger- and older-children, both $p < 0.001$.

3.3.2. Proportional numbers of saccades between eyes, nose, and mouth

To analyze each age group's saccade pattern during processing of faces of own and other races, we calculated the proportional numbers of saccades between the AOIs (left eye, right eye, nose, mouth) of faces, dividing the numbers of saccades between these AOIs by the total saccade numbers within each face.

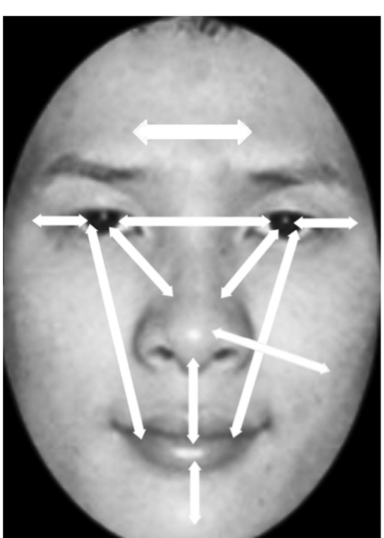

Fig. 4. Ten saccade groups: left eye–right eye, left eye–nose, left eye–mouth, left eye–other, right eye–nose, right eye–mouth, right eye–other, nose–mouth, nose–other, other–other.

Table 3
Number and amplitude of saccades on Chinese and Caucasian faces.

Group	Face race	Number of saccades	Amplitude of saccades
Younger children	Chinese	5.17(1.10)	3.92(0.90)
	Caucasian	5.33(1.24)	4.12(0.97)
Older children	Chinese	5.18(1.18)	3.51(0.61)
	Caucasian	5.45(1.09)	3.69(0.80)
Adults	Chinese	7.57(1.25)	3.87(0.67)
	Caucasian	7.73(1.44)	4.02(0.53)

An ANOVA with region (left eye–right eye, left eye–nose, left eye–mouth, right eye–nose, right eye–mouth, nose–mouth) and face race (Chinese, Caucasian) as within-subject factors, and age group (younger-children, older-children, adults) as a between-subjects factor, was conducted on the proportional numbers of saccades. The results showed that a three-way interaction among region, race, and age group was significant, $F(10,550) = 9.076$, $p < 0.001$, $\eta^2 = 0.142$.

To explore the effects of race in the three-way interaction, we conducted paired sample t tests on proportional numbers of saccades for each age group separately. The results showed that the effect of face race on children's proportional numbers of saccades was not significant for any saccade path, all Bonferroni method adjusted, $p > 0.05$. By contrast, adults' proportional numbers of saccades between left eye and right eye, left eye and nose, and right eye and nose on Chinese faces were significantly lower than those on Caucasian faces, all $t(29) < -3.75$, all Bonferroni method adjusted, $p < 0.01$. These race effects in t values are shown in Fig. 5.

To explore the simple age effect in the three-way interaction, multivariate tests with age group as the independent variable and proportional numbers of saccades on the six saccade paths between AOIs for both races were conducted, and the results showed that an age group effect was significant overall, $F(12,99) = 24.14$, $p < 0.001$, $\eta^2 = 0.745$. Tests of between-subjects effects revealed that the age group effect was significant for all saccade paths of both races of faces, all $F(2,110) > 12.2$, $p < 0.001$, $\eta^2 > 0.18$. Scheffe post hoc tests revealed that adults' proportional numbers of saccades were significantly higher than both older and younger children, regardless of the saccade path or face race, all $p < 0.002$; no difference between younger children and older children was significant, regardless of the saccade path or face race, all $p > 0.05$.

3.3.3. Saccade amplitude during learning and reviewing target faces

These data are shown in the fourth column of Table 3. The saccade amplitude is defined as the Euclidean distance between the coordinates of the first fixation and the second (last) fixation during a saccade (unit: degrees) (Fuhrmann, Komogortsev, & Tamir, 2009). In our study, saccade amplitude data from 60 of the 83 child participants (aged from 48 to 79 months) and all the adult participants were effectively recorded. An ANOVA with face race (Chinese, Caucasian) as a within-subject factor and age group (children, adults) as a between-subjects factor was conducted on the mean saccade amplitude when the participants fixated on the faces.

The interaction between face race and age group was not significant, $p > 0.05$. However, the main effect of face race was significant, $F(1,88) = 6.82$, $p = 0.011$, $\eta^2 = 0.072$. The mean saccade amplitude on own-race Chinese faces ($M = 3.82$ deg, $SD = 0.79$ deg) was significantly lower than that on other-race Caucasian faces ($M = 4.00$ deg, $SD = 0.82$ deg). The main effect of age was not significant, $p > .05$.

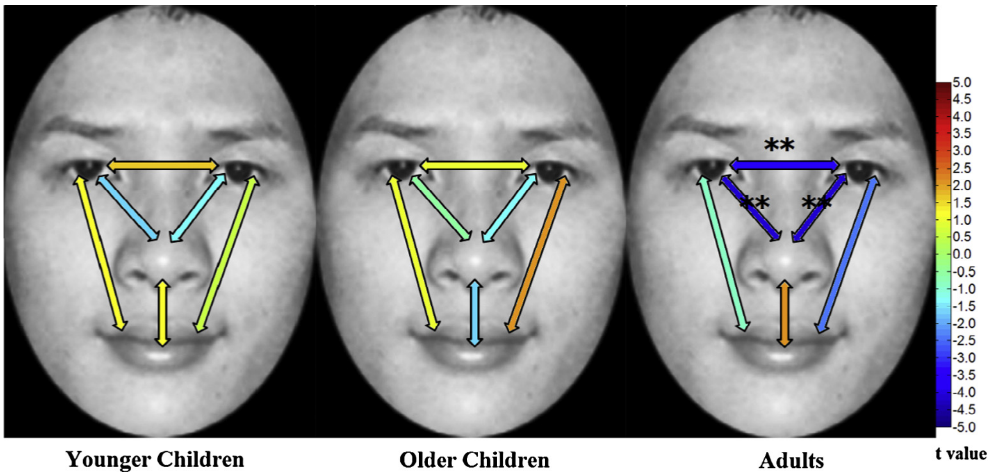

Fig. 5. Race effects on saccade paths with warmer colors representing more scanning for own-race faces and cooler colors representing more scanning for other-race faces (*Note:* ** denotes t values for which $p < 0.01$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

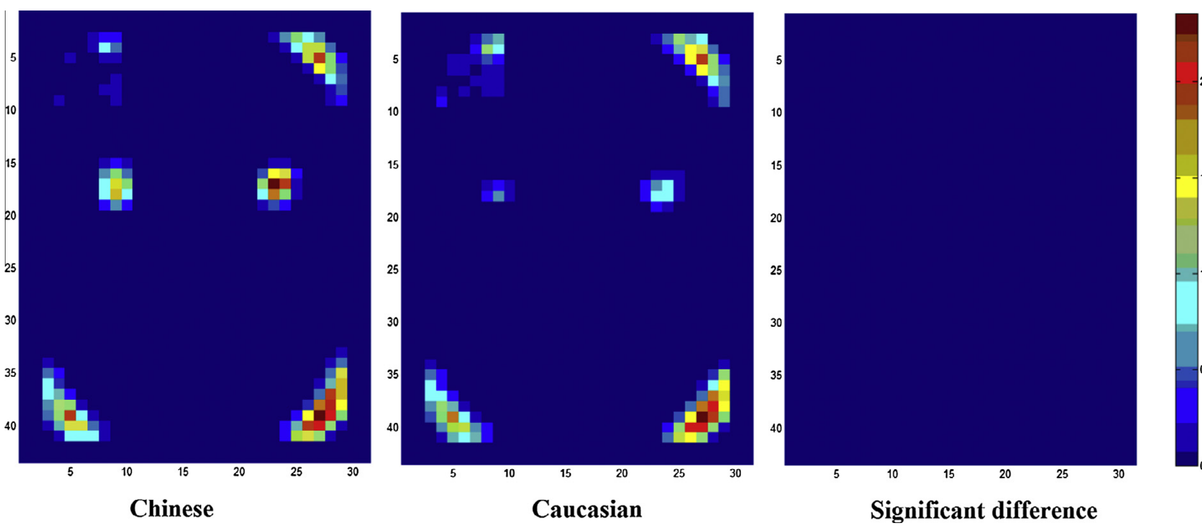

Fig. 6. Mean saliency maps for the Chinese target faces (left), Caucasian target faces (middle) and the significant difference (right). *X* and *Y* axes represent the mean horizontal and vertical coordinates of each pixel of the Chinese or Caucasian faces (as measured in the proportion of the corresponding axis of a face). The colors on the top of the temperature bar refer to the mean saliency values of the Chinese or Caucasian faces, with warm colors denoting high saliency and cold colors denoting low saliency. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.4. Stimulus saliency analysis

One possibility for the participants' differential attention to Chinese and Caucasian eyes, noses, and mouths might be that the Chinese and Caucasian features have different perceptual saliency such that participants' visual attention was naturally drawn to the eyes in the Caucasian faces and the nose and mouth in the Chinese faces. To test this possibility, we performed a saliency analysis using the Saliency Toolbox designed by Walther and Koch (2006). This toolbox can calculate saliency for each area in a photo based on a psychologically plausible neural network model. This model is built on the assumption that more directed selective attention should be paid to areas with greater saliency for better recognition (Walther & Koch, 2006). During the analysis of salience, each face photo was automatically divided into 37 * 28 grids. The saliency results of each of the Chinese face photos were spatially averaged to derive a mean saliency map for the Chinese target faces (Fig. 6 left), and for the Caucasian target faces (Fig. 6 middle). Then, the Chinese and Caucasian face saliency maps were compared using the "gene mattest" procedure (independent *t*-tests) in Matlab2010a, variance assumed to be unequal. Results showed that after adjustments for type I error using the FDR method, there was no significant difference of saliency between Chinese and Caucasian acquaintance faces or between Chinese and Caucasian foil faces, as shown in Fig. 6 right.

4. Discussion

This study examined child and adult visual scanning of faces of own and other races in a face learning and recognition task. Eye-tracking findings from the current study indicated that 4- to 7-year-old children and adults differentially fixated the internal features of faces of different races. They fixated more on Caucasian eyes than Chinese eyes, and fixated more on the Chinese nose and mouth than the Caucasian nose and mouth. These results are in accord with our previous study with Chinese adults (Fu et al., 2012).

Consistent with the findings of the AOI analysis, the iMap analysis showed that both Chinese child and adult participants fixated more on the eye regions of the Caucasian faces. In particular, they appeared to fixate on the pupils of the Chinese eyes significantly less than on those of the Caucasian eyes. In contrast, the participants fixated significantly more on the region just below the eyes of the Chinese faces than on the corresponding region of the Caucasian faces. In addition, adults' proportional fixation on the nose was significantly more than that of children. Furthermore, analysis of the age group effect revealed an increasing tendency to avoid direct eye contact by age, which is confirmed by the iMap analysis of the race effect: only in adults was there a significant difference of fixation duration on the nose between different races. Correspondingly, only in adults, the proportional number of saccades (1) between the two eyes, and (2) between the nose and each eye, on own-race faces was significantly lower than on other-race faces.

These results taken together suggest that Chinese children may already have learned from the experience of processing own-race faces that avoiding direct eye contact is more acceptable within Chinese culture; however, they do not have a well-formed habit of avoiding direct eye contact for less experienced Caucasian faces. In addition, the habit of avoiding direct eye contact is more established in adults and thus the race effect is more salient in adults. This may be due to adults' increasing experience in Chinese society where direct eye contact is avoided out of respect for others (Pitta, Fung, & Isberg, 1999). In other words, the adults performed more "politely" than the children.

Our novel scan path analyses revealed that participants' mean saccade amplitude during processing of own-race faces was significantly lower than that during processing of other-race faces, indicating more fined-grain perceptual processing, as suggested by Maw and Pomplun (2004). Given that extraction of individual identity feature information on faces requires more finer-grain perceptual processing (Liu, Harris, & Kanwisher, 2002), our results may offer support for the "social-categorization" model which argues that observers focus more on group feature information which is relatively coarse when viewing out-group or other-race faces, while they focus more on individual feature information indicating more fine-grained processing when viewing in-group or own-race faces (Bernstein, Young, & Hugenberg, 2007).

No significant difference was found between younger and older children. That is, we did not demonstrate that the age range from 48 to 80 months is a key period for facial scanning strategy development. However, adults' fixation duration/saccade numbers on the whole faces, proportional fixation percentage on the nose, proportional numbers of saccades between AOIs, and accuracy in recognizing faces were significantly higher than those of children, demonstrating a more attentive and holistic facial processing strategy. The contrast between child and adult performance suggests additional advantages in face recognition among more mature and experienced observers. A nose-centered strategy is believed to be effective for processing several different facial features at the same time (Fu et al., 2012), and the saccades between the eyes, nose, and mouth indicate integration of these different facial features. The difference in processing strategy between children and adults may reflect the outcome of expertise development that occurs with adults' greater experience of processing faces. Previous studies have demonstrated an important role for holistic processing in expert face recognition (Richler, Cheung, & Gauthier, 2011). Future studies could explore the effect of intervention on facial processing strategy to support face recognition performance, e.g. instructing participants to fixate more diligently on the inner facial features (eyes, nose, mouth, especially the nose), and transfer fixations between the eyes, nose, and mouth more frequently during learning faces.

In summary, our results demonstrate that abundance of visual experience with own-race faces and the lack of it with other-race faces may result in different facial scanning strategies and cognitive resource allocation in both adults and children as young as 4–7 years of age. The findings therefore inform our understanding of the role of visual experience in the development of face processing. As mentioned in the introduction, there has been some research on the visual scanning of own- and other-face faces in infancy and adulthood, but few studies on how children visually scan these two types of faces. The present data thus bridge an important gap in our knowledge about the development of the processing of faces of own and other races and the role of experience throughout the developmental period. Taken together with the existing research results on infants and adults, we conclude that differences between processing faces of own and other races which begin in infancy continue to develop in childhood, and may not reach maturity until adulthood. However, given the fact that only Chinese participants were included in this study, future studies with other-race participants such as Caucasian are necessary for the generalization of this conclusion to other ethnic groups.

In summary, we used multiple methods to analyze the eye-tracking data of Chinese children and adults when they scanned faces of own and other races. Results revealed that regardless of age group, proportional fixation duration on the eyes of Chinese faces was significantly lower than that on the eyes of Caucasian faces, whereas proportional fixation duration on the nose and mouth of Chinese faces was significantly higher than that on the nose and mouth of Caucasian faces. In addition, participants' saccade amplitude on Chinese faces was significantly lower than that on Caucasian faces, potentially reflecting finer-grained processing for own-race faces. Moreover, adults' fixation duration/saccade numbers on the whole faces, proportional fixation percentage on the nose, proportional number of saccades between AOIs, and accuracy in recognizing faces were higher than those of children. These results together demonstrate that an abundance of visual experience with own-race faces and a lack of it with other-race faces may result in differential facial scanning in both adults and children. Furthermore, the increased experience of processing faces may result in a more holistic and advanced scanning strategy in Chinese adults.

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