Journal of Experimental Child Psychology 126 (2014) 161–177

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Category-specific face prototypes are emerging, but not yet mature, in 5-year-old children

Lindsey A. Short [a], Kang Lee [b], Genyue Fu [c], Catherine J. Mondloch [a,*]

[a] Department of Psychology, Brock University, St. Catharines, Ontario L2S 3A1, Canada
[b] Department of Human Development and Applied Psychology, University of Toronto, Toronto, Ontario M5S 1V6, Canada
[c] Department of Psychology, Zhejiang Normal University, Jinhua, Zhejiang 321004, China

ARTICLE INFO

Article history:
Received 10 March 2014
Revised 21 April 2014
Available online 14 June 2014

Keywords:
Aftereffects
Norm-based coding
Children's face space
Experience
Category-specific prototypes
Race

ABSTRACT

Adults' expertise in face recognition has been attributed to norm-based coding. Moreover, adults possess separable norms for a variety of face categories (e.g., race, sex, age) that appear to enhance recognition by reducing redundancy in the information shared by faces and ensuring that only relevant dimensions are used to encode faces from a given category. Although 5-year-old children process own-race faces using norm-based coding, little is known about the organization and refinement of their face space. The current study investigated whether 5-year-olds rely on category-specific norms and whether experience facilitates the development of dissociable face prototypes. In Experiment 1, we examined whether Chinese 5-year-olds show race-contingent opposing aftereffects and the extent to which aftereffects transfer across face race among Caucasian and Chinese 5-year-olds. Both participant races showed partial transfer of aftereffects across face race; however, there was no evidence for race-contingent opposing aftereffects. To examine whether experience facilitates the development of category-specific prototypes, we investigated whether race-contingent aftereffects are present among Caucasian 5-year-olds with abundant exposure to Chinese faces (Experiment 2) and then tested separate groups of 5-year-olds with two other categories with which they have considerable experience: sex (male/female faces) and age (adult/child faces) (Experiment 3). Across all three categories, 5-year-olds showed no category-contingent opposing aftereffects. These results demonstrate that 5 years of age is a stage characterized by minimal separation in the norms and associated

* Corresponding author. Fax: +1 905 688 6922.
E-mail address: cmondloch@brocku.ca (C.J. Mondloch).

http://dx.doi.org/10.1016/j.jecp.2014.04.004

coding dimensions used for faces from different categories and suggest that refinement of the mechanisms that underlie expert face processing occurs throughout childhood.

Introduction

Young children demonstrate several characteristics of adult-like face processing. They process faces holistically (e.g., de Heering, Houthuys, & Rossion, 2007), are more accurate in recognizing upright versus inverted faces (e.g., Mondloch, Le Grand, & Maurer, 2002) and own-race versus other-race faces (e.g., Sangrigoli & de Schonen, 2004), and show sensitivity to featural and relational (i.e., feature spacing) cues to identity (e.g., McKone & Boyer, 2006; Mondloch et al., 2002). Despite these abilities, children continue to make more errors on a variety of face perception tasks until mid-adolescence (e.g., Baudouin, Gallay, Durand, & Robichon, 2010; de Heering, Rossion, & Maurer, 2012; Freire & Lee, 2001; Mondloch, Dobson, Parsons, & Maurer, 2004; Schwarzer, 2000). There is debate as to whether these age-related improvements in face processing can be attributed to face-specific perceptual development or to more general cognitive and perceptual development (reviewed in McKone, Crookes, Jeffery, & Dilks, 2012). For example, Weigelt and colleagues (2014) reported improved performance in both face perception and face memory tasks between 5 and 10 years of age. However, whereas improvements in face memory were domain specific, improvements in face perception were not; similar improvements in perception were observed for cars, bodies, and scenes.

Regardless of the extent to which improvements in face perception during childhood reflect domain-specific versus domain-general development, two statements appear to be accurate. First, many of the mechanisms underlying adult-like face processing are present early in life (McKone et al., 2012). Second, face perception (e.g., the ability to discriminate faces) continues to improve throughout childhood (e.g., Baudouin et al., 2010; Mondloch et al., 2004). Thus, childhood may be characterized as a period of refinement. For example, although even infants are sensitive to differences among faces in feature spacing (Hayden, Bhatt, Reed, Corbly, & Joseph, 2007), adult-like sensitivity develops after 10 years of age (Mondloch et al., 2002) even when memory demands are eliminated (Mondloch et al., 2004). In the current study, we examined the extent to which refinements in norm-based face coding may contribute to children's tendency to make more errors than adults on face perception tasks. In particular, we examined whether 5-year-olds' face space is less well refined than that of adults with regard to the dimensions of faces from different categories.

Norm-based coding

Adult expertise in face processing has traditionally been attributed to the use of norm-based coding. According to Valentine (1991), individual faces are encoded relative to a face prototype (i.e., average face) extracted from all faces previously encountered. Individual faces differ on a variety of dimensions (e.g., distance between the eyes), and each dimension is represented as a unique vector in a multidimensional face space. Within this face space, individual faces are represented as distinct points; the farther a face is from the prototype, the more distinctive and less attractive it appears (Rhodes & Tremewan, 1996).

The face prototype is continuously updated by experience. Adaptation is an experimental method commonly employed to examine the malleability of the prototype. For example, repeated exposure to faces distorted in a similar direction (e.g., features compressed inward) produces a temporary shift in the prototype that results in unaltered faces appearing distorted in the opposite direction while similarly distorted faces appear more attractive, referred to as figural aftereffects (Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003; Webster & MacLin, 1999). Thus, judgments of attractiveness require participants to reference a norm that is temporarily altered by exposure to distorted faces. Aftereffects have been found for the perception of sex, race, emotional expression (Webster, Kaping, Mizokami, & Dumahel, 2004), age (O'Neil & Webster, 2011), and identity (e.g., Anderson & Wilson, 2005; Leopold, O'Toole, Vetter, & Blanz, 2001; Rhodes & Jeffery, 2006). Furthermore, for both identity and figural adaptation, the more extreme the adapter is, the larger the aftereffect is (Rhodes et al., 2005; Robbins, McKone, & Edwards, 2007), which provides additional evidence of norm-based coding (Jeffery et al., 2010).

In adults, norm-based coding underlies the perception of face identity (Robbins et al., 2007; but see Ross, Deroche, & Palmeri, 2014) and is thought to facilitate discrimination around the norm (Wilson, Loffler, & Wilkinson, 2002) by reducing redundancy in the information shared by all faces, which frees neural resources and allows for greater sensitivity to the distinctive characteristics of individual faces (Rhodes & Leopold, 2011; Rhodes, Watson, Jeffery, & Clifford, 2010; Webster & MacLeod, 2011). Consistent with this account, there is a positive correlation between face recognition memory and the magnitude of aftereffects (Dennett, McKone, Edwards, & Susilo, 2012; Rhodes, Jeffery, Taylor, Hayward, & Ewing, 2014). Moreover, individuals with congenital prosopagnosia (Palermo, Rivolta, Wilson, & Jeffery, 2011) and autism (e.g., Ewing, Pellicano, & Rhodes, 2013), both of which are associated with deficits in face processing, show reduced identity aftereffects relative to typical populations.

Children as young as 4 years rely on norm-based coding (reviewed in Jeffery & Rhodes, 2011). At this age, children show both figural aftereffects (Jeffery et al., 2010; Short, Hatry, & Mondloch, 2011) and identity aftereffects (Jeffery, Read, & Rhodes, 2013). Like adults, more extreme adapters produce stronger aftereffects in children (Jeffery et al., 2011, 2013), and even expression appears to be coded in a norm-based manner by 9 years of age, the youngest age tested (Burton, Jeffery, Skinner, Benton, & Rhodes, 2013). Although there is some evidence that children's face space might be more malleable than that of adults (e.g., Hills, Holland, & Lewis, 2010), most studies have found that adults' and children's aftereffects are similar in size (Jeffery et al., 2010; Nishimura, Maurer, Jeffery, Pellicano, & Rhodes, 2008) and that the temporal dynamics of aftereffects are analogous in adults and children as young as 8 years (Nishimura, Robertson, & Maurer, 2011).

Refinement of face space

Children appear to represent faces in a multidimensional face space that has at least some adult-like characteristics. However, children may differ from adults in the organization or refinement of their face space. For example, although children exhibit evidence for norm-based coding, they require greater differences among faces in order to consistently rate unaltered faces as more attractive than faces with compressed or expanded features (Anzures, Mondloch, & Lackner, 2009; Crookes & McKone, 2009; Jeffery et al., 2010), which demonstrates that they are less sensitive to deviations from the norm. Furthermore, although 8-year-old children tend to rely on the same coding dimensions as adults, they exhibit difficulty in using more than one dimension at a time (Nishimura, Maurer, & Gao, 2009).

In the current study, we tested another factor that may contribute to the slow development of expert face processing—a reliance on a face space that is relatively undifferentiated with regard to faces from different categories. Adults possess multiple face prototypes that represent the different face categories encountered in the environment (e.g., race). Such separable prototypes may aid recognition; identification thresholds are lower around a race-specific average relative to a mixed-race/race-generic average (Armann, Jeffery, Calder, & Rhodes, 2011). Following adaptation to two face categories distorted in opposite directions (e.g., compressed Caucasian and expanded Chinese faces), adults' judgments of attractiveness/normality shift in opposite directions, which is possible only if these faces are represented with regard to separable norms and at least some category-specific coding dimensions. Such opposing aftereffects have been found for faces that differ according to race (Jaquet, Rhodes, & Hayward, 2008; Little, DeBruine, Jones, & Waitt, 2008), sex (Jaquet & Rhodes, 2008; Little, DeBruine, & Jones, 2005), orientation (Rhodes et al., 2004), age, and species (Little et al., 2008). Although opposing aftereffects indicate that faces from different categories are coded with regard to some category-specific dimensions, there is also some overlap in the coding dimensions used for these faces (Jaquet & Rhodes, 2008). When adults are adapted to distorted faces of one race, significant aftereffects emerge for a face race that was never shown during adaptation; however, these aftereffects are smaller than those of the adapted race (Jaquet et al., 2008). Such partial transfer of aftereffects reflects the shared coding dimensions across categories.

It may be the case that, unlike adults, children rely on a single prototype and its corresponding dimensions for all faces. Using an opposing aftereffects paradigm, Short and colleagues (2011) found evidence for race-specific norms (Caucasian/Chinese) in Caucasian 8-year-olds and some evidence for dissociable norms in Caucasian 5-year-olds; however, opposing aftereffects in 5-year-olds were driven almost entirely by simple aftereffects for own-race faces, which suggests that 5-year-olds' face space may be less well refined than that of adults and 8-year-olds. Therefore, it is possible that 5 years of age is a stage characterized by the emergence of separable norms for own- and other-race faces.

The current study

The current study was designed to further examine whether 5-year-old children rely on race-specific norms and investigate whether experience facilitates the development of dissociable face prototypes. In all studies, we used the storybook method initially designed by Anzures and colleagues (2009) to examine figural attractiveness aftereffects. In Experiment 1, we examined whether, like Caucasian 5-year-olds with minimal experience with other-race faces (Short et al., 2011), Chinese 5-year-olds show race-contingent aftereffects driven by simple aftereffects for own-race faces. We then used a transfer of aftereffects study in which Caucasian and Chinese children were adapted to distorted faces from a single race and tested with faces of both races. The goal of this second study was to determine whether 5-year-olds show simple aftereffects for other-race faces and the extent to which aftereffects transfer across races.

In Experiment 1, all participants had minimal experience with faces from the opponent category (i.e., other-race faces). In Experiments 2 and 3, we examined whether ample experience with a given category facilitates the development of category-specific prototypes in 5-year-old children. We investigated whether race-contingent aftereffects are present among Caucasian 5-year-olds who have ample exposure to Chinese faces and then tested children with two other categories with which they have considerable experience: sex (male/female faces) and age (adult/child faces).

Experiment 1a: Race-contingent aftereffects among Chinese 5-year-olds

Race is a highly meaningful face category for young children and, therefore, is suitable for examining category-specific face norms. Infants show own-race biases in visual preference and face recognition tasks (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005, 2007). Moreover, children as young as 3 years show a consistent own-race recognition advantage (Sangrigoli & de Schonen, 2004) and by 4 years display social biases based on race (Bigler & Liben, 1993) and attend to race when making inferences about the social relationships between children (Shutts, Roben, & Spelke, 2013).

In Short and colleagues' (2011) study, Caucasian 5-year-olds showed race-contingent aftereffects; however, these effects were driven by simple aftereffects for own-race faces with no shifts in attractiveness preferences for other-race faces. Crucially, all children tested in this study were from a predominantly Caucasian community and had minimal experience with Chinese faces. This weak evidence for opposing aftereffects suggests that young children who have minimal experience with other-race faces might not represent own- and other-race faces with regard to dissociable norms. To examine the robustness of this finding, we used the same method employed by Short and colleagues to test whether Chinese 5-year-olds who have minimal experience with Caucasian faces show race-contingent aftereffects.

Method

Participants

We tested 24 Chinese 5-year-olds (±6 months of age, 12 female and 12 male) from Jinhua, China, a city with a population that is 99.99% Chinese. An additional three children were tested but excluded from all analyses because they failed to meet criterion ($n = 2$) or were inattentive during testing ($n = 1$).

Materials

The original computerized storybook used by Short and colleagues (2011) was translated into Mandarin for Chinese participants. Stimuli consisted of colored photographs of Caucasian and mainland Chinese 4- to 6-year-old children. Faces were distorted using the Spherize function in Adobe Photoshop (Version 8.0). The experiment consisted of three phases: pre-adaptation attractiveness trials, adaptation, and post-adaptation attractiveness trials (see Fig. 1). Pre- and post-adaptation stimuli were divided into two sets of 16 face pairs (8 per race); each pair consisted of two versions of the same identity. In each set, there were four face pairs for each race comprising an unaltered face paired with an expanded face (+70%) and four face pairs comprising an unaltered face paired with a compressed face (−70%). Face pairs from one set were shown pre-adaptation, and face pairs from the other set were shown post-adaptation; the order in which the two sets were presented was counterbalanced across participants. Faces of 12 different identities (six Caucasian and six Chinese) were used as adaptation stimuli and were presented in the context of the 5-min computerized storybook used by Short and colleagues. In the storybook, Caucasian faces were distorted in one direction, whereas Chinese faces were distorted in the opposite direction (±90%). Only one race of face was presented on each page, and race of face alternated from page to page.

Procedure

The testing procedure was identical to that described by Short and colleagues (2011, Experiment 4). Children were seated in front of a 24-inch computer monitor and completed two sets of criterion trials to ensure that they understood task instructions. In each set of trials, children were simultaneously shown three objects that varied in attractiveness. They were then shown two objects at a time ($n = 2$ trials) and pointed to the most attractive object in each pair. Children were excluded from all analyses if they made more than one error, defined as selecting a less attractive item (e.g., a paper bag) as more attractive than the more attractive item with which it was paired (e.g., a green present with polka dots).

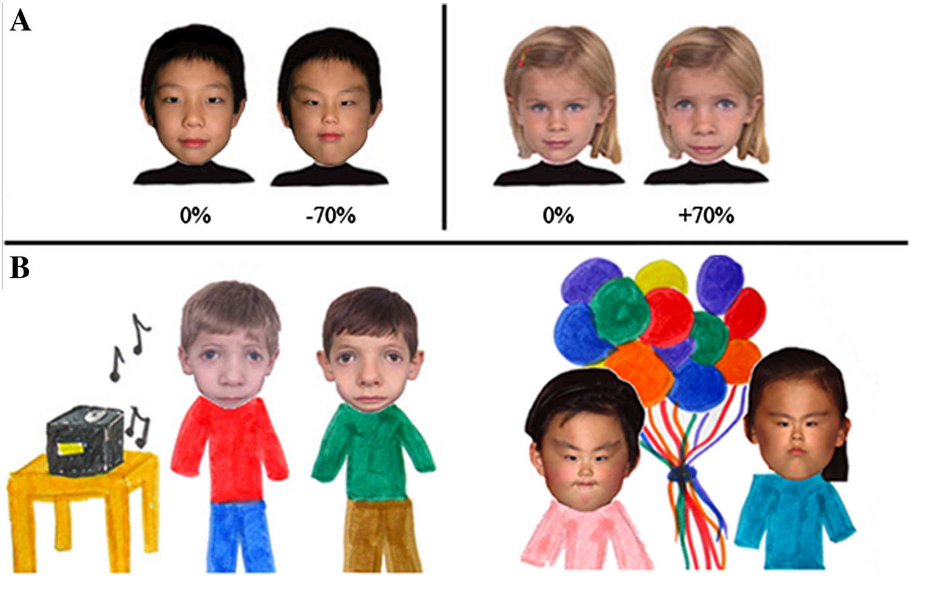

Fig. 1. (A) Sample face pairs shown during test trials in Experiments 1 and 2. (B) Sample pages from the adaptation storybook used in Experiment 1a. In Experiment 1b, children were adapted to only one face race; in all other experiments, children were adapted to faces from two categories distorted in opposite directions.

Children then completed 16 pre-adaptation trials. Children were told that they would be shown pairs of siblings and that their job was to point to the prettiest or most handsome face in each pair. Each child viewed 16 pairs (eight Caucasian and eight Chinese). Each face pair remained on the screen for 3 s and was then replaced with a blank screen. Participants indicated their choice by pointing to the side of the screen on which the more attractive face appeared. The next trial did not begin until a response had been made.

After pre-adaptation trials were completed, participants were read a 5-min story about two birthday parties: one attended by Caucasian children and the other attended by Chinese children. Half of the participants were adapted to expanded Caucasian faces (+90%) and compressed Chinese faces (−90%), and the other half were adapted to compressed Caucasian faces and expanded Chinese faces. Each page of the storybook contained between one and six faces, and the size and location of the faces varied to eliminate low-level retinotopic adaptation. Following the storybook, participants were shown an additional 16 face pairs (eight Caucasian and eight Chinese) and selected the most attractive face in each pair. To maintain adaptation, face pairs remained on the screen for 3 s and were then replaced with a blank screen. After each post-adaptation trial, two top-up faces were presented: one Caucasian and one Chinese; top-up faces were distorted in a way that was consistent with adaptation (Rhodes et al., 2003). The first top-up face matched the race of the previous trial, and the second top-up face matched the race of the upcoming trial. Top-up faces were paired with a comment designed to encourage participants (e.g., "I agree!"), and participants received reinforcement regardless of their response.

Results and discussion

For each participant, we recorded the number of distorted faces selected on expanded and compressed trials for the face race that was compressed during adaptation (Caucasian for half of the participants and Chinese for the other half) and for the face race that was expanded during adaptation. To determine whether there were any attractiveness biases prior to adaptation, we examined whether the number of +70% and −70% faces selected as most attractive pre-adaptation differed for the race of face to be expanded and the race of face to be compressed. A 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures analysis of variance (ANOVA) revealed no main effects, $ps > .31$, $\eta_p^2 s \leq .04$, or interaction, $p = .35$, $\eta_p^2 = .04$, indicating that prior to adaptation children were no more likely to select the +70% or −70% face for either the race of face to be expanded or the race of face to be compressed. As expected, the number of distorted faces selected pre-adaptation was low across all conditions ($Ms \leq 1.29$).

To determine whether Chinese 5-year-olds exhibited evidence for race-contingent aftereffects, we calculated change scores for both the expanded face race and the compressed face race by subtracting the number of distorted faces selected pre-adaptation from the number of distorted faces selected post-adaptation for each level of distortion. Opposing aftereffects would be evident if following adaptation the number of −70% faces selected as most attractive increased more for the face race that was compressed during adaptation than for the face race that was expanded and, at the same time, the number of +70% faces selected as most attractive increased more for the face race that was expanded during adaptation than for the face race that was compressed.

We conducted a 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the change in number of distorted faces chosen as the dependent variable. There were no main effects, $ps > .37$, $\eta_p^2 s < .04$, or interaction, $p = .22$, $\eta_p^2 = .07$. As shown in Fig. 2A, the number of +70% faces selected as most attractive did not increase any more for the face race that was expanded during adaptation ($M = .25$, $SE = .26$) than for the face race that was compressed ($M = -.17$, $SE = .30$). Likewise, the number of −70% faces selected as most attractive did not increase any more for the face race that was compressed during adaptation ($M = .21$, $SE = .25$) than for the face race that was expanded ($M = .17$, $SE = .17$). Indeed, single-sample *t* tests[1] revealed that in all conditions the magnitude of aftereffects did not differ significantly from 0, $ps > .32$.

[1] All reported single-sample *t* tests were two-tailed and uncorrected for multiple comparisons.

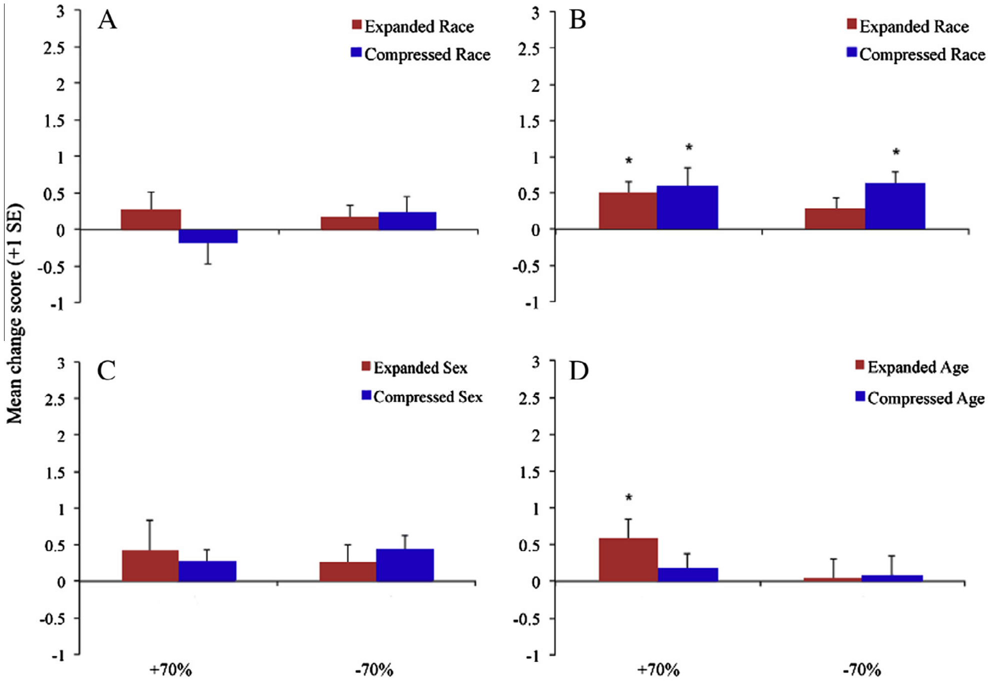

Fig. 2. Mean change scores for +70% and −70% test faces for the face category that was expanded versus the face category that was compressed during adaptation for Experiment 1a (A: Chinese 5-year-olds tested with Chinese and Caucasian faces), Experiment 2 (B: Caucasian 5-year-olds with multicultural exposure tested with Chinese and Caucasian faces), Experiment 3a (C: 5-year-olds tested with male and female faces), and Experiment 3b (D: 5-year-olds tested with adult and child faces). An asterisk (∗) indicates that aftereffects were significantly different from 0 ($p < .05$).

Our results show no evidence for race-contingent aftereffects among Chinese 5-year-olds. However, among Caucasian 5-year-olds tested in a racially homogeneous population (Short et al., 2011), opposing aftereffects were present, although they were driven by simple aftereffects for own-race faces. To determine whether Chinese children showed simple aftereffects for own-race faces, we conducted single-sample t tests comparing change scores for +70% Chinese faces for the 12 children adapted to expanded Chinese faces ($M = .08$, $SE = .45$) and change scores for −70% Chinese faces for the 12 children adapted to compressed Chinese faces ($M = .58$, $SE = .38$) with 0. In both conditions, the magnitude of aftereffects did not differ significantly from 0, $ps > .15$.

Chinese children with minimal experience with Caucasian faces showed no evidence for separable prototypes for Caucasian and Chinese faces. Following adaptation to Caucasian and Chinese faces distorted in opposite directions, attractiveness judgments for the expanded face race did not shift in the opposite direction of attractiveness judgments for the compressed face race. These results contrast with those of Short and colleagues (2011); in their study, Caucasian 5-year-olds did show evidence of opposing aftereffects. However, whereas 8-year-olds' opposing aftereffects were driven by shifts in attractiveness judgments for both Caucasian and Chinese faces, 5-year-olds' opposing aftereffects were driven by shifts in attractiveness judgments only for own-race faces. Based on these findings, Short and colleagues concluded that separable representations for own- and other-race faces are emerging by 5 years of age.

Opposing aftereffects provide evidence that faces from different categories are represented with regard to separable norms and category-specific coding dimensions (Jaquet & Rhodes, 2008). Weak opposing aftereffects, or the absence thereof, suggest that the coding dimensions that 5-year-olds rely on are largely overlapping for own- and other-race faces. To directly test this hypothesis, in Experiment 1b we examined the extent to which aftereffects transfer across face race among Caucasian and Chinese 5-year-olds.

Experiment 1b: Transfer of aftereffects across face race

Participants were adapted to distorted faces of only one race but judged the attractiveness of both Caucasian and Chinese faces during pre- and post-adaptation trials. Adults show partial transfer of aftereffects across face race, indicating that there are some shared coding dimensions for own- and other-race faces (Jaquet et al., 2008). In children, complete transfer of aftereffects across face race (i.e., no difference in the magnitude of aftereffects for the face race that was adapted vs. the face race that was not) would provide evidence of completely overlapping representations and coding dimensions for own- and other-race faces. Partial transfer of aftereffects would indicate separable representations with some shared underlying dimensions.

Half of the participants were adapted to distorted own-race faces and half were adapted to distorted other-race faces, which also allowed us to compare the magnitude of simple aftereffects for own-race versus other-race faces. Children were adapted only to compressed faces because past studies have found that viewing compressed faces during adaptation tends to produce larger aftereffects than viewing expanded faces (Jaquet & Rhodes, 2008; Jaquet et al., 2008), and we wanted to give children every opportunity to show partial transfer of aftereffects. We previously reported figural aftereffects for own-race faces in 5-year-old children using a similar paradigm (Short et al., 2011; see also Jeffery et al., 2010). However, to date there is no evidence that adaptation shifts attractiveness judgments for other-race faces in young children. An absence of simple aftereffects for other-race faces in participants adapted to only other-race faces would suggest that these faces might be represented as individual exemplars rather than in a norm-based fashion.

Method

Participants

We tested two groups of 5-year-old children (±6 months of age) who had minimal contact with other-race faces: 48 Caucasian children (27 female and 21 male) from St. Catharines, Ontario, Canada, who had minimal experience with Chinese faces, and 48 Chinese children (24 female and 24 male) from Jinhua, China, who had minimal experience with Caucasian faces. An additional 11 children were tested but excluded from all analyses because they failed to meet criterion ($n = 1$), were inattentive ($n = 1$), or were unable to follow task instructions ($n = 9$).

Materials and procedure

Pre- and post-adaptation trials were similar to those used in Experiment 1a. However, adaptation stimuli were presented in the context of the computerized storybook used by Anzures and colleagues (2009) in which there was a single surprise birthday party that was attended by only one race of children. All of the faces in the storybook were Caucasian for half of the children and Chinese for the other half. Adapting faces were compressed by −90%. Each storybook contained eight face identities, and the identities of the adapting faces differed from those used during pre- and post-adaptation trials. A single top-up face was presented following each post-adaptation trial.

Results and discussion

We examined whether the number of −70% faces selected as most attractive pre-adaptation differed for the race of face that matched adaptation and for the race of face that did not match adaptation across the two adaptation conditions (adapt to own-race faces and adapt to other-race faces). A 2 (Face Race: race that matched adapting stimuli or race that did not match adapting stimuli) × 2 (Adaptation Condition: adapt to own-race faces or adapt to other-race faces) mixed ANOVA for pre-adaptation trials revealed no main effects or interaction, $ps > .14$, $\eta^2_p s \leq .02$. The number of distorted faces selected pre-adaptation was low across all conditions ($Ms \leq .83$).

To determine the magnitude of simple aftereffects, we calculated change scores for both the race of face that matched adaptation and the race of face that did not match adaptation by subtracting the number of compressed faces selected pre-adaptation from the number of compressed faces selected post-adaptation. Single-sample *t* tests indicated that the magnitude of aftereffects was significantly greater than 0 in all conditions for both participant races, all $ps < .04$. We then conducted a 2 (Face Race: race that matched adapting stimuli or race that did not match adapting stimuli) × 2 (Adaptation Condition: adapt to own-race faces or adapt to other-race faces) × 2 (Participant Race: Caucasian or Chinese) mixed ANOVA with the change in number of compressed faces chosen as the dependent variable. As shown in Fig. 3, there was a main effect of face race, $F(1,92) = 5.01$, $p = .03$, $\eta_p^2 = .05$; aftereffects were larger for the face race that matched adaptation ($M = 1.27$, $SE = 0.14$) than for the face race that did not match adaptation ($M = 0.92$, $SE = 0.13$), indicating partial transfer of aftereffects. There was also a main effect of participant race, $F(1,92) = 4.92$, $p = .03$, $\eta_p^2 = .05$. The increase in the number of compressed faces chosen following adaptation was larger among Caucasian participants ($M = 1.33$, $SE = 0.15$) than among Chinese participants ($M = 0.85$, $SE = 0.15$). There were no other main effects or interaction, all $ps > .69$, $\eta_p^2\text{s} \leq .002$. Most notably, the magnitude of aftereffects did not differ as function of adaptation condition; aftereffects were no larger when participants adapted to own-race faces relative to other-race faces.

There are two key findings from the current experiment. First, the magnitude of aftereffects did not differ for own-race versus other-race faces, suggesting that children process other-race faces using norm-based coding. These results are consistent with the finding that expertise does not affect the magnitude of aftereffects; in adults, aftereffects are no larger for own-race faces than for other-race faces (Jaquet et al., 2008). Second, aftereffects were larger for the face race that matched adaptation relative to the face race that did not match adaptation, which indicates partial transfer of aftereffects and suggests that 5-year-olds have somewhat separable representations for own- and other-race faces. However, this dissociability might not be as great as that of adults and 8-year-olds because 5-year-olds show weak to no evidence for race-contingent aftereffects; it may be that the opposite distortions simply cancel each other out in the context of an opposing aftereffects paradigm. Evidence that partial transfer of aftereffects emerges prior to opposing aftereffects for face race is consistent with 8-year-olds showing partial transfer of aftereffects between upright and inverted faces (Jeffery, Taylor, & Rhodes, 2014), whereas 10-year-olds do not show orientation-contingent opposing aftereffects (Robbins, Maurer, Hatry, Anzures, & Mondloch, 2012).

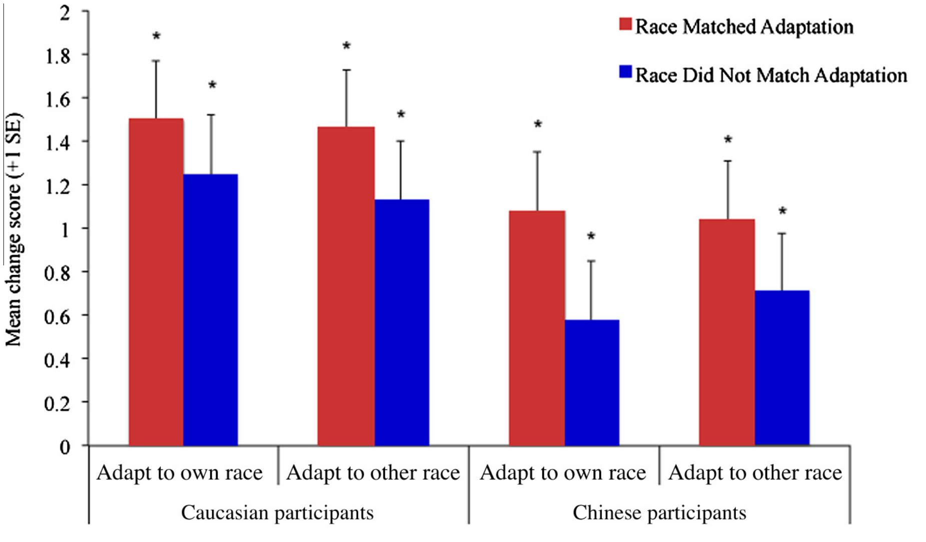

Fig. 3. Increases in the number of −70% faces chosen following adaptation to own-race versus other-race faces. An asterisk (∗) indicates that aftereffects were significantly greater than 0 ($p < .05$).

Experiment 2: Race-contingent aftereffects among children with ample experience with other-race faces

The results of Experiment 1 indicate that separable norms and associated coding dimensions begin to emerge as early as 5 years but become increasingly refined as a function of age (see also Short et al., 2011). To the extent that experience with different face categories plays a role in the development of separable norms, it is possible that children with ample exposure to other-race faces show greater separability than children who lack this experience. In Experiment 2, we tested Caucasian 5-year-olds raised in a multiethnic community (i.e., with considerable experience with Chinese faces) with the opposing aftereffects paradigm used in Experiment 1a. We tested half of the participants with the original version of the storybook and half with a version in which the social differences between races were emphasized. Both physical and social categorical differences are necessary to elicit opposing aftereffects (Bestelmeyer et al., 2008; Jaquet, Rhodes, & Hayward, 2007; Short & Mondloch, 2010). In the race-emphasized version of the storybook, we heightened awareness of the social differences by describing the dissimilarities between the Caucasian children at the party in Canada and the Chinese children at the party in China. Thus, this condition provides the strongest test for race-contingent aftereffects (i.e., high experience with other-race faces and social differences emphasized).

Method

Participants

A sample of 48 Caucasian 5-year-olds (±6 months of age, 24 female and 24 male) participated in this study. All children were tested in Toronto, Ontario, Canada, a multicultural city with a large Chinese population. Given this large Chinese population, all children presumably encountered numerous Chinese individuals in their daily lives; in the current sample of children, 79% of parents indicated that their children attended schools or day-care facilities where they regularly interacted with Chinese peers.[2] An additional six children were tested but excluded from all analyses because they were inattentive ($n = 2$) or unable to follow task instructions ($n = 4$).

Materials and procedure

Pre- and post-adaptation test stimuli were identical to those used in Experiment 1a for all children. Half of the participants were tested with the version of the storybook used in Experiment 1a, and half were tested with a different version in which the social categorical differences between the races were emphasized by describing two birthday parties that took place in different parts of the world. Children watched Matt's birthday party, which took place in Canada and represented a typical North American party (e.g., children played musical chairs and ate cake), and Liyang's birthday party, which took place in China and represented a traditional Chinese celebration (e.g., children hung lanterns and ate dumplings). In both versions of the storybook, one race of face was presented on each page, race of face alternated from page to page, and Caucasian and Chinese faces were distorted in opposite directions (±90%).

Results and discussion

Analyses were identical to those of Experiment 1a except that the between-participants factor of storybook version was added. A 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) × 2 (Storybook: original or race-emphasized) mixed ANOVA for pre-adaptation trials revealed no main effects or interaction, $ps > .07$, $\eta_p^2 s < .07$. As expected, the number of distorted faces selected pre-adaptation was low across all conditions ($Ms \leq 1.08$).

To determine whether 5-year-olds exhibited evidence for race-contingent aftereffects and whether storybook condition influenced the magnitude of these effects, we conducted a 2 (Adaptation Condition:

[2] We analyzed the data once with all 48 participants included and once with only the participants whose parents indicated that their children attended day-care facilities where they regularly interacted with Chinese peers ($n = 38$). Results did not differ across conditions; thus, we report analyses conducted with all 48 participants.

expanded or compressed) × 2 (Distortion: +70% or −70%) × 2 (Storybook: original or race-emphasized) mixed ANOVA with the change in number of distorted faces chosen as the dependent variable. There was no evidence of opposing aftereffects. The adaptation condition by distortion interaction did not approach significance, $p = .51$, $\eta_p^2 = .01$, nor did the three-way interaction among adaptation condition, distortion, and storybook, $p = .59$, $\eta_p^2 = .01$. The significant interaction between adaptation condition and storybook, $F(1,46) = 6.15$, $p = .02$, $\eta_p^2 = .12$, only reflects a greater increase in the number of both +70% and −70% faces selected among children who read the race-emphasized storybook than among those who read the original storybook. Indeed, adaptation seemed to create a nonspecific tolerance for facial distortions. Single-sample *t* tests revealed that for the original storybook, the magnitude of aftereffects differed significantly from 0 in all conditions, *ps* < .01, except for −70% faces for the face race that was compressed, $p = .07$. For the race-emphasized storybook, the magnitude of aftereffects differed significantly from 0 for ±70% faces for the face race that was compressed, *ps* < .02, but not for ±70% faces for the face race that was expanded, *ps* > .43. However, as shown in Fig. 2B, for both storybook conditions, the number of +70% faces selected as most attractive did not increase any more for the expanded face race than for the compressed face race. Likewise, the number of −70% faces selected as most attractive did not increase any more for the compressed face race than for the expanded face race.

Combined with the results of Short and colleagues (2011), our findings in Experiment 1 suggest that 5 years of age truly is a stage characterized by the emergence of separable representations for own- and other-race faces. The results of Experiment 2 suggest that experience does not facilitate the development of race-specific norms. Children with ample experience with other-race faces showed no evidence for race-contingent aftereffects even when the social differences between races were emphasized. To examine whether the lack of opposing aftereffects in young children is specific to face race or extends to other relevant face categories, in Experiment 3 we investigated whether 5-year-olds show opposing aftereffects for two other categories with which children have abundant experience—sex and age of face.

Experiment 3a: Sex-contingent aftereffects

Sex is a highly salient and meaningful category for young children. By 3 months of age infants show a visual preference for the face sex of their primary caregiver (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002), and by 10 months they readily categorize faces by sex (Younger & Fearing, 1999). Between 2 and 5 years of age, children spontaneously classify others based on sex (reviewed in Katz & Kofkin, 1997) and show a clear preference for interacting with same-sex peers (Maccoby, 2002). The early emergence of such biases may be attributable to parents' frequent mentioning of sex differences in everyday conversations with their children (Katz & Kofkin, 1997), which heightens awareness of the distinction between male and female individuals. Given the social relevance of face sex and the ample experience that children have with male and female faces, it is possible that the mental representation of face sex may be particularly well refined and differentiated among even very young children.

To determine whether young children reference separable norms for face sex, we examined whether 5-year-olds show opposing aftereffects for male and female faces. If children fail to show opposing aftereffects for sex of face, this would provide additional evidence that ample experience with a face category is not sufficient to facilitate the development of category-specific norms during early childhood.

Method

Participants

A sample of 24 Caucasian 5-year-olds (±6 months of age, 12 female and 12 male) participated in this experiment. An additional 2 children were tested but excluded from all analyses because they were inattentive during testing ($n = 1$) or failed to understand task instructions ($n = 1$).

Materials and procedure

Stimuli consisted of colored photographs of Caucasian male and female adult faces. Female face stimuli were acquired from the Maurer Vision Lab at McMaster University, and male face stimuli were acquired from the NimStim database (Tottenham et al., 2009). All faces displayed a neutral expression. All phases of the procedure were identical to those used in Experiment 1a except that the Caucasian identities were replaced by male faces and the Chinese identities were replaced by female faces.

Results and discussion

Analyses were identical to those of Experiment 1a. A 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the number of +70% and −70% faces selected as attractive during pre-adaptation trials as the dependent variable revealed no main effects or interaction, *ps* > .31, η_p^2s ≤ .04, indicating that children were no more likely to select the +70% or −70% face for either the face sex to be expanded or the face sex to be compressed. The number of distorted faces selected pre-adaptation was low across all conditions (*M*s ≤ .50).

To determine whether 5-year-olds exhibited evidence for sex-contingent aftereffects, we conducted a 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the change in number of distorted faces chosen as the dependent variable. There were no main effects or interaction, *ps* > .30, η_p^2s < .05 (see Fig. 2C). Single-sample *t* tests revealed that in all conditions the magnitude of aftereffects did not differ significantly from 0, *ps* > .10, although the magnitude of aftereffects for −70% faces for the compressed face sex did approach significance, *p* = .06.

The results of Experiment 3a are consistent with our findings from Experiment 2 and suggest that 5-year-olds do not rely on separable norms even for face categories with which they have a great deal of experience. Unlike adults (Jaquet & Rhodes, 2008; Little et al., 2005), young children exhibited no evidence for sex-contingent aftereffects. To confirm our findings, in Experiment 3b we examined one other category with which children have abundant experience—face age.

Experiment 3b: Age-contingent aftereffects

Young adult faces are the most frequently encountered age category during infancy (Rennels & Davis, 2008); however, as children grow older and enter day care and preschool, they receive ample experience with child faces. Information about age is rapidly extracted from faces by both adults and children (Rhodes, 2009), and even young children show differential discrimination and recognition performance for faces from different age categories (e.g., George, Hole, & Scaife, 2000; Rhodes & Anastasi, 2012). Here we examined whether young children reference separable norms for adult versus child faces.

Method

Participants

A sample of 24 Caucasian 5-year-olds (±6 months of age, 12 female and 12 male) participated in this experiment. An additional four children were tested but excluded from all analyses because they were inattentive during testing (*n* = 2) or stopped responding during the post-adaptation trials (*n* = 2).

Materials and procedure

Stimuli consisted of colored photographs of Caucasian adults and 4- to 6-year-old children. For each face age, half of the faces were female and half were male. Adult female face stimuli were acquired from the Maurer Vision Lab at McMaster University, and adult male face stimuli were acquired from the NimStim database (Tottenham et al., 2009). All children's faces were obtained from a sample of photographs taken in the Face Perception Lab at Brock University. Pre- and post-adaptation trials were identical to those used in Experiment 1a except that the Caucasian identities were replaced by adult faces and the Chinese identities were replaced by child faces.

Faces of 12 different identities (six child and six adult) were used as adaptation stimuli. These faces were presented in the context of a 5-min computerized storybook about two parties; one party was for children only, and the other was an office party for adults. Storybook pages that included child faces were hand-drawn (similar to those used in Experiments 1 and 2); however, storybook pages that included adult faces were photographs taken in an office. We used different methods for presenting the adult and child faces because we wanted to ensure that children perceived the adult faces as belonging to actual adults; placing the adult faces on hand-drawn bodies made the faces appear child-like and unrepresentative of a workplace environment. Half of the participants were adapted to expanded adult faces (+90%) and compressed child faces (−90%), and the other half were adapted to the reverse condition.

Results and discussion

All analyses were identical to those of Experiment 1a. The 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the number of +70% and −70% faces selected as attractive during pre-adaptation trials as the dependent variable revealed no main effects or interaction, *ps* > .15, η_p^2s < .09. Children were no more likely to select the +70% or −70% face for either the face age to be expanded or the face age to be compressed. The number of distorted faces selected pre-adaptation was low across all conditions (*M*s ≤ 1.17).

A 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the change in number of distorted faces chosen as the dependent variable revealed no main effects or two-way interaction, *ps* > .23, η_p^2s ≤ .06 (see Fig. 2D). Single-sample *t* tests revealed that the magnitude of aftereffects differed significantly from 0 for +70% faces for the face age that was expanded, *p* = .03. However, in all other conditions the magnitude of aftereffects did not differ significantly from 0, *ps* > .41.

Similar to face sex, we did not find evidence for age-contingent aftereffects in young children. Such converging evidence demonstrates that 5-year-olds do not rely on separable norms even for face categories with which they have a great deal of experience. Combined with the results of Experiments 1 and 2, these results suggest that 5 years of age is a stage characterized by minimal separation in the norms and associated coding dimensions used for faces from different categories.

Combined analysis of original storybooks

The absence of opposing aftereffects across four groups of 5-year-olds cannot be attributed to a lack of power. First, our method yielded partial transfer of aftereffects across face race. Second, we collectively analyzed the data from Experiment 1a, Experiment 2 (children tested with the original storybook), and Experiments 3a and 3b (*N* = 96). A 2 (Adaptation Condition: expanded or compressed) × 2 (Distortion: +70% or −70%) repeated-measures ANOVA with the change in number of distorted faces chosen as the dependent variable revealed no main effects or interaction, *ps* > .08, η_p^2s ≤ .03, which indicates that the lack of opposing aftereffects was not due to a small sample size.

General discussion

Collectively, our findings indicate that separable representations of faces belonging to different categories (race, age, and sex) are emerging, but not yet mature, at 5 years of age. Caucasian and Chinese children showed attractiveness aftereffects for both own- and other-race faces (Experiment 1b) that partially transferred to the face race not seen during adaptation. This is a significant finding for two reasons. First, it shows that 5-year-olds rely on at least some separable coding dimensions for own- and other-race faces, just as 8-year-olds (youngest age tested) do for upright and inverted faces (Jeffery et al., 2014). Second, it confirms that our testing protocol is sufficiently engaging to maintain children's attention and is sensitive to category-specific shifts in face norms (i.e., is capable of detecting differences in the magnitude of aftereffects between two categories; Experiment 1b).

Nonetheless, 5-year-olds' representations of faces belonging to different categories are not sufficiently distinct to drive opposing aftereffects. The same protocol that elicits simple aftereffects and partial transfer thereof in 5-year-olds (Experiment 1b) and opposing aftereffects in 8-year-olds and adults (Short et al., 2011) failed to elicit opposing aftereffects in 5-year-olds even when children were tested with categories with which they had abundant experience (Experiments 2, 3a, and 3b). Our results do not discount the overall role of experience in the refinement of face space. Indeed, the importance of early experience is well established; unlike visually normal adults, adults deprived of early patterned visual input due to bilateral congenital cataracts show no evidence for opposing aftereffects for upright and inverted faces (Robbins et al., 2012). Rather, our results suggest that 5 years of experience is not sufficient to support the development of separable prototypes.

Our results demonstrate that 5-year-olds' face space is considerably less well refined than that of adults and 8-year-olds. Two potential models may describe the organization of 5-year-olds' face space. Past research (e.g., Jeffery et al., 2010, 2013) has shown that children as young as 4 years rely on norm-based coding, at least for own-race faces. With regard to face race, children might use norm-based coding for own-race faces but process other-race faces as individual exemplars. Alternatively, young children might rely on a category-generic prototype. This second model is more plausible because the results of Experiment 1b demonstrate that children show significant aftereffects for other-race faces that are of a comparable magnitude to those for own-race faces. Furthermore, there was a significant transfer of aftereffects across face race, which indicates overlap in the coding dimensions used for own- and other-race faces. Lastly, although it is conceivable that children may initially process other-race faces as individual exemplars, this same explanation does not hold true for faces from other categories. It is hard to imagine that children would have a prototype for female faces but process male faces as exemplars. A more parsimonious explanation is that children initially encode all faces with regard to a category-generic prototype that gradually differentiates with age. Such an explanation is consistent with the recent finding that children's biases based on male and female attractiveness tend to increase with age (Rennels & Langlois, in press), which may be due to the development of separable representations for face sex as children progress from early to middle childhood. Among adults, identity aftereffects are larger for adapt–test face pairs that lie opposite to a sex-specific norm relative to a sex-generic norm (Rhodes et al., 2011; see Armann et al., 2011, for similar findings for face race). We predict that young children might not show this effect, which would provide additional evidence for reliance on a category-generic prototype during early childhood.

A number of factors may drive the development and increased refinement of face space across childhood. Some of this refinement may occur as a function of general cognitive and perceptual development. For example, increases in visual acuity may enhance sensitivity to the various dimensions of face space, whereas improvements in working memory allow for a greater number of dimensions to be processed concurrently. Consistent with this viewpoint, children are less sensitive than adults to facial distortions (Anzures et al., 2009; Crookes & McKone, 2009; Jeffery et al., 2010) and to differences in feature spacing not only in human faces (e.g., Mondloch et al., 2002) but also in houses (Robbins, Shergill, Maurer, & Lewis, 2011) and monkey faces (Mondloch, Maurer, & Ahola, 2006). Furthermore, although sensitive to multiple face dimensions, 8-year-olds have difficulty in processing these dimensions simultaneously (Nishimura et al., 2009). Collectively, these results suggest that at least some general cognitive/perceptual development underlies increases in the refinement of face space.

Some face-specific development may also drive the increased refinement of face space. In particular, development and increased specialization of face-specific regions in the brain may improve sensitivity to relevant dimensions and even increase the number of dimensions used to process faces of a given category. Adults show a strong right hemispheric bias when processing faces (e.g., Kanwisher, McDermott, & Chun, 1997); however, there is evidence that children show less hemispheric specialization (Anes & Short, 2009) and decreased localization (Passarotti et al., 2003) for face perception than adults. Moreover, significant increases in the size and specificity of face-selective cortical brain regions have been found throughout childhood and into adolescence (e.g., Grill-Spector, Golarai, & Gabrieli, 2008). Such findings suggest that face-specific brain regions continue to undergo refinement throughout childhood and may support fine-tuning of the category-specific dimensions of face space.

Young children's decreased reliance on category-specific norms may partially explain their poor performance on some face perception tasks relative to adults. Norm-based coding is thought to facilitate discrimination around the norm (Wilson et al., 2002), and in adults category-specific prototypes appear to enhance recognition; face identification is better around a race-specific average relative to a mixed-race average (Armann et al., 2011). The use of separable norms may be more economical than reliance on a single norm because faces naturally lie closer to a category-specific prototype relative to a category-generic prototype. Furthermore, relying on separable norms may ensure that only relevant dimensions are used to encode faces from a given category. For example, dimensions that are specific to Chinese faces will not aid in encoding Caucasian faces, and a failure to exclude these irrelevant dimensions may increase errors in recognition for Caucasian faces. Future studies should examine whether, like individual differences in the magnitude of figural aftereffects (Dennett et al., 2012) and identity aftereffects (Rhodes et al., 2014), individual differences in the magnitude of opposing aftereffects correlate with recognition. If a positive correlation is found between the size of opposing aftereffects and recognition accuracy, this would provide additional support for the notion that separable prototypes aid in recognition.

Collectively, our results suggest that although the mechanisms that underlie expert face processing are in place by 5 years of age, considerable refinement of these mechanisms occurs throughout childhood. Weigelt and colleagues (2014) argued that face perception (which they restricted to the ability to discriminate faces) is mature by 5 years of age because a considerable increase in discrimination threshold between 5 and 10 years of age is also evident for cars, bodies, and scenes. They suggested that only face memory shows domain-specific development. Although we agree that performance on their discrimination task improved similarly across categories, we question equating evidence of domain-general development with maturity. Indeed, we are agnostic about the extent to which the refinement of face space is based on domain-specific development and about the degree to which this refinement reflects development in perception versus memory, although evidence that children are less sensitive than adults to deviations along dimensions (e.g., Anzures et al., 2009) suggests that perceptual factors likely play a role. Given that domain-general development contributes significantly to age-related changes in children's ability to recognize facial identity, we recommend that future studies examine which aspects of face processing are refined throughout childhood rather than dismissing any domain-general changes as trivial.

Acknowledgments

Research support was provided by a Discovery Grant and a Discovery Accelerator Supplement Award from the Natural Sciences and Engineering Research Council of Canada (C.J.M.) and by a Vanier Scholarship (L.A.S.). We thank Weifang Zhang, Xiaomei Zhou, and Liping Sun for assistance in testing Chinese participants.

References

Anderson, N. D., & Wilson, H. R. (2005). The nature of synthetic face adaptation. *Vision Research, 45*, 1815–1828.

Anes, M. D., & Short, L. A. (2009). Adult-like competence in perceptual encoding of facial configuration by the right hemisphere emerges after 10 years of age. *Perception, 38*, 333–342.

Anzures, G., Mondloch, C. J., & Lackner, C. (2009). Face adaptation and attractiveness aftereffects in 8-year-olds and adults. *Child Development, 80*, 178–191.

Armann, R., Jeffery, L., Calder, A. J., & Rhodes, G. (2011). Race-specific norms for coding face identity and a functional role for norms. *Journal of Vision, 11*(13). http://dx.doi.org/10.1167/11.13.9 [art. 9].

Bar-Haim, Y., Ziv, T., Lamy, D., & Hodes, R. M. (2006). Nature and nurture in own-race face processing. *Psychological Science, 17*, 159–163.

Baudouin, J., Gallay, M., Durand, K., & Robichon, F. (2010). The development of perceptual sensitivity to second-order facial relations in children. *Journal of Experimental Child Psychology, 107*, 195–206.

Bestelmeyer, P. E. G., Jones, B. C., DeBruine, L. M., Little, A. C., Perrett, D. I., Schneider, A., et al (2008). Sex-contingent face aftereffects depend on perceptual category rather than structural encoding. *Cognition, 107*, 353–365.

Bigler, R. S., & Liben, L. S. (1993). A cognitive–developmental approach to racial stereotypes and reconstructive memory in Euro-American children. *Child Development, 64*, 1507–1518.

Burton, N., Jeffery, L., Skinner, A. L., Benton, C. P., & Rhodes, G. (2013). Nine-year-old children use norm-based coding to visually represent facial expression. *Journal of Experimental Psychology: Human Perception and Performance, 39*, 1261–1269.

Crookes, K., & McKone, E. (2009). Early maturity of face recognition: No childhood development of holistic processing, novel face encoding, or face-space. *Cognition, 111*, 219–247.

de Heering, A., Houthuys, S., & Rossion, B. (2007). Holistic face processing is mature at 4 years of age: Evidence from the composite face effect. *Journal of Experimental Child Psychology, 96*, 57–70.

de Heering, A., Rossion, B., & Maurer, D. (2012). Developmental changes in face recognition during childhood: Evidence from upright and inverted faces. *Cognitive Development, 27*, 17–27.

Dennett, H. W., McKone, E., Edwards, M., & Susilo, T. (2012). Face aftereffects predict individual differences in face recognition ability. *Psychological Science, 23*, 1279–1287.

Ewing, L., Pellicano, E., & Rhodes, G. (2013). Atypical updating of face representations with experience in children with autism. *Developmental Science, 16*, 116–123.
Freire, A., & Lee, K. (2001). Face recognition in 4- to 7-year-olds: Processing of configural, featural, and paraphernalia information. *Journal of Experimental Child Psychology, 80*, 347–371.
George, P. A., Hole, G. J., & Scaife, M. (2000). Factors influencing young children's ability to discriminate unfamiliar faces by age. *International Journal of Behavioral Development, 24*, 480–491.
Grill-Spector, K., Golarai, G., & Gabrieli, J. (2008). Developmental neuroimaging of the human ventral visual cortex. *Trends in Cognitive Sciences, 12*, 152–161.
Hayden, A., Bhatt, R. S., Reed, A., Corbly, C. R., & Joseph, J. E. (2007). The development of expert face processing: Are infants sensitive to normal differences in second-order relational information? *Journal of Experimental Child Psychology, 97*, 85–98.
Hills, P. J., Holland, A. M., & Lewis, M. B. (2010). Aftereffects for face attributes with different natural variability: Children are more adaptable than adolescents. *Cognitive Development, 25*, 278–289.
Jaquet, E., & Rhodes, G. (2008). Face aftereffects indicate dissociable, but not distinct, coding of male and female faces. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 101–112.
Jaquet, E., Rhodes, G., & Hayward, W. G. (2007). Opposite aftereffects for Chinese and Caucasian faces are selective for social category information and not just physical face differences. *Quarterly Journal of Experimental Psychology, 60*, 1457–1467.
Jaquet, E., Rhodes, G., & Hayward, W. G. (2008). Race-contingent aftereffects suggest distinct perceptual norms for different race faces. *Visual Cognition, 16*, 734–753.
Jeffery, L., McKone, E., Haynes, R., Firth, E., Pellicano, E., & Rhodes, G. (2010). Four- to six-year-old children use norm-based coding in face-space. *Journal of Vision, 10*(5). http://dx.doi.org/10.1167/10.5.18 [art. 18].
Jeffery, L., Taylor, L., & Rhodes, G. (2014). Transfer of figural face aftereffects suggests mature orientation selectivity in eight-year-olds' face coding. *Journal of Experimental Child Psychology*, *126*, 229–244.
Jeffery, L., Read, A., & Rhodes, G. (2013). Four-year-olds use norm-based coding for face identity. *Cognition, 127*, 258–263.
Jeffery, L., & Rhodes, G. (2011). Insights into the development of face recognition mechanisms revealed by face aftereffects. *British Journal of Psychology, 102*, 799–815.
Jeffery, L., Rhodes, G., McKone, E., Pellicano, E., Crookes, K., & Taylor, E. (2011). Distinguishing norm-based from exemplar-based coding of identity in children: Evidence from face identity aftereffects. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1824–1840.
Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience, 17*, 4302–4311.
Katz, P. A., & Kofkin, J. A. (1997). Race, gender, and young children. In S. S. Luthar, J. A. Burack, D. Cicchetti, & J. R. Weisz (Eds.), *Developmental psychopathology* (pp. 51–74). Cambridge, UK: Cambridge University Press.
Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Ge, L., & Pascalis, O. (2007). The other-race effect develops during infancy: Evidence of perceptual narrowing. *Psychological Science, 18*, 1084–1089.
Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Gibson, A., Smith, M., et al (2005). Three-month-olds, but not newborns, prefer own-race faces. *Developmental Science, 8*, F31–F36.
Leopold, D. A., O'Toole, A. J., Vetter, T., & Blanz, V. (2001). Prototype-referenced shape encoding revealed by high-level aftereffects. *Nature Neuroscience, 4*, 89–94.
Little, A. C., DeBruine, L. M., & Jones, B. C. (2005). Sex-contingent face after-effects suggest distinct neural populations code male and female faces. *Proceedings of the Royal Society B: Biological Sciences, 272*, 2283–2287.
Little, A. C., DeBruine, L. M., Jones, B. C., & Waitt, C. (2008). Category contingent aftereffects for faces of different races, ages, and species. *Cognition, 106*, 1537–1547.
Maccoby, E. E. (2002). Gender and group processes: A developmental perspective. *Current Directions in Psychological Science, 11*, 54–58.
McKone, E., & Boyer, B. L. (2006). Sensitivity of 4-year-olds to featural and second-order relational changes in face distinctiveness. *Journal of Experimental Child Psychology, 94*, 134–162.
McKone, E., Crookes, K., Jeffery, L., & Dilks, D. D. (2012). A critical review of the development of face recognition: Experience is less important than previously believed. *Cognitive Neuropsychology, 29*, 174–212.
Mondloch, C. J., Dobson, K. S., Parsons, J., & Maurer, D. (2004). Why 8-year-olds cannot tell the difference between Steve Martin and Paul Newman: Factors contributing to the slow development of sensitivity to the spacing of facial features. *Journal of Experimental Child Psychology, 89*, 159–181.
Mondloch, C. J., Le Grand, R., & Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception, 31*, 553–566.
Mondloch, C. J., Maurer, D., & Ahola, S. (2006). Becoming a face expert. *Psychological Science, 17*, 930–934.
Nishimura, M., Maurer, D., & Gao, X. (2009). Exploring children's face space: A multidimensional scaling analysis of the mental representation of facial identity. *Journal of Experimental Child Psychology, 103*, 355–375.
Nishimura, M., Maurer, D., Jeffery, L., Pellicano, E., & Rhodes, G. (2008). Fitting the child's mind to the world: Adaptive norm-based coding of facial identity in 8-year-olds. *Developmental Science, 11*, 620–627.
Nishimura, M., Robertson, C., & Maurer, D. (2011). Effect of adaptor duration on 8-year-olds' facial identity aftereffects suggests adult-like plasticity of the face norm. *Vision Research, 51*, 1216–1222.
O'Neil, S. F., & Webster, M. A. (2011). Adaptation and the perception of facial age. *Visual Cognition, 19*, 534–550.
Palermo, R., Rivolta, D., Wilson, C. E., & Jeffery, L. (2011). Adaptive face space coding in congenital prosopagnosia: Typical figural aftereffects but abnormal identity aftereffects. *Neuropsychologia, 49*, 3801–3812.
Passarotti, A. M., Paul, B. M., Bussiere, J. R., Buxton, R. B., Wong, E. C., & Stiles, J. (2003). The development of face and location processing: An fMRI study. *Developmental Science, 6*, 100–117.
Quinn, P. C., Yahr, J., Kuhn, A., Slater, A. M., & Pascalis, O. (2002). Representation of the gender of human faces by infants: A preference for female. *Perception, 31*, 1109–1121.
Rennels, J. L., & Langlois, J. H. (in press). Children's attractiveness, gender, and race biases: A comparison of their strength and generality. *Child Development.* doi: http://dx.doi.org/10.1111/cdev.12226.
Rennels, J. L., & Davis, R. E. (2008). Facial experience during the first year. *Infant Behavior & Development, 31*, 665–678.

Rhodes, M. G. (2009). Age estimation of faces: A review. *Applied Cognitive Psychology, 23*, 1–12.
Rhodes, M. G., & Anastasi, J. S. (2012). The own-age bias in face recognition: A meta-analytic and theoretical review. *Psychological Bulletin, 138*, 146–174.
Rhodes, G., Jaquet, E., Jeffery, L., Evangelista, E., Keane, J., & Calder, A. J. (2011). Sex-specific norms code face identity. *Journal of Vision, 11*(1). http://dx.doi.org/10.1167/11.1.1 [art. 1].
Rhodes, G., Jeffery, L., Taylor, L., Hayward, W. G., & Ewing, L. (2014). Individual differences in adaptive coding of face identity are linked to individual differences in face recognition ability. *Journal of Experimental Psychology: Human Perception and Performance, 40*(3), 897–903. http://dx.doi.org/10.1037/a0035939.
Rhodes, G., & Jeffery, L. (2006). Adaptive norm-based coding of facial identity. *Vision Research, 46*, 2977–2987.
Rhodes, G., Jeffery, L., Watson, T. L., Clifford, C. W. G., & Nakayama, K. (2003). Fitting the mind to the world: Face adaptation and attractiveness aftereffects. *Psychological Science, 14*, 558–566.
Rhodes, G., Jeffery, L., Watson, T. L., Jaquet, E., Winkler, C., & Clifford, C. W. G. (2004). Orientation-contingent face aftereffects and implications for face-coding mechanisms. *Current Biology, 14*, 2119–2123.
Rhodes, G., & Leopold, D. A. (2011). Adaptive norm-based coding of face identity. In A. J. Calder, G. Rhodes, M. H. Johnson, & J. V. Haxby (Eds.), *The Oxford handbook of face perception* (pp. 263–286). Oxford, UK: Oxford University Press.
Rhodes, G., Robbins, R., Jaquet, E., McKone, E., Jeffery, L., & Clifford, C. W. G. (2005). Adaptation and face perception: How aftereffects implicate norm-based coding of faces. In C. W. G. Clifford & G. Rhodes (Eds.), *Fitting the mind to the world: Adaptation and after-effects in high-level vision* (pp. 213–240). Oxford, UK: Oxford University Press.
Rhodes, G., & Tremewan, T. (1996). Averageness, exaggeration, and facial attractiveness. *Psychological Science, 7*, 105–110.
Rhodes, G., Watson, T. L., Jeffery, L., & Clifford, C. W. G. (2010). Perceptual adaptation helps us identify faces. *Vision Research, 50*, 963–968.
Robbins, R. A., Maurer, D., Hatry, A., Anzures, G., & Mondloch, C. J. (2012). Effects of normal and abnormal visual experience on the development of opposing aftereffects for upright and inverted faces. *Developmental Science, 15*, 194–203.
Robbins, R., McKone, E., & Edwards, M. (2007). Aftereffects for face attributes with different natural variability: Adapter position effects and neural models. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 570–592.
Robbins, R. A., Shergill, Y., Maurer, D., & Lewis, T. L. (2011). Development of sensitivity to spacing versus feature changes in pictures of houses: Evidence for a slow development of a general spacing detection mechanism? *Journal of Experimental Child Psychology, 109*, 371–382.
Ross, D. A., Deroche, M., & Palmeri, T. J. (2014). Not just the norm: Exemplar-based models also predict face aftereffects. *Psychonomic Bulletin & Review, 21*, 47–70.
Sangrigoli, S., & de Schonen, S. (2004). Effect of visual experience on face processing: A developmental study of inversion and non-native effects. *Developmental Science, 7*, 74–87.
Schwarzer, G. (2000). Development of face processing: The effect of face inversion. *Child Development, 71*, 391–401.
Short, L. A., Hatry, A. J., & Mondloch, C. J. (2011). The development of norm-based coding and race-specific face prototypes: An examination of 5- and 8-year-olds' face space. *Journal of Experimental Child Psychology, 108*, 338–357.
Short, L. A., & Mondloch, C. J. (2010). The importance of social factors is a matter of perception. *Perception, 39*, 1562–1564.
Shutts, K., Roben, C. K. P., & Spelke, E. S. (2013). Children's use of social categories in thinking about people and social relationships. *Journal of Cognition and Development, 14*, 35–62.
Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168*, 242–249.
Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *Quarterly Journal of Experimental Psychology A, 43*, 161–204.
Webster, M. A., Kaping, D., Mizokami, Y., & Dumahel, P. (2004). Adaptation to natural face categories. *Nature, 428*, 558–561.
Webster, M. A., & MacLeod, D. I. A. (2011). Visual adaptation and face perception. *Philosophical Transactions of the Royal Society: Biological Sciences, 366*, 1702–1725.
Webster, M. A., & MacLin, O. H. (1999). Figural aftereffects in the perception of faces. *Psychonomic Bulletin & Review, 6*, 647–653.
Weigelt, S., Koldewyn, K., Dilks, D. D., Balas, B., McKone, E., & Kanwisher, N. (2014). Domain-specific development of face memory but not face perception. *Developmental Science, 17*, 47–58.
Wilson, H. R., Loffler, G., & Wilkinson, F. (2002). Synthetic faces, face cubes, and the geometry of face space. *Vision Research, 42*, 2909–2923.
Younger, B. A., & Fearing, D. D. (1999). Parsing items into separate categories: Developmental change in infant categorization. *Child Development, 70*, 291–303.