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Children (but not adults) judge similarity in own- and other-race faces by the color of their skin

Benjamin Balas [a,*], Jessie Peissig [b], Margaret Moulson [c]

[a] Center for Visual and Cognitive Neuroscience, Department of Psychology, North Dakota State University, Fargo, ND 58108, USA
[b] Department of Psychology, California State University, Fullerton, Fullerton, CA 92834, USA
[c] Department of Psychology, Ryerson University, Toronto, Ontario M5B 2K3, Canada

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ABSTRACT

Both face shape and pigmentation are diagnostic cues for face identification and categorization. In particular, both shape and pigmentation contribute to observers' categorization of faces by race. Although many theoretical accounts of the behavioral other-race effect either explicitly or implicitly depend on differential use of visual information as a function of category expertise, there is little evidence that observers do in fact differentially rely on distinct visual cues for own- and other-race faces. In the current study, we examined how Asian and Caucasian children (4–6 years of age) and adults use three-dimensional shape and two-dimensional pigmentation to make similarity judgments of White, Black, and Asian faces. Children in this age range are capable of making category judgments about race but also are sufficiently plastic with regard to the behavioral other-race effect that it seems as though their representations of facial appearance across different categories are still emerging. Using a simple match-to-sample similarity task, we found that children tend to use pigmentation to judge facial similarity more than adults and also that own-group versus other-group category membership appears to influence how quickly children learn to use shape information more readily. Therefore, we suggest that children continue to adjust how

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* Corresponding author.
E-mail address: benjamin.balas@ndsu.edu (B. Balas).

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different visual information is weighted during early and middle childhood and that experience with faces affects the speed at which adult-like weightings are established.

Introduction

Faces are highly multidimensional stimuli. A wide variety of visual features may carry diagnostic information for individuation and categorization, and a key goal of face recognition research for many years has been to characterize observers' use of distinct cues in face processing tasks. For example, the various distinctions between "featural" and "configural" processing have been elaborated in many studies (Maurer, Le Grand, & Mondloch, 2002). Briefly, featural processing is usually understood in terms of analysis of discrete parts of the face (e.g., eyes, nose, mouth), whereas configural processing is often understood in terms of metric descriptors of how those features are arranged relative to one another within the face (e.g., eye-to-eye spacing). Similarly, the distinction between "holistic" face processing (usually as revealed via the composite face effect [Young, Hellawell, & Hay, 1987]) and fragmented localized processing has also been described at length. Holistic processing of the face is thought to rely on some description of facial appearance that encodes the entire face pattern as a whole rather than via a fragmented representation of multiple constituent parts. These dichotomies between featural/configural analysis and local/holistic analysis are sufficiently high level that it is not trivial to relate the candidate mechanisms to a specific set of visual features. However, face recognition also appears to rely on a specific vocabulary of low-level features; intermediate spatial frequencies (~8–16 cycles/face) are the most useful for a range of recognition tasks (Costen, Parker, & Craw, 1996; Nasanen, 1999; Ruiz-Soler & Beltran, 2006), and horizontal orientation energy (e.g., edges) similarly appears to be more useful for recognition than vertical orientations (Dakin & Watt, 2009; Goffaux & Dakin, 2010). Thus, in terms of both candidate high-level features and well-specified low-level features, face recognition appears to depend on distinct visual information to varying degrees. Some visual features are more useful than others, and skilled observers preferentially use these. Ultimately, understanding how face recognition works will depend on understanding which sources of information contribute the most to various tasks and how observers recruit distinct visual cues for face individuation and categorization judgments.

Experience with faces appears to influence the extent to which specific visual features or specific processing strategies are used to support face recognition. Developmentally, it appears that infants and young children might not use the same representations as adults to recognize faces. For example, holistic processing of face patterns appears not to be fully mature until nearly 7 years of age (Mondloch, Pathman, Le Grand, Maurer, & de Schonen, 2007), although the composite face effect (De Heering, Houthuys, & Rossion, 2007) is evident in children as young as 4 years. The classic face inversion effect (Yin, 1969) also appears to change over development (Carey & Diamond, 1977; Schwarzer, 2000), although the extent to which this reflects face-specific development has been disputed (Crookes & McKone, 2009). In terms of the use of specific information to individuate and categorize faces, children also appear to be less sensitive to some aspects of facial appearance than adults, suggesting that the vocabulary they use to represent and recognize faces is changing developmentally. For example, children's sensitivity to differences in the spacing between discrete facial features appears to change substantially during childhood (Mondloch, Le Grand, & Maurer, 2002), remaining below adult levels up to 10 years of age. Children also do not appear to use spatial frequency information in the same way as adults until middle childhood; the typical adult-like bias for intermediate spatial frequencies (8–16 cycles/face) does not appear to be robust during early childhood (Leonard, Karmiloff-Smith, & Johnson, 2010). In addition to developmental changes in how information is used for face recognition, there are similar results that arise from examining the impact of face experience vis-à-vis differential exposure to own-race versus other-race faces in adult observers. Specifically, other-race faces appear to be recognized via different visual cues or strategies than own-race faces, suggesting that facial appearance is represented differentially as a function of experience. For example, other-race faces appear to be less susceptible to the inversion effect (Balas & Nelson, 2010) and are not processed holistically to the same extent as own-race faces (Michel, Rossion, Han, Chung, & Caldara, 2006; Tanaka, Kiefer, & Bukach, 2004). Sensitivity to configural information in other-race faces also differs from that in own-race faces, perhaps reflecting an overall inability to adequately process appearance as a gestalt (Hayward, Rhodes, & Schwaninger, 2007). Taken together, these results suggest that, in general, observers use experience with faces to identify diagnostic visual information that they ultimately use preferentially to guide behavior in face recognition tasks.

In the current study, we chose to examine how expertise considered in terms of both development and differential exposure to faces belonging to distinct categories (own- vs. other-race faces) modulated the use of three-dimensional (3D) shape and two-dimensional (2D) pigmentation for face recognition. The distinction between shape and pigmentation is a particularly interesting dichotomy to consider, especially given our interest in understanding the impact of experience on face recognition by comparing own- and other-race face processing. Although face shape has long been tacitly assumed to be the predominant cue for recognition, pigmentation appears to make a substantial contribution to face recognition in general (Russell, 2003; Russell, Biederman, Nederhouser, & Sinha, 2007; Russell, Sinha, Biederman, & Nederhouser, 2006) and the social perception of other-race faces in particular (Dixon & Maddox, 2005). The deleterious effects of contrast negation on face recognition appear to be driven in large part by disruption of natural pigmentation (Vuong, Peissig, Harrison, & Tarr, 2005), suggesting that observers cannot ignore pigmentation information in face images. Observers appear to use both face shape and pigmentation to categorize faces according to race (Hill, Bruce, & Akamatsu, 1995), and shape and pigmentation make separate contributions to the behavioral other-race effect (Bar-Haim, Seidel, & Yovel, 2009) and its neural basis (Balas & Nelson, 2010; Balas, Westerlund, Hung, & Nelson, 2011). The dependence of the other-race effect on shape (Brooks & Gwinn, 2010) versus pigmentation (Sun & Balas, 2012; Willenbockel, Fiset, & Tanaka, 2011) remains unclear to some extent, but it is clear that shape and pigmentation are perceptually meaningful properties of facial appearance that affect how own- and other-race faces are processed. Finally, compared with other proposed processing dichotomies in face processing, such as the featural/configural distinction that dominates much of the face recognition literature, 3D shape and 2D pigmentation are easily definable physical properties of the face. Although the *perceptual* dimensions of shape and pigmentation remain unclear (we do not know how head shape and skin tone are represented neurally), the *physical* variables (the real-world properties of a person's face) under consideration are very easy to specify; in our case, by ‘‘shape'' we refer to the 3D volume taken up by the head and face, and by ‘‘pigmentation'' we refer to the 2D surface reflectance (including luminance, color, and texture). Recent developments in commercially available graphics software for rendering human faces with independent control of shape and skin tone have made it possible to disentangle these aspects of appearance effectively (Balas & Nelson, 2010; Oosterhof & Todorov, 2008), and image acquisition hardware for obtaining 3D range data and 2D texture maps of real human faces has also become relatively easy to obtain and use. Thus, shape and pigmentation are easily specified and manipulated properties of facial appearance that are known to influence how faces are categorized according to race as evidenced by behavioral and neural indexes.

We chose to compare how adults and 4- to 6-year-old children used shape and pigmentation information to make similarity judgments about own- and other-race faces. Specifically, we tested Caucasian and Asian children and adults using a match-to-sample task composed of within-category similarity judgments of White, Black, and Asian faces. To our knowledge, this is the first study to examine how shape and pigmentation are recruited differentially *within* race categories rather than how shape and pigmentation contribute to establishing a boundary across race categories. We chose to work with 4- to 6-year-olds for a number of reasons. Children in this age range exhibit differential processing of faces belonging to ‘‘own'' and ‘‘other'' categories both behaviorally (Sangrigoli & de Schonen, 2004) and neurally (Short, Hatry, & Mondloch, 2011). The other-race effect also appears to be plastic at this point during childhood (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005), suggesting that children of this age may still be ‘‘tuning'' or ‘‘narrowing'' their perception of faces considerably based on their experience with faces in the environment. Indeed, previous results with infants (9 months of age) and adults demonstrate that sensitivity to race-specific shape and pigmentation changes substantially between late infancy and adulthood (Balas & Nelson, 2010; Balas et al., 2011), making early childhood a critically important target for examining the impact of differential experience. Finally, children in this age range can reliably complete a match-to-sample paradigm that is meaningful to administer to adults, facilitating comparison between the two groups.

In the current study, we used a morphable model of face appearance (Blanz & Vetter, 1999) to generate faces from multiple race categories that could be matched to another face with regard to either the 3D shape of the head or the 2D surface pigmentation. That is, given two different faces, we were able to manipulate their appearance so that the two faces could have the same 3D shape and unique skin tone or share the same skin tone but differ according to 3D shape. In the first instance we would call those two faces “shape-matched,” and in the second instance we would call those faces “color-matched,” according to which properties were manipulated so that they were shared. We used these stimuli to create within-race face triads that required participants to choose which of two test stimuli most closely resembled a sample stimulus—the shape-matched face or the color-matched face. We hypothesized that increased exposure to faces might lead to changes in the way shape and color were weighted in order to make similarity judgments within racial categories. Specifically, we anticipated that experience as defined by development (children vs. adults) or by biased exposure to faces belonging to a specific category (own- vs. other-race faces) would have a consistent impact on how these cues are used for resemblance judgments.

Method

Participants

Our full sample of participants was composed of four non-overlapping groups of observers: Caucasian children and adults and Chinese children and adults. We recruited a total of 36 adults: 18 Caucasian adults (10 female) between 18 and 26 years of age and 18 Asian adults (7 female) between 18 and 28 years of age. Adult participants were recruited from the North Dakota State University undergraduate community and received course credit for participation in the study.

We also recruited a sample of 36 children: 18 Caucasian children (12 female) between the ages of 3;3 and 5;3 (years;months) (*M* = 49.8 months, *SD* = 7.5) and 18 Asian children (11 female) between the ages of 3;6 and 6;0 (*M* = 56.5 months, *SD* = 9.0). All of our Caucasian children were recruited from a mid-sized community in the American Midwest, whereas Asian children were recruited from a similarly sized community in Southern California and a large metropolitan area in Ontario, Canada.

Adults were asked to report their own race prior to participating, whereas children were included in the study based on parental report of the children’s race. Some children in the nominal “Asian” group were of mixed-race background, which we recorded but did not use as a basis for exclusion. Specifically, we tested 8 children in this group whose parents reported mixed race/ethnicity (5 who listed “Caucasian” or “White” as the other race, 1 who listed “Iranian,” 1 who listed “Jamaican,” and 1 who listed “Indian”). Compared with a sample of children that might be obtained outside of North America, the Asian participant groups considered here are likely to have more heterogeneous experience with faces. Specifically, the exposure to White faces is likely to be elevated relative to participants living in a nation with a majority Asian population. However, because this should only lessen the impact of differential face experience, we argue that the inclusion of this group is meaningful given that positive effects would indicate that smaller differences in exposure lead to systematic biases in face perception. No participants in any of our participant groups were known to have existing visual or neurological impairments.

Stimuli

We created artificial faces using commercial software (FaceGen, Singular Inversions) so that 3D face shape and pigmentation could be manipulated independently. Specifically, we created five pairs of exemplar faces within each of three different racial categories (White, Black, and Southeast Asian). Each stimulus pair was then used to create two additional faces, one with the shape of the first face and pig-

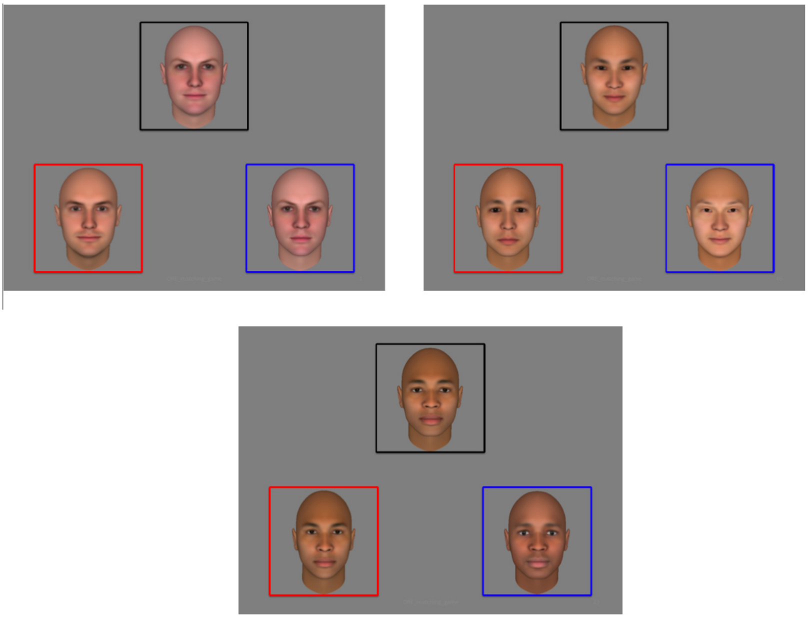

Fig. 1. Examples of single trials from the experiment, each depicting a stimulus triad from one of the race categories used here. In each panel, the face at the top is the sample face, with a shape-matched face at the bottom left and a pigmentation-matched face at the bottom right. Participants were given unlimited time to indicate which of the two images in the bottom row most closely resembled the face at the top.

mentation of the second face and another with the shape of the second face and pigmentation of the first face, for a total of 20 faces per race (Fig. 1). The five pairs of faces in each racial category were chosen to be of approximately equal similarity to one another, although we emphasize here (and raise this point again in the Discussion) that we did not explicitly match the magnitude of shape/pigmentation differences across races. We chose to use three different race categories so that we could include an additional other-race category (Black faces) that was not the "own-race" category for either participant group.

These 20 faces per racial category yielded a total of 10 stimulus triads for each race that were the basis of individual trials in our task. Stimulus triads were composed of a face drawn from one of the original pairs generated via FaceGen and its accompanying shape-matched and color-matched faces. Individual trials in the task were generated by printing each sample face at the top of a horizontally oriented medium gray 8.5 × 11-inch page and the two test faces at the bottom, offset to the left and right (see Fig. 2). In this manner, one test face shared the sample's 3D shape but differed in pigmentation, whereas the other test face shared the sample's pigmentation but differed in shape. Our definition of "shape" in this case includes all of the internal features of the face as well as the outline of the head and jaw. Variation in the shape and pigmentation of individual faces within race categories resulted solely from the use of FaceGen to generate stimuli; no explicit manipulation of shape and pigmentation was implemented during the creation of the initial stimulus pairs. All faces were presented in full color and were approximately 2 × 2 inches in size. The full set of stimuli was presented in a three-ring binder with transparent sleeves included to protect the stimulus triads. The use of a binder to administer the task was purely practical; given the variation in testing sites across our groups of participants, a paper version of the task was an easy way to standardize stimulus appearance.

Procedure

The face similarity task was composed of 10 trials per race (a total of 30 trials), all presented in a three-ring binder at a small desk or table with variable seating to accommodate children and adults. Trials were blocked by race, and the order of blocks was counterbalanced across participants.

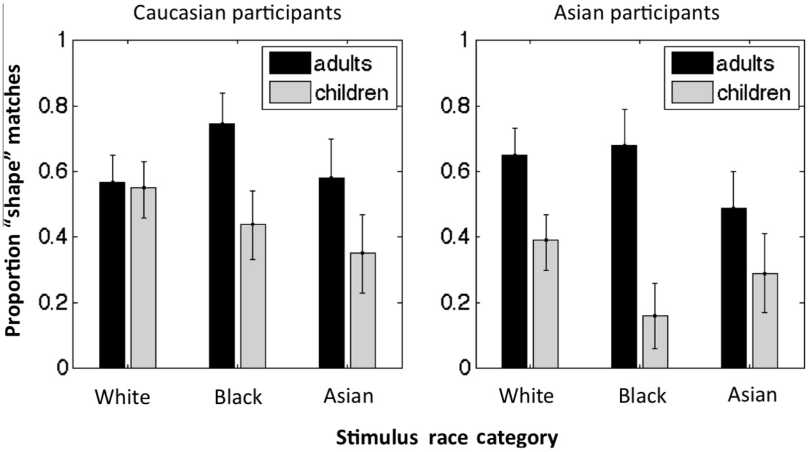

Fig. 2. Mean proportions of shape judgments across all three stimulus races for child and adult participants of both races. Error bars represent 95% confidence intervals of the mean.

Participants were told that they would be asked to look at a series of faces and determine which of two test faces looked the most like a sample face presented at the top. Participants were told that there was no right or wrong answer and that they should respond based on their own opinion of which face resembled the sample face most closely. An experimenter administered the task to children and adults. On each trial, participants were asked, "Which of the two faces on the bottom looks the most like the person at the top?" They were given unlimited time to choose one of the target faces. Responses were coded according to whether participants chose the shape-matched face or the color-matched face on each trial. Positive feedback was given verbally to children following each trial regardless of their answer. Children typically completed the task within 10 to 15 min and were rewarded with a small "passport" booklet to put stamps and stickers in or a sheet of stickers of their choosing. Adult participants typically completed the task in slightly less time and received course credit for their participation.

Prior to the main task, children completed 4 practice trials with simple objects (stuffed animals) to ensure that they understood the task. If children expressed confusion or displayed uncooperativeness during the practice trials, they were excluded from the current study. Based on this criterion, 2 children (1 male and 1 female) were excluded from our Caucasian sample.

Results

For each participant, we determined the proportion of shape matches made per racial group. We submitted these values to a mixed-design repeated-measures analysis of variance (ANOVA) with participant race (Asian or Caucasian) and participant age (child or adult) as between-participants factors and stimulus race (White, Black, or Asian) as a within-participants factor. The proportion of shape matches is displayed as a function of these categories in Fig. 2.

Our analysis revealed a main effect of stimulus race, $F(2, 136) = 8.67$, $p < .001$, $\eta^2 = .11$, as well as main effects of age, $F(1, 68) = 39.30$, $p < .001$, $\eta^2 = .37$, and participant race, $F(1, 68) = 5.37$, $p = .024$, $\eta^2 = .073$. The main effect of stimulus race was driven by a significantly lower proportion of shape matches made in triads composed of Asian faces ($M = .43$) relative to triads composed of either White faces ($M = .54$) or Black faces ($M = .51$). The main effects of observer age and race were driven by a significantly lower proportion of shape matches made by children ($M = .36$) compared with adults ($M = .62$) and by Asian participants ($M = .44$) compared with Caucasian participants ($M = .54$), respectively.

These main effects were qualified by significant two-way interactions between stimulus race and participant race, $F(2, 136) = 3.09$, $p = .05$, $\eta^2 = .04$, and also between stimulus race and age, $F(2, 136) = 13.75$, $p < .001$, $\eta^2 = .17$. These were further qualified by a three-way interaction among all three factors, $F(2, 136) = 4.15$, $p = .018$, $\eta^2 = .058$. To examine this interaction in more detail, we carried out pairwise comparisons (via two-tailed independent-samples t tests) between child and adult shape match proportions within each cell defined by stimulus race and participant race. That is, with all other variables matched, did the responses of children differ from those of adults? We found that, in general, children did exhibit a significantly smaller shape bias than adults, with the only exceptions being that White children did not differ from White adults when judging similarity in Caucasian faces, $t(34) = 0.272$, $p = .79$, Cohen's $d = 0.09$, and that the difference between Asian children and Asian adults was only marginally significant after adjusting our critical value for multiple comparisons, $t(34) = 2.46$, $p = .02$ (less than an uncorrected .05 but not below the adjusted threshold), Cohen's $d = 0.84$. Otherwise, the comparisons between adults and children were significant for Caucasian observers judging Asian faces, $t(34) = 2.69$, $p < .01$, Cohen's $d = 0.93$, for Asian observers judging Caucasian faces, $t(34) = 4.47$, $p < .001$, Cohen's $d = 1.53$, and for observers of both races judging Black faces ($p < .001$ in both cases, Cohen's ds = 1.23 and 3.00 for Caucasian and Asian observers, respectively). Thus, we find that the effect of development on shape bias depends on the combination of participant and stimulus race, such that the difference between children's and adults' use of pigmentation versus shape appears to be smallest when observers judge faces of their own race. This is most evident when we consider the data from Caucasian observers because the data supporting this conclusion from Asian observers hinges on a marginal result that may simply be somewhat underpowered.

Discussion

Our results reveal several interesting features regarding how face shape and pigmentation are recruited for recognition within perceptually distinct racial categories. Specifically, with regard to our developmental hypothesis, we found that children were significantly more likely than adults to use pigmentation cues to judge facial similarity; faces that shared surface pigmentation were chosen as "best matches" more frequently by children than by adults in general. We note that our data do not clearly point to an unambiguous pigmentation bias during childhood or a shape bias during adulthood; rather, our developmental effects suggest that there is developmental change in the reliance on these cues even if there is not a significant bias for one or the other. This main effect of age is consistent with prior results suggesting that children appear to default to using skin color/surface pigmentation for racial categorization judgments, and continued development/experience results in increased use of shape cues. For example, Sorce (1979) varied both the race-specific skin color and the race-specific eye and mouth shape of a set of line drawings of faces and asked young children (3–5 years) to sort these stimuli into categories. The result was that children appeared to find skin color particularly salient. Skin color and pigmentation in general may simply be a more salient dimension to children relative to adults and so contributes more to judgments of category membership and has a strong influence on judgments of individuation and resemblance within distinct categories. Thus, our data make an important contribution to the literature by demonstrating how independent visual cues differentially affect face processing *within* race categories as a function of development. Shape and color are used in different ways at different ages to judge resemblance within categories, not just to define categories. An important caveat to this conclusion, however, is that we must be cautious in interpreting our data in terms of shape and pigmentation specifically when lower level accounts may also be a useful way of describing our results. In particular, we point out that we did not explicitly match the perceptual difference between shape-matched and color-matched stimuli in our task either across the whole stimulus set or across race categories. Therefore, although our results are largely consistent with prior reports that children are more likely than adults to use surface pigmentation over 3D shape, it is also possible that the differences between faces of different pigmentation in our stimulus set are of different magnitude than the differences induced by shape variation. Furthermore, the extent to which this is true may vary by race category. Were this the case, it would not account for any effects of development (both groups saw the same stimuli) but would require us to accept other accounts that explain what is changing over the course of development in terms of shape/pigmentation use for face recognition. Specifically, one alternative explanation of our data would be that children default to using something like raw image similarity computed at a low level to make resemblance judgments, whereas adults preferentially use 3D shape because they have learned that it is a more robust cue for identity/resemblance. We suggest that at this time both of these accounts offer new insights into how face learning proceeds during childhood and that our current stimulus set has the benefit of being naturalistic; real faces in the world do not have tightly controlled variation across shape and pigmentation dimensions after all. Nonetheless, an important question for future research is whether children truly prefer to use pigmentation more than adults per se or if instead a pure image similarity account is really a better description of how facial discrimination/similarity is perceived by children.

If we consider experience as operationalized via differential processing of own- and other-race faces, we also see some evidence that observer race affects the way shape and pigmentation are recruited. Broadly speaking, our results are consistent with several recent studies demonstrating how observers belonging to different racial groups scan faces differentially (Fu, Hu, Wang, Quinn, & Lee, 2012; Liu et al., 2011; Wheeler et al., 2011), suggesting that visual information pickup strategies may be modulated by experience (although the contribution of a genetic component cannot be ruled out entirely). More specifically, we found that Asian participants appeared to be significantly more likely to use pigmentation to judge similarity than Caucasian observers and that this difference was somewhat more evident when comparing children of both races; the critical interaction between observer race and age was only marginal in the omnibus ANOVA, $F(1, 68) = 2.98$, $p = .089$, $\eta^2 = .042$, but we note that the 95% confidence intervals (CIs) for children's use of shape as a function of their own race do not overlap (95% CI, Caucasian children = [3.65–5.27], Asian children = [2.00–3.63], Cohen's $d = 0.70$), but the CIs for adults do (95% CI, Caucasian adults = [5.50–7.13], Asian adults = [5.26–6.89], Cohen's $d = 0.12$).

The result that Asian observers appear to use pigmentation more readily than Caucasian observers is to some extent consistent with recent results from Michel, Rossion, Bulthoff, Hayward, and Vuong (2013), who found that Caucasian adults tended to use shape information preferentially for both own- and other-race faces but that Asian adults tended to rely on pigmentation information for both races. In each case, adult observers in their task tended to persist in using shape/pigmentation information for all faces even if these cues were not apparently optimal for the category of faces under consideration. By contrast, however, we also observed several important interactions in our data suggesting that own-race versus other-race status does play a role in determining how shape and pigmentation are recruited for explicit similarity judgments. If Caucasian and Asian observers were indeed locked into using shape and pigmentation, respectively, for all face judgments, our data in Fig. 2 should essentially look flat across both adult groups; what we find, however, is a more complex pattern suggestive of differential processing based on experience. Specifically, Caucasian observers appear not to differ in terms of their use of shape versus pigmentation for White and Asian faces, whereas Asian observers appear to use pigmentation more frequently for own-race faces. We also note that Caucasian children appear to show no difference in their use of shape relative to adults when we consider White face stimuli (see the results of our post hoc tests above). One way to summarize these results is to say that children use pigmentation more than adults in general but that experience with White faces tends to increase the use of shape to recognize White faces in particular. Thus, Asian children in our sample (who are likely exposed to both White and Asian faces by virtue of living in multicultural communities) tend to use pigmentation more often than Caucasian children (per the confidence intervals described above), and Caucasian children (who likely see primarily White faces) rapidly look like Caucasian adults when we consider White faces. Thus, experience does seem to matter in our data, although the differences are ultimately fairly subtle by adulthood; biased exposure seems to affect the rate at which shape and pigmentation cues are recruited in developmental time, specifically with regard to how children's more frequent use of pigmentation compared with adults varies as a function of face categories. This also appears to be true when we consider the data obtained from both participant groups' judgments of Black faces, which constituted an "other-race" category for both Asian and Caucasian participants. Both Asian children and Caucasian children used shape less frequently than race-matched adult participants, which is consistent with our suggestion that increased exposure to faces of a particular category leads to more rapid development of the use of shape for similarity judgments. Thus, the inclusion of a third stimulus category provides further evidence that developmental differences between adults and young children are most evident for multiple instances of other-race faces but that these differences appear to be smaller for own-race faces. Of course, as discussed previously, the extent to which we can interpret our results as being specifically about pigmentation rather than low-level image similarity depends on the low-level characteristics of our stimulus set; still, either interpretation seems to require the inclusion of experience to account for the full set of results. In addition, we lack detailed reports of face experience in our participant groups, forcing us to rely on regional demographics as the basis for our above discussion of expected differences in face experience in our samples.

Our results offer interesting insights into how distinct visual cues for appearance are used during early childhood to make similarity judgments across racial categories. However, we must acknowledge some important limitations to our design that constrain the conclusions we can draw from our data but that also suggest exciting directions for future work. First, we note that our sample of Asian children in particular was more heterogeneous geographically and in terms of parent race than our other populations. To the extent that community and parent race might independently influence recognition behavior, more closely controlling (or systematically varying) geographical location would be an important extension of these results. Despite the heterogeneity in the current sample, we do not appear to observe more highly variable performance relative to Caucasian children; nonetheless, these disparities in our populations are important factors for further consideration. Similarly, we also must acknowledge that all of our participants were tested in North America and had lived in either the United States or Canada for several years, meaning that heavily biased exposure favoring Asian faces was likely not characteristic of our sample of Asian observers (children or adults). Testing Asian children and adults who live in a majority-Asian community would be an important complement to the current data; unfortunately, this was not an option we were able to pursue. With regard to our operational definitions of 3D shape and 2D pigmentation, we also acknowledge that in the current study we took a very broad perspective on pigmentation information in particular. Surface properties, as we have considered them, are composed of variation in luminance, color, and texture, each of which may make more or less of a contribution to similarity judgments developmentally or across participant categories defined by visual experience. In the adult literature, there are often slight discrepancies between studies that have used grayscale stimuli (Brooks & Gwinn, 2010) and studies that used full-color images (Sun & Balas, 2012), suggesting that separate pigmentation channels defined by variation in luminance and hue, respectively, may make unique contributions to face processing, especially with regard to race. A more fine-grained analysis of how different aspects of facial pigmentation are recruited by children and adults would offer a more comprehensive picture of how the vocabulary of face representation changes developmentally.

Overall, the current results demonstrate that children and adults differentially use shape and pigmentation to judge facial similarity and that the development of adult-like use of visual information appears to be influenced by visual experience. Thus, children's exposure to faces of different racial categories not only shapes the way children define category boundaries in terms of distinct visual cues but also influences how they use visual information within a category to make judgments about resemblance and possibly identity.

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