



PAPER

Perceptual narrowing towards adult faces is a cross-cultural phenomenon in infancy: a behavioral and near-infrared spectroscopy study with Japanese infants

Megumi Kobayashi,^{1,2} Viola Macchi Cassia,³ So Kanazawa,⁴
Masami K. Yamaguchi⁵ and Ryusuke Kakigi¹

1. Department of Integrative Physiology, National Institute for Physiological Sciences, Japan

2. Japan Society for Promotion of Science, Japan

3. Department of Psychology, University of Milano-Bicocca, Italy

4. Department of Psychology, Japan Women's University, Japan

5. Department of Psychology, Chuo University, Japan

Abstract

Recent data showed that, in Caucasian infants, perceptual narrowing occurs for own-race adult faces between 3 and 9 months of age, possibly as a consequence of the extensive amount of social and perceptual experience accumulated with caregivers and/or other adult individuals of the same race of the caregiver. The neural correlates of this developmental process remain unexplored, and it is currently unknown whether perceptual tuning towards adult faces can be extended to other cultures. To this end, in the current study we tested the ability of 3- and 9-month-old Japanese infants to discriminate among adult and infant Asian faces in a visual familiarization task (Experiment 1), and compared 9-month-olds' cerebral hemodynamic responses to adult and infant faces as measured by near-infrared spectroscopy (NIRS) (Experiment 2). Results showed that 3-month-olds exhibit above-chance discrimination of adult and infant faces, whereas 9-month-olds discriminate adult faces but not infant faces (Experiment 1). Moreover, adult faces, but not infant faces, induced significant increases in hemodynamic responses in the right temporal areas of 9-month-old infants. Overall, our data suggest that perceptual narrowing towards adult faces is a cross-cultural phenomenon occurring between 3 and 9 months of age, and translates by 9 months of age into a right-hemispheric specialization in the processing of adult faces.

Research highlights

- In Japanese infants, newborn face discrimination decreases between 3 and 9 months of age, whereas adult face discrimination is maintained.
- Perceptual narrowing towards adult faces is a cross-cultural phenomenon.
- At 9 months of age, hemodynamic responses are selective to adult faces in the right temporal areas.
- Nine-month-olds show a right-hemisphere specialization in the processing of adult faces.

Introduction

A large body of evidence has recently accumulated indicating that the first year of life is a crucial time for the development of face processing abilities. For example, newborn infants show spontaneous preference for certain visual attributes that are inherent to faces, and by 3 months of age their visual preference becomes specific to the geometry of the face (e.g. Chien, 2011; Macchi Cassia, Turati & Simion, 2004; Macchi Cassia, Kuefner, Westerlund & Nelson, 2006). Accordingly, visual

Address for correspondence: Megumi Kobayashi, Department of Integrative Physiology, National Institute for Physiological Sciences, 38, Nishigo-Naka, Myodaiji, Okazaki, 444-8585, Japan; e-mail: megumik@nips.ac.jp

deprivation during the first few months of life in individuals born with bilateral congenital cataracts produces permanent deficits in holistic/configural face processing (Le Grand, Mondloch, Maurer & Brent, 2004; Robbins, Nishimura, Mondloch, Lewis & Maurer, 2010). Moreover, between birth and 3 months of age infants develop a familiarity preference for specific categorical traits (i.e. species, race, gender) of the faces they experience most often in their social environment (Bar-Haim, Ziz, Lamy & Hodes, 2006; Di Giorgio, Méary, Pascalis & Simion, 2012; Quinn, Yahr, Kuhn, Slater & Pascalis, 2002), and towards the end of the first year they become more selective in their face processing and discrimination as a function of experience with distinct facial categories (Kelly, Quinn, Slater, Lee, Ge *et al.*, 2007; Pascalis, de Haan & Nelson, 2002).

Indeed, natural experience acquired with human faces leads, between 6 and 9 months, to a decline in the ability to distinguish among monkey (Pascalis *et al.*, 2002) and non-primate faces (Simpson, Varga, Frick & Frigaszy, 2010). Similarly, by the end of the first year, infants raised by a female primary caregiver are better able to process and categorize female faces compared to male faces (see review by Ramsey, Langlois & Marti, 2005), and both Caucasian and Asian infants raised in a monoracial environment show superior visual discrimination for faces of people of their own race ('own-race faces') (Anzures, Quinn, Pascalis, Slater & Lee, 2010; Kelly *et al.*, 2007; Kelly, Liu, Lee, Quinn, Pascalis *et al.*, 2009; Spangler, Schwarzer, Freitag, Vierhaus, Teubert *et al.*, 2013).

These findings show that perceptual experience provided to each infant by his/her own social environment is crucial in shaping face representation during the first year of life. They have been interpreted within the framework of the perceptual narrowing hypothesis (for reviews see Maurer & Werker, 2014; Scott, Pascalis & Nelson, 2007), according to which perceptual experience in multiple perceptual domains prompts a drop in infants' sensitivity to infrequent or non-relevant stimuli, and triggers perceptual tuning toward those stimuli that are more frequent and relevant in the infant's environment. Indeed, converging evidence suggests that biases in face discrimination abilities emerge at 9 months of age as a consequence of natural asymmetries in the amount of experience that infants accumulate with various individuals within their social environment. Observational studies (Sugden, Mohamed-Ali & Moulson, 2013) and data from parental reports (Rennels & Davis, 2008) indicate that there are large discrepancies in the demographic features of the faces to which infants are typically exposed during their first year, and the majority of infants' experience is with individuals who share the same race, age and gender of their primary caregiver.

Recently, research exploring how infants' and children's ability to process and recognize faces is modulated by face age has provided further evidence supporting the view that early experience provided by the social environment has a crucial role in shaping face representation. Macchi Cassia and colleagues (Macchi Cassia, Bulf, Quadrelli & Proietti, 2014) have shown that, although 3-month-old infants can discriminate between familiar and novel faces for both adult and infant faces, 9-month-olds can differentiate among adult faces but not among infant faces. These findings suggest that perceptual narrowing occurs for face age as well as for species and race, as by 9 months of age infants' face representation tunes towards adult faces. This is consistent with earlier demonstrations that young children (i.e. 3-year-olds) are more expert at processing and discriminating adult faces compared to infant faces (Macchi Cassia, Kuefner, Picozzi & Vescovo, 2009), child faces (Macchi Cassia, Pisacane & Gava, 2012) or older adult faces (Proietti, Pisacane & Macchi Cassia, 2013).

In interpreting these findings, the authors (see also Macchi Cassia, 2011) made the argument that, together with differences in the amount of interactions, enhanced motivation to attain attentional and physical proximity to caregivers may play an important role in the emergence of an early bias towards adult faces. In a similar vein, Scherf and Scott (2012) highlighted the critical role of the age-appropriate developmental task of forming an attachment relationship with a primary caregiver in driving the infant's need to perceptually differentiate the primary caregiver(s) from other individuals in his/her social environment. Within this framework, the current study aimed to extend the existing evidence on perceptual narrowing to adult faces by investigating the cross-cultural nature of this phenomenon.

To our knowledge, there is only one study investigating age-related face processing biases in developmental populations from different ethnic groups (Macchi Cassia, Luo, Pisacane, Li & Lee, 2014). In this study, the authors adopted a combined cross-race/cross-age design and showed that both Caucasian and Mainland Chinese 3-year-old children manifested an adult face bias, which was confined to own-race faces. Children from both ethnic groups were more accurate at discriminating adult own-race faces than child own-race faces and showed an increased use of expert face processing strategies for the former face type. Although this evidence indicates that, by 3 years of age, children from at least two different ethnic groups manifest an adult-like age bias in favor of adult faces, it leaves open the question of whether the over-representation of adult faces from the participants' own ethnic group emerges in the first year of life as a universal cross-cultural phenomenon.

To fill this gap, the current study tested whether discrimination abilities of Japanese infants narrow to adult human faces within the same time frame as Caucasian infants (Macchi Cassia, Proietti & Pisacane, 2013). In Experiment 1, a familiarization/novelty preference procedure was used to test the ability of 3- and 9-month-old Japanese infants to discriminate among adult and infant faces. If the developmental pattern observed in Caucasian infants generalizes to Japanese infants, their infant face discrimination would decrease between 3 and 9 months, while their adult face discrimination would be maintained.

A second aim of the current study was to investigate the neural signature of perceptual tuning toward adult faces by comparing hemodynamic responses for adult and infant faces in 9-month-old infants, as measured by near-infrared spectroscopy (NIRS). So far, the neural correlates of perceptual narrowing in infants have been investigated in a limited number of studies using event-related potentials (ERPs), which offer good temporal but relatively poor spatial resolution. Although limited, this research indicates that the specificity to upright (vs. inverted) human (vs. monkey) faces of the N290 and P400, the two putative face-sensitive infant ERP components, increases between 6 and 9 months of age (de Haan, Pascalis & Johnson, 2002; Halit, de Haan & Johnson, 2003; Scott & Monesson, 2010). At 9 months, race (Caucasian vs. African American) modulates the amplitude of the P400 (Balas, Westerlund, Hung & Nelson, 2011; Vogel, Monesson & Scott, 2012).

The effects of age on infants' neural response to faces have to date not been described. Two electrophysiological studies with young children reported that ERP responses to adult and non-adult faces differ for several components in the time range of 80–400 ms, but the direction of such differences varies across studies. Melinder and colleagues (Melinder, Gredebäck, Westerlund & Nelson, 2010) found that in 5-year-old children the amplitude of the N170 was enhanced for child faces compared to young and older adult faces, and the P2 was smaller for child faces than for older adult faces. Peykarjou and colleagues (Peykarjou, Westerlund, Macchi Cassia, Kuefner & Nelson, 2013) reported that face age modulates the amplitude of the P1 and the N170 in 3-year-old children, with adult faces eliciting larger amplitudes than infant faces. Although these findings suggest that by 3 years of age the child's brain differentiates between adult and non-adult faces, they leave open the question of whether face age modulates face-sensitive neural activity earlier in development.

By using NIRS, in Experiment 2 we measured hemodynamic responses to adult and infant faces in 9-month-olds' bilateral temporal areas. Neuroimaging

studies with adults revealed that some cortical areas in the occipito-temporal region, including the inferior occipital gyrus (occipital face area; OFA), the middle fusiform gyrus (fusiform face area; FFA) and superior temporal sulcus (STS), have an important role in face processing, as they show higher activation in response to face images than to images of non-face objects (Haxby, Hoffman & Gobbini, 2000; Kanwisher, McDermott & Chun, 1997; Kanwisher & Yovel, 2006; Puce, Allison, Asgari, Gore & McCarthy, 1996). Recently, developmental studies have used NIRS to explore the extent to which temporal areas are involved in face processing in the earliest stages of development. NIRS is a noninvasive neuroimaging technique that measures relative signal changes of oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb) and total-hemoglobin (total-Hb) concentration (Hoshi, Kobayashi & Tamura, 2001; Villringer & Chance, 1997). Unlike other neuroimaging methods, including functional magnetic resonance imaging (fMRI), NIRS is very suitable for measuring brain activity in awake infants because it does not require the participant's body and head to be fixed during the recording of hemodynamic responses.

Earlier NIRS studies have reported a significant increase in hemodynamic responses to various types of face stimuli in the right temporal region of the infant's brain from the age of 5 months (e.g. Carlsson, Lagercrantz, Olson, Printz & Bartocci, 2008; Honda, Nakato, Otsuka, Kanazawa, Kojima *et al.*, 2010; Ichikawa, Kanazawa, Yamaguchi & Kakigi, 2010; Nakato, Otsuka, Kanazawa, Yamaguchi, Watanabe *et al.*, 2009; Otsuka, Nakato, Kanazawa, Yamaguchi, Watanabe *et al.*, 2007), and this response is independent from the low-level features of the stimuli (Kobayashi, Otsuka, Kanazawa, Yamaguchi & Kakigi, 2012). Based on this evidence, we aimed to investigate whether face-related hemodynamic activity in the right temporal area of 9-month-old infants differentiates between adult and infant faces.

Experiment 1

Method

Participants

The final sample included 24 3-month-old infants (15 females, M age = 104.04 days; range = 83–118 days) and 24 9-month-old infants (13 females, M age = 279.13 days; range = 257–297 days). All participants were healthy and full-term and all were Japanese. Within each age group, infants were assigned randomly and in equal numbers to the two face age conditions

(adult and infant). An additional 33 infants were tested, but were excluded from the analyses due to fussiness ($n = 6$), a side bias greater than 90% (i.e. looking more than 90% of the time to one side) either in the pre-familiarization or in the post-familiarization test trials ($n = 25$), or longer looking times in the last three trials than in the first three trials during the familiarization phase ($n = 2$). Participants were recruited through advertisements posted in local newspapers. The study was explained to the parents and their written informed consent was obtained.

Stimuli

Stimuli were color photographs of six female adult faces and six newborn infant faces of Japanese origin pictured in a frontal view with neutral expression (Figure 1). Face images were cropped using Adobe Photoshop, with all faces sharing similar black hair. When viewed from approximately 40 cm, each image subtended approximately $12.34^\circ \times 17.40^\circ$ of visual angle for adult faces, and $10.33^\circ \times 13.18^\circ$ for infant faces. Faces from each age group were paired into three invariable pairs. When



Figure 1 Examples of the adult and infant faces used as stimuli. Faces were presented on a white background.

presented bilaterally on the screen, the distance between the inner portion of the faces was approximately 21° .

Fourier analysis performed on the six adult face images and the six infant face images revealed that differences in power between the images were more evident in the low spatial frequencies range than in the high spatial frequencies for both adult and infant faces. This suggests that one cue for discriminating among faces of both ages is provided by differences in spectral power at low spatial frequencies. Considering the cut-off values reported for 4-month-old and 8-month-old infants estimated by Peterzell, Werner and Kaplan (1995) and Gwiazda, Brill, Mohindra and Held (1980), these cues should be equally available to the 3-month-old and the 9-month-old infants tested in the current study, who should be equally able to utilize the differences in spectral power at low spatial frequencies to discriminate among adult faces as well as among infant faces.

Apparatus

All infants were tested when sitting on the parent's lap at a viewing distance of approximately 40 cm from a 22-inch CRT monitor, which was controlled by a computer (Dospa Prime Galleria). Both the infant and the monitor were surrounded by an enclosure covered with black cloth. The parent was unaware of the hypothesis of the study and the predicted looking preference in each experimental condition, and was instructed to remain silent. Each infant's looking behavior throughout the experiment was recorded through a charge-couple device (CCD) camera positioned just below the monitor, which was connected to a TV monitor and a digital video recorder positioned outside the enclosure. The experimenter, who was blind to the face age condition each infant was assigned to, started the sequence of the trial by looking at the live image of the infant's face displayed on the TV monitor. The recorded images of the infant's face and looking behavior allowed for the offline coding of looking times during the pre- and post-familiarization trials.

Procedure

Infants in both age groups were assigned randomly to one of the two face age conditions and one of the three face pairs ($n = 4$). Infants were tested using a familiarization/novelty preference procedure composed of three phases: a pre-familiarization test phase consisting of two 10-sec trials, a familiarization phase consisting of six 15-sec trials, and a post-familiarization test phase consisting of two 10-sec trials. The pre-familiarization and the post-familiarization test phases were identical in order to

compare infants' preferential looking behavior before and after familiarization. Each trial began with a cartoon image appearing at the center of the screen, accompanied by a beeping sound to attract the infant's attention. As soon as the infant looked at the cartoon, the image was turned off and the face stimuli were activated. At the end of the 10 s or 15 s, the stimuli disappeared from the screen and the cartoon image reappeared. During the familiarization trials, infants were shown two images of the same face presented bilaterally on the screen. During the pre- and the post-familiarization test trials, infants were shown the familiar (non-target) face paired with a novel (target) face from the same age group, with the left/right position of the familiar and novel stimuli counterbalanced across infants in the first trial and reversed in the second trial.

One observer analyzed frame-by-frame the video-recordings of infants' eye movements to record total looking time to each of the two faces during each phase of the testing session. In addition, video-recordings of 16 of the infants (eight of the 24 3-month-olds and eight of the 24 9-month-olds) were analyzed by a second independent observer. Both observers were unaware of the face age condition in which the infants were tested and the position (left/right) where the familiar and novel faces were presented on the screen. Interobserver agreement (Pearson correlation) calculated on total fixation times throughout the experiment was $r = 0.94$, $p < .05$ for the 3-month-olds and $r = 0.93$, $p < .05$ for the 9-month-olds. The presence of a spontaneous preference for the target or the non-target face during the pre-familiarization test trials, and/or successful discrimination between the familiar and the novel face during the post-familiarization trials, were inferred from the participants' tendency to look longer at one of the two stimuli across the two trials of each phase.

Results

Familiarization trials

For each infant, the total looking time for the two face stimuli during each familiarization trial was averaged across the first three trials and last three trials (Table 1). The effect of familiarization was examined in a three-way analysis of variance (ANOVA) with participant's age (3 or 9 months) and face age (adult or infant) as between-participants factors and familiarization trial (first three or last three) as the within-participants factor. The analysis revealed significant main effects of participants' age, $F(1, 44) = 7.27$, $p < .01$, $\eta^2 = .11$, and trial, $F(1, 44) = 14.18$, $p < .01$, $\eta^2 = .05$, with the 3-month-old infants showing overall longer looking times than the 9-

Table 1 Mean and standard deviation of total looking time during the first three and the last three familiarization trials for 3- and 9-month-old infants in the adult face and the infant face conditions of Experiment 1

Condition	N	Familiarization trials			
		First three		Last three	
		M (s)	SD (s)	M (s)	SD (s)
3 m					
Adult	12	14.00	0.67	13.74	0.88
Infant	12	13.80	1.12	13.13	1.67
9 m					
Adult	12	13.06	1.55	12.01	2.34
Infant	12	12.97	1.31	12.00	2.34

month-olds, and all infants showing a similar decline in mean looking time across familiarization irrespective of the age of the target faces. No other effects or interaction were significant (all $ps > .10$).

Test trials

In order to compare looking times for the two faces during the pre-familiarization and the post-familiarization test trials and to facilitate comparison across the two age groups, we computed two mean novelty preference scores for each participant, one for each type of test trial (Figure 2). Each score was calculated by dividing the looking time toward the target/novel face by the total looking duration toward both the target/novel and the non-target/familiar faces, then averaging the results across the two test trials and multiplying the ratio by 100. A group mean novelty score that is significantly different from the chance level of 50% reflects spontaneous and/or learned preference, whereas a score that is not different from 50% indicates a lack of preference and discrimination. Novelty preference scores were analyzed in a three-way ANOVA with participants' age (3 or 9 months) and face age (adult or infant) as between-participants factors, and test phase (pre- or post-familiarization) as the within-participants factor. The ANOVA yielded a significant main effect of test phase, $F(1, 44) = 39.12$, $p < .01$, $\eta^2 = .27$, as well as a significant interaction among all three factors, $F(1, 44) = 4.44$, $p < .05$, $\eta^2 = .03$. To follow up this interaction, we performed two separate two-way ANOVAs, one for each age group. For the 3-month-olds, the main effect of the test phase was significant, $F(1, 22) = 13.72$, $p < .01$, $\eta^2 = .13$, whereas no other effects attained statistical significance (all $ps > .7$). Novelty preference scores were larger for the post-familiarization trials (adult face: $M = 58.1\%$, infant face: $M = 57.7\%$) than for the pre-

familiarization trials (adult face: $M = 49.3\%$, infant face: $M = 47.9\%$) in both the adult and the infant face conditions. For 9-month-olds, the analysis revealed a significant main effect of test phase, $F(1, 22) = 31.0$, $p < .01$, $\eta^2 = .15$, which was qualified by a significant Face Age \times Test Phase interaction, $F(1, 22) = 9.64$, $p < .01$, $\eta^2 = .05$. Planned paired t -tests showed that the novelty preference scores were significantly larger for the post-familiarization trials than for the pre-familiarization trials in the adult face condition (pre-familiarization: $M = 46.6\%$ vs. post-familiarization: $M = 62.1\%$), $t(11) = 5.47$, $p < .01$, $d = 2.20$, but not in the infant face condition (pre-familiarization: $M = 51.1\%$ vs. post-familiarization: $M = 55.5\%$), $t(11) = 2.00$, $p = .07$, $d = .59$. Moreover, independent t -tests showed that the percentage of time spent looking at the target face differed between the two face age conditions in the post-familiarization trials (adult condition: $M = 62.1\%$ vs. infant condition: $M = 55.5\%$), $t(11) = 2.09$, $p < .05$, $d = .74$, and in the pre-familiarization trials (adult condition: $M = 46.6\%$ vs. infant condition: $M = 51.1\%$), $t(11) = 3.19$, $p < .05$, $d = .91$.

These findings were further explored through a series of one-sample t -tests which showed that, for the 3-month-old infants, the percentage of time spent looking at the target novel stimulus during the post-familiarization test trials was significantly different from the chance level of 50% in both the adult face condition ($M = 57.7\%$), $t(11) = 2.58$, $p < .05$, $d = 1.05$, and the infant face condition, ($M = 58.1\%$), $t(11) = 3.42$,

$p < .01$, $d = 1.40$, whereas the preference score did not differ from 50% in either condition during the pre-familiarization test trials (both $ps > .44$). In contrast, the 9-month-olds' novelty preference score during the post-familiarization test trials was significantly above 50% in the adult face condition ($M = 62.1\%$), $t(11) = 4.84$, $p < .01$, $d = 1.98$, but not in the infant face condition ($M = 55.5\%$), $t(11) = 2.04$, $p = .07$, $d = .84$. Of note, the 9-month-olds' preference score in the adult face condition (but not in the infant face condition, $p > .47$) differed from 50% even during pre-familiarization test trials ($M = 46.6\%$), $t(11) = 2.41$, $p < .05$, $d = .98$, but the direction of the pre-familiarization preference was opposite to the direction of the post-familiarization preference, thus excluding any impact of pre-existing preference on the novelty preference engendered by the familiarization trials. Indeed, although a preference for the to-be-familiar face during the pre-familiarization trials was apparent in 10 out of the 12 infants included in the sample, all these infants displayed a preference for the novel face during the post-familiarization trials. In addition, the preference for the to-be-familiar face in pre-familiarization trials did not arise from a preference for a specific identity, as we counterbalanced the novel and to-be-familiar identity within each face pair across participants. Overall then, we believe that the presence of a significant preference for the to-be-familiar adult face during pre-familiarization trials did not hinder the novelty effect observed during post-familiarization trials.

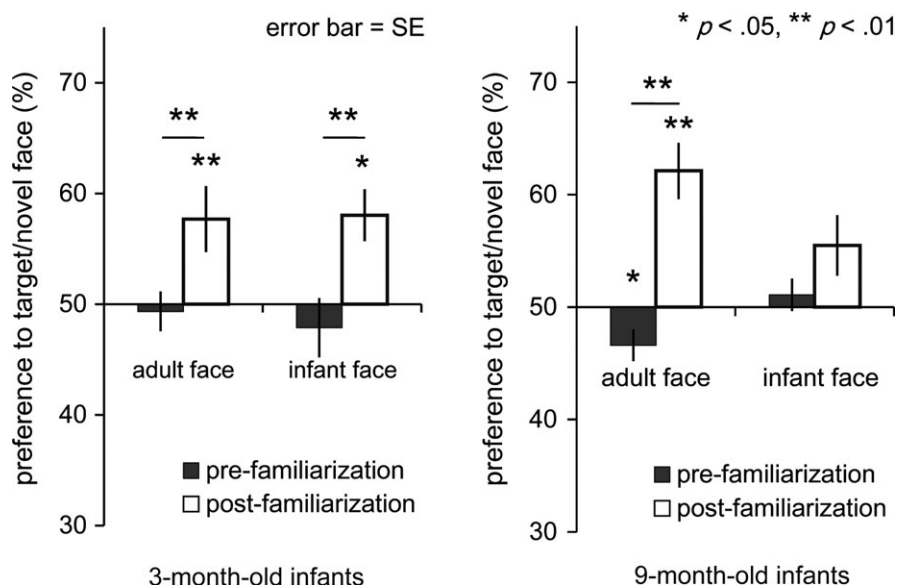


Figure 2 Mean preference scores to the target (novel) face manifested by the 3-month-old infants and the 9-month-old infants tested in Experiment 1 during the pre-familiarization and the post-familiarization test trials. Error bars represent ± 1 standard error of the means.

Experiment 2

Methods

Participants

The final sample consisted of 12 full-term, healthy 9-month-old Japanese infants (6 females, M age = 271.1 days; range = 256–287 days). An additional 7 infants were tested but not included in the sample due to fussiness ($n = 2$), motion artifacts ($n = 3$), or an insufficient number of available trials ($n = 2$; at least three trials for both the adult face condition and infant face condition). The procedure followed ethical standards (the Declaration of Helsinki, BMJ 1991; 302:1194) and was approved by the Ethical Committee of Chuo University and the National Institute for Physiological Sciences. Parents gave prior written informed consent for their infant's participation.

Stimuli

The stimuli for the test period were full-color photographs of five out of the six Japanese adult female faces and five out of the six newborn infant faces used in Experiment 1. For the baseline period, we used full-color photo images of vegetables (see Otsuka *et al.*, 2007, Nakato *et al.*, 2009, Kobayashi *et al.*, 2011, 2012, 2014). The size of the face stimuli was the same as in Experiment 1, and the size of the vegetable images were approximately $16.8^\circ \times 16.8^\circ$, when viewed from approximately 40 cm. The face stimuli and the vegetables images were accompanied by two different beeping sounds presented at 1 Hz to keep the infant's attention. The sound was the same for the adult and the infant face condition, and the relation between the sounds and the visual stimuli was counterbalanced across infants.

Procedure

Infants were tested individually while sitting on the experimenter's or the parent's lap and facing a 22-inch CRT monitor approximately 40 cm away. Infants' hemodynamic responses were recorded while they passively watched the stimuli, and trial presentation continued until they stopped looking at the display. Participants' looking behavior was videotaped during the experiment.

The testing session was composed of a baseline period and a test period. In both periods, images were flashed for a duration of 800 ms, and a 200-ms ISI was filled with a small red cross that acted as a central fixation point. During the test period, infants were tested in two conditions: the adult face condition and the infant face

condition. The two conditions were alternated between trials, with the order counterbalanced across infants. In both conditions, the five facial identities were shown in random order within each trial. Each test period lasted 5 s and was preceded by a baseline period of at least 10 s, whose exact duration was controlled by the experimenter. Data recorded during the baseline period were used as the baseline.

Recording

By using HITACHI ETG-4000 system (Hitachi Medical, Chiba, Japan), we recorded hemodynamic responses from 24 channels simultaneously, with 12 channels for each the right and left temporal area. The instrument, which generates two different wavelengths (695 and 830 nm), measured the time course of oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb), and the sum (total hemoglobin, total-Hb) with a 0.1-s time resolution. We used a pair of probes, each consisting of nine optical fibers (3×3 arrays) with five light emitters and four detectors, and set the inter-fiber distance at 2 cm. For each hemisphere, the probes were positioned on the bilateral temporal areas centered at T5 and T6 position according to the International 10–20 system (Jasper, 1958; see Honda *et al.*, 2010; Kobayashi *et al.*, 2011, 2012, 2014; Ichikawa *et al.*, 2010; Nakato *et al.*, 2009; Nakato, Otsuka, Kanazawa, Yamaguchi & Kakigi, 2011a; Nakato, Otsuka, Kanazawa, Yamaguchi, Honda *et al.*, 2011b; Yamashita, Kanazawa, Yamaguchi & Kakigi, 2012, for other infant studies recording from the same sites). After positioning the probes on the infant's head, the experimenter established whether the probes were contacting the infant's scalp correctly via the ETG-4000 system, which automatically detects the channels that are inadequate to measure the hemodynamic responses. We rejected the channels from the analysis in which inappropriate contact between the probes and the infant's scalp was detected due to hair interference.

Data analysis

As in previous NIRS studies (Honda *et al.*, 2010; Nakato *et al.*, 2009; Otsuka *et al.*, 2007), test trials were discarded from analysis if (1) the infant looked away from the face stimuli or became fussy, (2) the infant glanced back to the experimenter's or parent's face during the preceding baseline period, or (3) the analysis of sharp changes in the time courses of the raw oxy-Hb data detected motion artifacts.

The raw data of hemoglobin changes from the individual channels were digitally filtered with a band-

pass of 0.02–1.0 Hz to eliminate any longitudinal signal drift and high frequency measurement noise. Then we averaged the raw data of each channel across the trials for each subject from 2 s before the test trial onset to 10 s after the test trial offset. From the raw time series data of oxy-, deoxy-, and total-Hb, the *Z*-scores at each time point were calculated in the adult face condition and infant face condition for each channel and each subject. We calculated the *Z*-scores as the difference of the means between the baseline and test condition divided by the standard deviation (*SD*) of the 2-s baseline using the following formula:

$$d = (Test - M \text{ baseline}) / S$$

Test represents the raw data value at each data point (adult face condition and infant face condition) and *M baseline* represents the mean of raw data during the 2-s-baseline period. *S* represents the *SD* of the baseline. Because the raw data of NIRS signals were relative values and could not be averaged directly across participants or channels (Matsuda & Hiraki, 2006; Shimada & Hiraki, 2006), we applied normalized *Z*-scores to the analysis.

We averaged *Z*-scores from 2 s to 6 s after stimulus onset across participants for each test condition, and then performed statistical analyses against these mean *Z*-scores for the oxy-, deoxy-, and total-Hb concentrations. Two-tailed one-sample *t*-tests against a chance level of 0 (baseline) were conducted for the mean *Z*-score during the 2-s to 6-s period of the test trials in both temporal areas. Repeated-measure ANOVAs with two factors, face age (adult or infant) as the between-participant factor and hemisphere (right or left) as the within-participant factor, were conducted on the mean *Z*-score. Furthermore, oxy-Hb changes in each of the 24 channels for both the adult face and the infant face conditions were tested through a two-tailed one-sample *t*-test against the baseline. The multiple comparisons were corrected by a false discovery rate (FDR) (Singh & Dan, 2006).

Results

We obtained hemodynamic responses from 12 9-month-olds who looked at the stimuli for more than three trials in both the adult face and the infant face conditions. The mean number of valid trials was 3.9 (*SD* = 1.27) for the adult face condition and 4.1 (*SD* = 1.38) for the infant face condition. The mean number of channels was 11.8 for the adult face condition and 11.9 for the infant face condition.

Figure 3 shows the time course of the average oxy-Hb, deoxy-Hb and total-Hb concentrations in the bilateral temporal areas obtained from 12 channels for each hemisphere under the adult face condition (the black line) and the infant face condition (the gray line) during

the presentation of adult faces and infant faces. Increases in oxy-Hb and total-Hb concentrations in the adult face condition occurred about 2 s after the beginning of the test trial. The decrease occurred in the right temporal area after the end of the test trial, and in the left temporal area just before the end of the test. In contrast to oxy-Hb and total-Hb, deoxy-Hb changes in both temporal areas were observed not in response to the adult faces, but in response to the infant faces.

Figure 4 represents the mean *Z*-score of oxy-Hb, deoxy-Hb and total-Hb concentration from 2 s to 6 s after face stimulus onset. A repeated-measure ANOVA with face age (adult or infant) and hemisphere (left or right) as within-subject factors was performed on the average *Z*-score of oxy-Hb, deoxy-Hb and total-Hb from 2 s to 6 s after the face stimulus onset, respectively. This analysis revealed a significant effect of condition for oxy-Hb concentration, $F(1, 11) = 10.87, p < .01, \eta^2 = .27$, deoxy-Hb, $F(1, 11) = 9.00, p < .05, \eta^2 = .25$, and total-Hb, $F(1, 11) = 5.63, p < .05, \eta^2 = .11$. No other effect or interaction reached statistical significance for oxy-, deoxy-, or total-Hb (all *ps* > .10). To examine the possibility that there were differential hemoglobin changes for the presentation of faces compared to the vegetable baseline stimuli, we performed a two-tailed one-sample *t*-test on the *Z*-scores against a chance level of 0 (baseline) for each hemoglobin change separately. Oxy-Hb concentration increased significantly in response to adult faces only in the right temporal area, $t(11) = 4.02, p < .05$, whereas the decrease in deoxy-Hb concentration was significant in response to adult faces in the left temporal area, $t(11) = 3.16, p < .01$. For total-Hb, there were no significant changes (*ps* > .10).

Discussion

In this study, we investigated the presence of a processing bias toward adult faces in Japanese infants using behavioral looking time measures and neuroimaging measures of brain activation. The results of Experiment 1 replicated and extended an earlier demonstration of perceptual narrowing toward adult faces in Caucasian infants (Macchi Cassia *et al.*, 2014) by showing that the same narrowing process occurs in infants of a different culture. Just like Caucasian infants, Japanese infants showed discrimination of both adult and infant faces at 3 months of age, but failed to differentiate among infant faces at 9 months. These findings are the first to demonstrate that perceptual narrowing toward adult faces is a cross-cultural phenomenon.

The finding that the discrimination bias towards adult faces is not confined to Caucasian infants is consistent

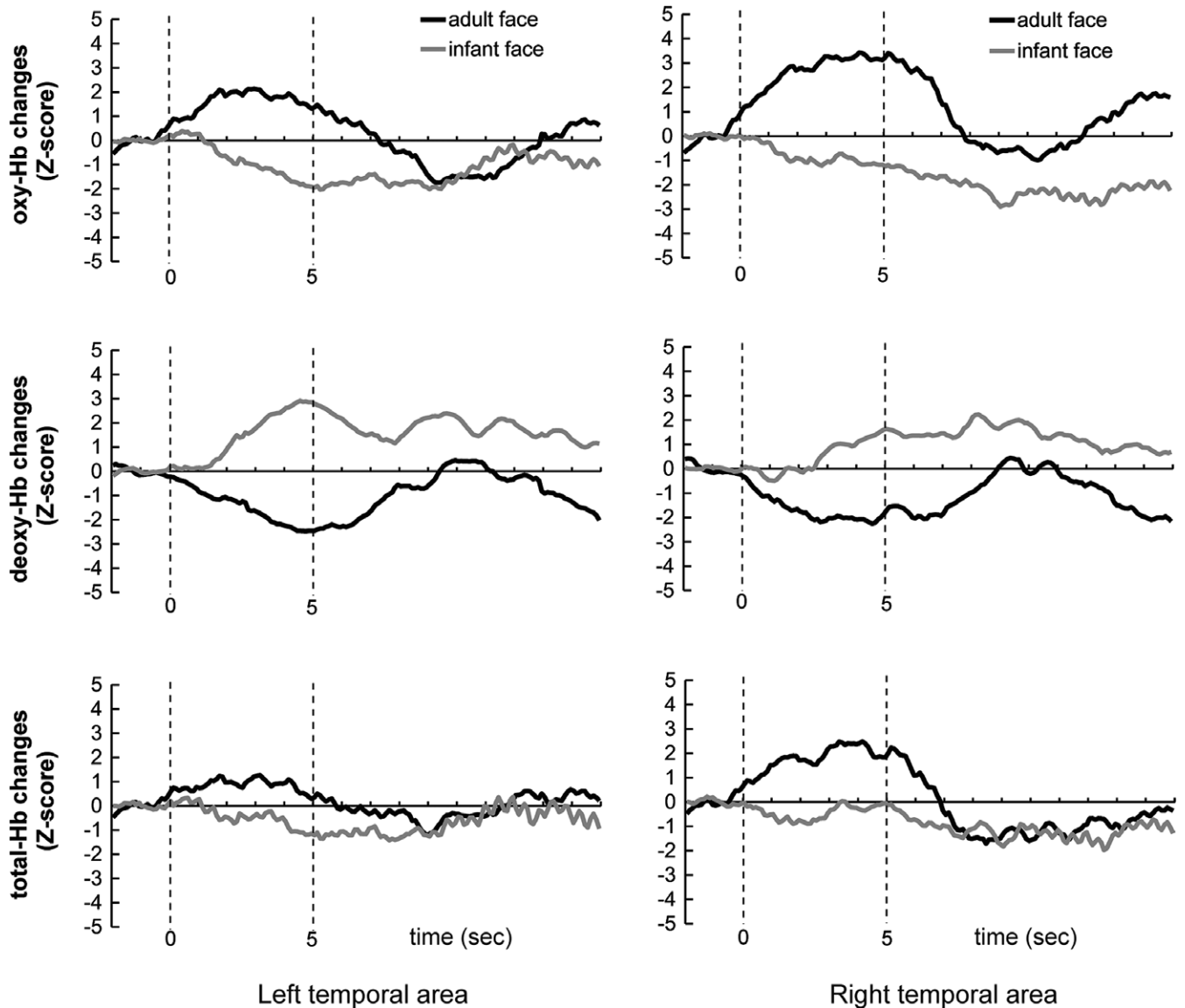


Figure 3 The time course of oxy-Hb (top), deoxy-Hb (middle), and total-Hb (bottom) concentration during the presentation of adult and infant faces. The time course of oxy-Hb changes were obtained from 12 channels for each temporal area under the adult face condition (the black line) and infant face condition (the gray line). Zero on the horizontal axis represents the beginning of the test period, and 10 represent the end of the test period.

with existing evidence that the ‘own-race bias’ in 9-month-old infants is a universal phenomenon that extends to different cultures (Kelly *et al.*, 2009). In a series of studies, Kelly and colleagues showed that Caucasian and Chinese 3-month-olds discriminated among both own- and other-race faces, whereas 9-month-olds in both ethnic groups discriminated among own-race faces, but failed to discriminate other-race faces. Despite cultural differences in visual exploration strategies revealed by eye movements (Kelly, Liu, Rodger, Mielle, Ge *et al.*, 2011), perceptual tuning to

own-race faces occurs within the same time window across different cultures. Results from the current study show that the same developmental pattern holds across different cultures even in the case of face age.

Results from Experiment 2 showed that adult faces, but not infant faces, induced significant increases in hemodynamic responses in the temporal areas of the brain, and that this enhanced hemodynamic response to adult faces was localized in the right temporal area, suggesting a right-hemispheric specialization in the processing of adult faces. These results are consistent

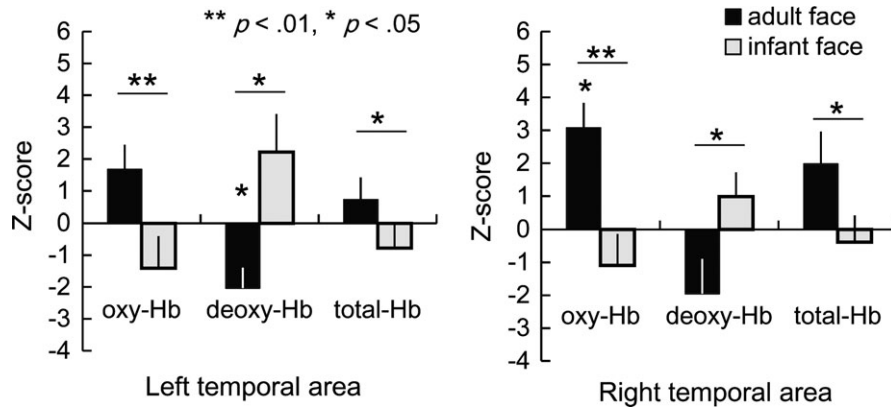


Figure 4 Mean Z-scores of oxy-, deoxy-, and total-Hb concentration. The black bars represent the mean Z-scores for the infant face condition; the light gray bars represent the mean Z-scores for the adult face condition.

with those reported by Balas *et al.* (2011), showing that differences in ERP responses evoked by own-race versus other-race faces were more evident in the right than in the left hemisphere of 9-month-old infants' brains. Taken together, these results indicate that by 9 months of age faces from one's most frequently encountered ethnic and age group/s are processed predominantly in the right hemisphere.

The finding of a right-hemispheric advantage in the processing of adult faces, in comparison to infant faces, might reflect heavier reliance on configural perceptual strategies in the processing of the former compared to the latter. It has been shown that, in both adults (Campbell, Landis & Regard, 1986; Haxby *et al.*, 2000; Hillger & Koenig, 1991; Honda, Watanabe, Nakamura, Miki & Kakigi, 2007; Rossion, Dricot, Develder, Bodart & Crommelinck, 2000; Scott & Nelson, 2006; Watanabe, Kakigi & Puce, 2003) and infants (Scott & Nelson, 2006), configural information embedded in faces is processed mainly in the right hemisphere. For example, Scott and Nelson (2006) showed that, similar to the adult face-sensitive N170, the P400 recorded in the right hemisphere of 8-month-old infants was more sensitive to configural changes than to featural changes in the information embedded in a familiarized face, with larger amplitude in response to the former than to the latter. Thus, studies that used adult faces as stimuli demonstrated that changes in the nature of face processing occur in many ways from 3 to 9 months of age, as infants shows greater sensitivity to configural second-order information (Bhatt, Bertin, Hyden & Reed, 2005; Hayden, Bhatt, Reed, Corbly & Joseph, 2007) and greater proficiency of integrating internal and external facial features (Cashon & Cohen, 2004; Schwarzer, Zauner & Jovanovic, 2007). These changes of abilities in perceptual processing likely reflect acquisition of perceptual

expertise with adult faces in infancy, which may well be related to the right hemispheric advantage in the processing of this face category, as observed in the current study.

Indeed, perceptual narrowing not only leads to a decline in infants' responsiveness to non-relevant or infrequent stimuli, but also drives perceptual tuning toward those stimuli that are most prevalent in the infant's social environment. In the cases of species and race, perceptual tuning toward human faces within the infant's own race involves not only increased specificity (de Haan *et al.*, 2002) and right-lateralization of electrophysiological responses to those faces (e.g. Balas *et al.*, 2011), but also enhanced holistic processing of own-race faces in comparison to other-race faces (Ferguson, Kulkofsky, Cashon & Casasola, 2009), as revealed by eye-tracking investigations of infants' visual scanning patterns (Gaither, Pauker & Johnson, 2012; Liu, Quinn, Wheeler, Xaio, Ge *et al.*, 2011). Like own-race faces, adult faces are processed more configurally than non-adult (i.e. infant and child) faces by preschool-aged children (Macchi Cassia *et al.*, 2009, 2012); it is reasonable to assume that this processing advantage emerges earlier in the first year of life as a result of perceptual tuning toward adult faces. Future studies may explore this question by investigating the scanning patterns used by 9-month-old infants when exploring adult and infant faces.

In this study, NIRS recordings were performed on 9-month-old infants based on behavioral evidence that infants at this age show a discrimination advantage for adult faces over infant faces, with the aim of exploring the neural correlates of such an advantage. However, it is still possible that neural specialization for adult faces develops earlier than the perceptual specialization apparent in looking behavior. To explore this possibility,

future studies may use NIRS to investigate whether hemodynamic activity differentiates between adult and infant faces in 3-month-old infants, who show equal discrimination of adult and infant faces in their behavior.

To conclude, the current study provides the first investigation of age biases in non-Caucasian infants, and the first exploration of the neural correlates of perceptual tuning for adult faces in 9-month-old infants. Results suggest that a discrimination advantage for adult faces develops universally between 3 months and 9 months of age, and that by 9 months of age such an advantage translates into a right-hemispheric specialization in the processing of adult faces.

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