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Connecting Developmental Trajectories: Biases in Face Processing From Infancy to Adulthood

ABSTRACT: *The nature of the developmental trajectory of face recognition abilities from infancy through adulthood is multifaceted and currently not well understood. We argue that the understanding of this trajectory can be greatly informed by taking a more functionalist approach in which the influence of age-appropriate developmental tasks and goals are considered. To build this argument, we provide a focused review of developmental change across several important biases within face processing (species, race, age, and gender biases) from infancy through adulthood. We show that no existing theoretical framework can simultaneously and parsimoniously explain these very different trajectories and relative degrees of plasticity. We offer several examples of infant- and adolescent-specific developmental tasks that we predict have an essential influence on the content and description of information that individuals need to extract from faces at these very different developmental stages. Finally, we suggest that this approach may provide a unique opportunity to study the role of early experience in (i.e., age of acquisition effects) and the quality and range of experiences that are critical for shaping behaviors through the course of development, from infancy to adulthood. © 2012 Wiley Periodicals, Inc. Dev Psychobiol 54: 643–663, 2012.*

Keywords: *face recognition; own-race effect; own-age effect; gender effect; species effect; infancy; adolescence; developmental tasks; vision; plasticity; early experience*

INTRODUCTION

Face recognition is one of, if not the most, critical abilities for human beings to master. We rely on face recognition to identify our caregivers, family and friends, as well as potential romantic partners and foes. When face recognition abilities are deficient, there can be clear social consequences, as described by the neurologist, Oliver Sacks, who has congenital prosopagnosia, a life-long history of face-blindness:

I have had difficulty recognizing faces for as long as I can remember. My inability to recognize schoolmates would cause embarrassment and sometimes offense—it did not occur to them (or to me, for that matter) that I had a perceptual problem. I still sometimes fail to recognize my assistant, who has worked with me for 27 years. I sometimes don't even recognize myself. I tend to avoid conferences, parties, and large gatherings as much as I can, knowing that they will lead to anxiety and embarrassing situations—not only failing to recognize people I know well, but greeting strangers as old friends. (recent CNN interview)

Given the social importance of face recognition, one might predict that it develops quite early. In fact, there is a disparity in the literature about the timing of the onset of "mature" face processing and recognition of

unfamiliar faces in particular. On one hand, there is compelling evidence that within hours of birth newborn infants are selectively interested in visual stimuli that are face-like (Farroni et al., 2005) and that very young infants exhibit differentiation of familiar and unfamiliar faces in both behavioral (Barrera & Maurer, 1981; Turati, Macchi Cassia, Simion, & Leo, 2006) and neural responses (e.g., de Haan & Nelson, 1999). These data suggest that infants exhibit early proclivities in both the behavioral and neural basis of face recognition.

In stark contrast, there is also a wealth of data indicating that the developmental trajectory for mature face recognition abilities is actually quite long, extending through adolescence (Carey & Diamond, 1977; Carey, Diamond, & Woods, 1980; Diamond, Carey, & Black, 1983; Ellis, Sheppard, & Bruce, 1973; Flin, 1985; Mondloch, Dobson, Parsons, & Maurer, 2004; O'Hearn, Schroer, Minshew, & Luna, 2010) and peaking in adulthood near the age of 30 (Germine, Duchaine, & Nakayama, 2011). Furthermore, there is a remarkable consensus across developmental neuroimaging studies indicating that the cortical and subcortical regions comprising the face-processing network shows continued specialization beyond adolescence (e.g., Golarai et al., 2007; Golarai, Liberman, Yoon, & Grill-Spector, 2010; Scherf, Behrmann, Humphreys, & Luna, 2007; Scherf, Luna, Avidan, & Behrmann, 2011). A very unfortunate consequence of this disparity in the literature is that there are no theoretical accounts of the mechanisms supporting developmental change in face recognition behavior that can simultaneously account for the impressive abilities of infants as well as the ongoing improvements in the behavioral and neural specialization in adolescents.

The central goal of this paper is to bridge the findings from studies investigating the development of face processing in infancy with findings from studies investigating face recognition abilities across older ages by proposing a novel hypothesis about the underlying mechanisms of developmental change in the face-processing system. In particular, we focus on aspects of the developmental trajectory for face-processing skills from infancy through early adulthood. We argue that developmental changes in face-processing abilities are fundamentally influenced by transitions in age-appropriate developmental tasks or goals (e.g., formation of attachment relationships in infancy versus new interest in peers and potential sexual/romantic partners in adolescence). This hypothesis highlights the embodied nature of face processing and suggests that development might follow a nonlinear developmental trajectory, in line with dynamic systems (DSs) theory (Smith & Thelen, 2003).

To build this argument, we provide a focused review of developmental change in several biases in face recognition, including species, race, age, and gender biases. These biases are typically defined by the ability to discriminate and recognize individual, unfamiliar faces with one's own species, race, age group, or gender more accurately than within another species, race, age, or gender group, respectively. We present the existing, divergent theoretical accounts for face biases, which have almost exclusively considered the pattern of these biases within *adults*. We show how these frameworks are compelling in their attempt to explain the pattern of adult face biases. However, we will provide an analysis of the different developmental trajectories of these effects that reveals how these current frameworks are insufficient, in their current form, to account for the full range of the developmental data. As such, we offer an alternative account of these biases in face processing that incorporates the notion of *developmental tasks or goals* as fundamental to shaping these biases. We show that considering developmental tasks when evaluating developmental trajectories of particular behaviors will allow for a parsimonious integration of disparate findings that might otherwise be considered falsifications of one another.

ADULTS BIASES IN FACE PROCESSING

In adults, face recognition abilities often exhibit strong biases, such that discrimination and recognition are superior for specific categories of faces. These biases are strong across multiple categories and levels, including species, race, age, and gender. At the highest level of categorization, human adults exhibit more accurate recognition (Pascalis & Bachevalier, 1998) and discrimination abilities (Pascalis, de Haan, & Nelson, 2002) for human than for monkey faces, reflecting an ''own-species'' or ''species-specific'' bias in face processing.[1]

Within the set of human faces, adults often demonstrate superior abilities to discriminate and recognize an individual face within their own race compared to within another race; this bias is called the ''own-race'' effect (ORE; also called the cross-race effect, the other-race effect, the own-race bias, and the other-race bias, e.g., Hugenberg, Young, Bernstein, & Sacco, 2010; Levin, 1996, 2000; Meissner, Brigham, & Butz, 2005; Rhodes, Brake, Taylor, & Tan, 1989; Rodin, 1987; Sporer, 2001; Tanaka, Kiefer, & Bukach, 2004; Valentine, 1991). The ORE is a within-species effect

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[1]Interestingly, both Old World and New World monkeys also exhibit an own-species bias in face recognition abilities (Dufour, Pascalis, & Petit, 2006).

that further biases recognition and discrimination judgments of individual faces.

Similarly, several studies have reported an "own-age effect" (OAE) in face recognition such that adults are more accurate when recognizing faces from within their own-age range compared to both other adult faces outside their age range (Anastasi & Rhodes, 2006; Bäckman, 1991; Fulton & Bartlett, 1991; Perfect & Moon, 2005; Wright & Stroud, 2002) and child faces (Harrison & Hole, 2009; Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009a). More specifically, in several different kinds of face-processing tasks with unfamiliar adult faces (e.g., identifying a perpetrator from a lineup following observation of a video crime scene, more traditional individual recognition tasks) adults often exhibit better recognition for faces within their own-age group compared to faces from other age groups.

Finally, there is some evidence for an "own-gender" bias in face processing as well. In studies using simulated crime scenes (Shaw & Skolnick, 1994, 1999) and more classic old/new recognition memory paradigms (Wright & Sladden, 2003), adults are reportedly better at recognizing faces within their own gender. However, several studies have also reported that there is an asymmetry in this bias across the sexes with the effect being driven mostly by females performing better when recognizing female compared to male faces (Armony & Sergerie, 2007; Cross, Cross, & Daly, 1971; Lewin & Herlitz, 2002; McKelvie, 1987).

CURRENT THEORETICAL FRAMEWORKS FOR UNDERSTANDING ADULT FACE-PROCESSING BIASES

The presence and nature of these biases has been interpreted within several theoretical frameworks, all of which largely emphasize the role of *differential experience* with particular kinds of faces as an important factor for sculpting these biases. Importantly, these theories are all variations of the *Contact Hypothesis*, which argues that more face-to-face contact with individuals from "out-groups" will foster the ability to extract various types of visual cues or invoke processing strategies (e.g., configural processing) that support face recognition for individuals within these "out-groups" (Sporer, 2001). Within the set of Contact Hypotheses are perceptual learning/expertise and social cognitive models, which are not necessarily mutually exclusive.

In the perceptual learning/expertise category of models, much of the work has been done in the context of the ORE. These models suggest that life-long differences in exposure to faces within one's own race

compared to faces of other races (OR) lead to less practice recognizing faces from outside one's own race. As a result, configural (i.e., detecting metric spatial distances between features) and/or holistic processing (i.e., the ability to integrate featural and configural information to form a unitary representation) for OR faces is not as finely tuned as it is for same race (SR) faces (e.g., Mondloch et al., 2010; Rhodes et al., 1989; Tanaka et al., 2004). Similarly, Valentine (1991) has argued that infrequently experienced faces (e.g., OR faces) are differential encoded and represented in memory such that they cluster in the periphery of "face space" far away from the most average or typical face in the representational space.

The social cognitive theories argue that categorization of faces into the social categories of "in-group" and "out-group" has downstream consequences for how the faces are perceptually processed. For example, Levin (1996, 2000) argued that this social categorization leads to an asymmetrical search of the feature-space of OR and SR faces, which translates into differential recognition accuracy. Similarly, Rodin (1987) proposed that OR faces do not elicit the attention or motivation required for highly accurate individual recognition. Perhaps most famously, Sporer (2001) suggested that configural processing is only deployed for "in-group" faces. Finally, Hugenberg and colleagues (2010) suggest that social categorization, perceiver motivation, and perceiver experience discriminating SR and OR faces work together to drive selective attention during face encoding, thereby affecting face recognition.

Across these theories there are important commonalities, which have been the basis of strong criticisms. First, the labeling of the biases as "own" reflects how these theories largely assume that over the course of a lifetime individuals mostly interact with (i.e., perceive faces of) people within their own group affiliation (e.g., species, race, age, and gender). Indeed there is a wealth of evidence in support of the notion that particular kinds of experience observing faces influences the speed and efficiency of recognition (e.g., for such experiential influences on the ORE see Hugenberg et al., 2010). However, the assumption that group affiliation is largely stable and reflective of one's own social categories in most of the existing theories of face-processing biases overlooks the substantial individual differences in perceivers' experience individuating other faces (Hancock & Rhodes, 2008). In fact, in the following sections of the paper, our review of the existing work on the developmental trajectory of these biases reflects the potential role of these individual differences. As a result, we will refer to these biases more generally throughout the remainder of the paper (e.g., "species bias" as opposed to "own-species" bias).

Second, although the categorization of "out-group" faces is particularly clear with respect to some biases, like the own species effect, it is much less clear how to define in/out groups when it comes to (1) race, particularly for mixed race individuals and/or individuals adopted into OR families, and (2) age, especially since age changes throughout the lifespan such that older individuals once belonged to younger age groups (do they retain the expertise for processing younger previously own-age groups?).

Third, social categorization into in/out groups can be a highly fluid process that is very much influenced by the moment-to-moment context. For example, several studies have *induced* other-group effects (e.g., unfamiliar faces designated as belonging to one's own versus a rival university) in face recognition in young adults observing same-age, same-race faces (Bernstein, Young, & Hugenberg, 2007; DeSteno, Dasgupta, Bartlett, & Cajdric, 2004). In some cases, these other-group effects can actually override OR effects that are arguably more clearly based in life-long personal experience (Hehman, Mania, & Gaertner, 2010). These data suggest that merely categorizing a face as belonging to a member of an in-group can be sufficient to improve face recognition, compared with members of out-groups, even when holding perceptual experience constant (Hugenberg et al., 2010).

Fourth, proponents of the perceptual learning/expertise theories of face-processing biases have refined the role of experience in shaping face-processing bias by demonstrating that particular *kinds of experience* are required to improve recognition abilities for individual faces. Specifically, simple exposure, or contact, with faces from another social category (e.g., race) is not sufficient to diminish biases in face recognition. For example, laboratory-training studies indicate that an ORE can be reduced if participants are trained to *individuate* faces from another race (McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011; Tanaka & Pierce, 2009). Importantly, when the same participants spend an equal amount of time with another set of OR faces in a difficult task that requires visual attention (e.g., detecting differences in eye luminance), but not individuation, the ORE does not change (McGugin et al., 2011). These findings provide compelling evidence that increasing the relative contact with other group (e.g., race) faces does not necessarily modulate the magnitude of face-processing biases.

Finally, and of most relevance for the current argument, none of these theoretical frameworks have systematically evaluated the developmental origins of these biases and how they change over the lifespan. For example, there is a wealth of data demonstrating that species, race, and gender face biases (1) emerge in infancy and (2) are relatively plastic in early adulthood. However, there is very little work investigating how these biases change developmentally through childhood and adolescence or even later adulthood. In contrast, work on age biases has focused almost exclusively on adulthood, with a paucity of research focused on understanding these biases in infancy, childhood, and adolescence.

In the next section of this paper, we provide a review and comparison of the current work reflecting on the developmental trajectories and relative lifespan plasticity in the species, race, gender, and age biases in face recognition. Importantly, we argue that this analysis and comparison of the developmental trajectories of these multiple face-processing biases reveals that none of the existing theoretical frameworks can simultaneously account for all the developmental data. Furthermore, we argue that this analysis reveals important unanswered questions about these developmental trajectories and their relative plasticity. Answers to these questions will be critical for identifying the cognitive and neural mechanisms that mediate these biases, even in adults. Critically, we suggest that age-appropriate *developmental tasks/goals* induce changing needs for face processing developmentally, and as a result, fundamentally shape the emergence and plasticity of these biases. We conclude by providing several examples of developmental tasks that we predict are critical for organizing face-processing biases, particularly in infancy and adolescence.

DEVELOPMENTAL TRAJECTORY OF SPECIES BIASES

Comparative studies have shown that adult humans as well as adult non-human primates exhibit superior recognition abilities for faces within their own species (Dufour et al., 2006; Pascalis & Bachevalier, 1998). The overwhelming majority of the developmental work on the species bias in humans has investigated the emergence of this bias in infancy. Interestingly, the findings on the development of the species bias are not entirely consistent with any of the existing theoretical frameworks offered to explain face-processing biases. For example, at the age of 6 months, human infants do not exhibit an own-species face recognition advantage (Pascalis et al., 2002, 2005; Scott & Monesson, 2009; Simpson, Varga, Frick, & Fragaszy, 2011) despite the disproportionate (and likely exclusive) contact with and experience recognizing human compared to non-human primate and non-primate faces. This finding appears to be in direct contrast with predictions from both the perceptual learning/expertise and social cognitive theories of face-processing biases.

The own-species advantage is not measurable in human infants until the age of 9 months (Pascalis et al., 2002, 2005; Scott & Monesson, 2009, 2010; Simpson et al., 2011). Consistent with the perceptual learning/expertise theories, the developmental trajectory of the emergence of the own species bias is directly related to experience individuating faces, particularly in infancy (Scott & Monesson, 2009, 2010). For example, in a laboratory training study, human infants who were either exposed to monkey faces or learned to categorize monkey faces (e.g., learned 6 monkey faces all of which were labeled ''monkey''), between 6 and 9 months of age, showed a decline in their ability to distinguish among monkey faces (i.e., strengthening of own-species bias) following the training. In contrast, human infants trained to recognize monkey faces at the individual level (i.e., each face labeled with a different individual name) maintained the ability to distinguish among individual monkey faces preventing the emergence of an own species bias by 9 months of age (Scott & Monesson, 2009). Similarly, only those infants trained to recognize monkeys at the individual level exhibited greater amplitude for the N290 and P400 ERP responses (components previously found to index face processing in infants) to inverted relative to upright monkey faces (Scott & Monesson, 2010), which is consistent with the profile of ERP responses that adults exhibit when they observe upright and inverted human faces (e.g., Carmel & Bentin, 2002). Together, these infant studies indicate that the timing and the quality of the contact with other species faces may be critical to the emergence and magnitude of an other species bias in face-processing abilities in humans.

Additional support for the notion that early experience is essential for shaping a species bias comes from studies of patients who experienced early visual deprivation caused by bilateral congenital cataracts. These patients were tested as adolescents and adults for their ability to detect both featural and configural changes in human and monkey faces as well as in houses (Robbins, Nishimura, Mondloch, Lewis, & Maurer, 2010). Compared to age-matched controls, the patients were disproportionately impaired at discriminating configural changes in human faces, but scored in the normal range for discriminating configural differences in monkey faces (as well as in houses), which is much less skilled even in normal adults. In other words, as adolescents and adults, the patients exhibited a similar pattern of face-processing abilities as the typically developing 6-month olds described in the previous studies. The authors argued that early visual experience is necessary to set up (or preserve) the neural architecture used for processing faces, but not objects in general.

This set of findings has been interpreted as reflecting a process (or lack thereof) of perceptual tuning, or ''perceptual narrowing,'' as infants begin to carve a fairly undifferentiated representational space to represent specific individual faces in their environment (for review see Scott, Pascalis, & Nelson, 2007). Importantly, these findings are difficult to reconcile within the context of a social cognitive contact theory given that simple exposure and even categorization training fail to enhance recognition abilities for the monkey faces in these young infants. It is the particular process of learning to perceptually individuate the faces that is critical for modifying the own-species advantage in face recognition in infancy. To our knowledge, there are no such training studies, using other-species faces, to evaluate these hypotheses in any other age group.

Finally, comparative developmental findings with infant monkeys reveal a similar role for the importance of the timing and quality of contact with other species faces for the emergence of a species bias in face processing. Sugita (2008) reared infant monkeys in an environment without any (monkey or human) faces for 6–24 months. During the deprivation period, monkeys did not exhibit a visual preference for either human or monkey faces (i.e., they failed to exhibit an own-species bias). However, despite the lack of experience with faces in general, these same monkeys could discriminate between novel and familiar human and monkey faces in a visual paired comparison task. In contrast, control monkeys not deprived of exposure to faces (monkey or human) could only discriminate between novel and familiar monkey faces (not human faces). On one hand, these findings seem to be consistent with the predictions from the perceptual narrowing account. However, the control monkeys, who were raised with other monkeys, exhibited perceptual narrowing of their representational space only for monkey faces, despite observing the faces of their human caregivers on a daily basis. The perceptual narrowing account would predict that the control monkeys would maintain recognition abilities for human faces as a result of individuating the faces of their caregivers, as the human infants did following the individuation training with monkey faces.

Following the deprivation period, monkeys were selectively exposed to either monkey or human faces for 1 month. After this exposure period, the same monkeys who exhibited no visual preference for either monkey or human faces during the deprivation period showed a strong preference for the species of faces in their exposure environment. This finding is seemingly consistent with all forms of the Contact Hypothesis. However, these preferences did not change even after all the monkeys were placed in a normal animal room

for 1 year (i.e., exposure to lots of individual monkey faces and less exposure to lots of individual human faces). In other words, the monkeys initially deprived of the opportunity to observe any faces and who were then selectively exposed to human faces, still exhibited a preference for human faces even a year after exposure to many monkey faces in their natural environment. Sugita interpreted these findings to suggest that there may be a sensitive period during which early developmental experiences may have a disproportionate influence in shaping face-processing biases. It is important to note that the notion of critical or sensitive periods is neither predicted nor addressed in either the perceptual learning/expertise or the social cognitive theories. We will return to the issue of sensitive periods later in the paper.

In sum, both human and non-human primates exhibit species biases in face discrimination and recognition. Human infants exhibit a species bias by 9 but not 6 months of age, despite their overwhelmingly disproportionate (and potentially exclusive) exposure to human faces even by 6 months of age. Importantly, the emergence of this species bias in infancy is plastic. However, inducing such plasticity requires extensive experience individuating faces from another species. There is no work evaluating the long-term outcomes or consequences of this plasticity in the species bias in humans. For example, nothing is known about the relative plasticity in the species bias in adulthood (e.g., do primatologists have reduced own-species biases in adulthood even if the bulk of their experience with non-human primate faces in acquired in adulthood?). Deprivation studies in both human patients (with early congenital cataracts) and infant monkeys suggest that early experiences may have a life-long effect on the specific patterns of a species bias. Together these findings reveal an important issue about the potential primacy of early experiences for laying the foundation for face-processing biases. We contend that neither of the current versions of the perceptual learning/expertise nor the social-cognitive theories of face processing predicts nor accounts for the potential role of early experiences, a weakness that becomes apparent through this analysis of the developmental data on the species bias.

DEVELOPMENTAL TRAJECTORY OF RACE BIASES

Similar to species biases, work investigating the developmental trajectory and relative plasticity in race biases, and particularly the ORE, has also produced mixed results that are not easily reconciled with either the perceptual learning/expertise or the social cognitive theories of face-processing biases. In particular, our review of this work reveals that the pattern of emergence of this ''own-race'' bias (1) is actually in direct contrast with the pattern predicted by either of the perceptual learning/expertise or the social cognitive theories, (2) is closely tied to experiences individuating racially diverse faces, regardless of whether these faces exist in one's early environment directly, and (3) appears to be highly plastic even in adulthood, suggesting that early experiences may not be so important for the stability of an ORE.

First, similar to the work on the other species effect, the work investigating the emergence of the ORE in infants suggests that the face-processing system is initially undifferentiated and becomes increasingly specific during the first year of life. Although, the ORE is not present at birth (Kelly et al., 2005), many studies have shown that infants appear to develop an initial bias for own-race versus other-race faces by the end of the first year of life (Anzures, Quinn, Pascalis, Slater, & Lee, 2010; Ferguson, Kulkofsky, Cashon, & Casasola, 2009; Hayden, Bhatt, Zieber, & Kangas, 2009; Kelly et al., 2007, 2009; Liu et al., 2010; Vogel, Monesson, & Scott, in press). For example, Kelly and colleagues report sustained abilities to discriminate own-race faces and decreasing abilities to discriminate other-race faces from 3 to 9 months of age in both Caucasian (Kelly et al., 2007) and Chinese (Kelly et al., 2009) infants. In both of these studies, by 9-month-old infants show a clear advantage for discriminating faces within their own-race relative to other-race faces. Furthermore, this advantage appears to be related to a change in the way infants fixate own-race versus other-race faces. Between 4 and 9 months of age, infants consistently maintain the ability to fixate internal features in own-race faces, which is a characteristic of advanced face processing and potentially holistic processing in adults (O'Donnell & Bruce, 2001); however, they decrease their visual fixation time on internal features of other-race faces (Liu et al., 2010). In a related study, 8-month-old infants, but not 4-month olds, exhibited selective holistic processing of own-race but not other-race faces (Ferguson et al., 2009). Together these findings suggest that infants' face-processing system is initially undifferentiated and becomes increasingly specific with regard to encoding race during the first year of life. This increased specificity involves increased holistic processing of own-race faces, which is consistent with adult models of perceptual learning/ expertise. It is important to note that in all of the previously described studies, infants were developing in homes in which the parents and the child were of the same race.

Importantly, neither the perceptual learning nor the social-cognitive contact theories would necessarily predict this pattern of developmental change in the ORE, which is similar in some ways to that of the OSE. Both theories would predict that discrimination and recognition abilities for faces in the infant's local environment will become enhanced as a result of increasing contact over time, and furthermore, that there should be no change (from infant baseline) in discrimination abilities for faces not encountered in the local environment. However, empirical results suggest that this is not the developmental trajectory for either the species or race biases. Instead, infants' discrimination and recognition abilities remain *stable* for faces encountered in their local environment, but *decline* in response to faces that they do not encounter and individuate on a regular basis.

Second, developmental studies on race biases in face processing also call into question the notion of an ''own-race'' bias and instead, suggest that infants' and children's representational space for faces is tuned to represent the race of the faces in their ambient environment, which is not necessarily reflective of their ''own'' race (for review see Scott et al., 2007). For example, children raised in mixed-race environments show little or no other-race bias (Bar-Haim, Ziv, Lamy, & Hodes, 2006; de Heering, de Liederkerke, Deboni, & Rossion, 2010), and, in some cases a reversal of the other-race bias (Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005). Also, 3-month-old African infants who live in a predominately Caucasian environment show no such preference for either African or Caucasian faces (Bar-Haim et al., 2006). Similarly, Asian children and adolescents who were adopted into Caucasian homes as infants do not exhibit an ORE in their recognition memory abilities. This is in direct contrast to Caucasian children and adolescents raised in Caucasian homes who do exhibit a clear ORE that is stable across this age range age (de Heering et al., 2010). Finally, Sangrigoli et al. (2005) found that Korean adults who were adopted into Caucasian homes as children (3–9 years of age) exhibited a reversal of the OR bias in that they identified Caucasian faces better than Asian faces. These findings underscore the link between the race of the faces in an individual's local environment and a face-processing bias toward a particular race, which does not necessarily reflect the specific race of the observer.

Note that these findings are reasonably consistent with all forms of the Contact Hypothesis as long as out-groups are flexibly determined based on the facial characteristics of individuals in the infant's/child's immediate environment and not their own facial characteristics. Support for this interpretation of the Contact Hypothesis comes from laboratory training studies of the ORE in infants. For example, Caucasian infants trained on several Chinese faces from 6 to 9 months of age do not exhibit perceptual narrowing toward own-race faces during these 3 months (Heron-Delaney et al., 2011). These findings are consistent with findings from infant training studies of species biases in face processing (Pascalis et al., 2005; Scott & Monesson, 2009),[2] indicating an initial representational space for faces that is fairly undifferentiated and that becomes finely tuned to represent characteristics of the faces in one's ambient environment.

Together, these results suggest that the first signs of race biases in face recognition and discrimination are present in infancy and are influenced specifically by the experience of individuating faces. These findings are largely consistent with perceptual learning/expertise theories of face-processing biases. However, it is currently unclear whether or not the period between 6 and 9 months of age, when perceptually narrowing appears to occur for both the species and race biases, represents a sensitive period for the development of these biases in face processing. The work on race biases in children and adolescents suggests that early experiences may not have a lasting impact on this aspect of face processing, like it may with species biases, indicating a potentially different lifetime developmental trajectory for the race than the species bias.

By the age of 3 years, young children do evince stable race biases in face processing (Sangrigoli & de Schonen, 2004a, 2004b) and these biases may be related to the categorization of faces into own versus OR groups (Shutts & Kinzler, 2007). However, the studies investigating race biases in school-age children and early adolescence have produced a very mixed set of results about the longer-term developmental trajectory of these biases and the potential role of categorizing faces (as members of an ''out-group'') to the stability and plasticity of these biases. For example, two studies have reported no age-related change in the magnitude of the own-race bias in White and Black 5-year olds, 8-year-olds, and young adults (Pezdek, Blandon-Gitlin, & Moore, 2003) and in White participants ages 7, 12, and 17 years of age (Cross et al., 1971). In contrast, several studies have found evidence for a developmental increase in the magnitude of the own-race bias from childhood through adolescence (ages 7–14 years) in

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[2]However, unlike reported by Scott and Monesson (2009) and Heron-Delaney et al. (2011) did not provide labels or instructions for how parents should talk about the faces. If the parents naturally labeled the faces at the individual level these findings are consistent with Scott and Monesson (2009). However, if parents did not label the faces, it suggests that labeling may play a more influential role for other-species faces relative to other-race faces.

White individuals observing White and Japanese faces (Chance, Turner, & Goldstein, 1982) and in Caucasian and bi-racial (African-American-Caucasian) children and adults living in the United States, Norway, and South Africa (Goodman et al., 2007). These studies suggest that there may be an important developmental transition in race biases from early to later childhood, again, showing a pattern of less to more differentiation in the representational space for faces in the ambient environment. Unfortunately, there is no information on the differences in relative and/or meaningful contact that the participants had with individuals outside their race in any of these studies to help reconcile these conflicting findings with the existing versions of the Contact Hypothesis.

Finally, it is important to note that race biases in adulthood are quite flexible, which makes the question about the role of early experience in establishing these biases even more interesting. Laboratory training studies have been successful in reducing own-race biases in adult face recognition behavior, neural responses, and implicit race biases (Lebrecht, Pierce, Tarr, & Tanaka, 2009; Tanaka & Pierce, 2009). Importantly, only participants who learn to individuate OR faces during training, and not simply categorize them into a race, exhibit these changes with respect to their own-race bias.

In sum, much of the work characterizing the developmental trajectory of race biases in face-processing behavior appears to be fairly consistent with the Contact Hypothesis. The race bias is flexible at all ages tested (e.g., training studies with 6-month-old infants, young children adopted into other-race homes, training studies with adults), but this flexibility hinges on intensive experience individuating faces from a less familiar race (regardless of one's own race), which is very consistent with the perceptual expertise hypotheses. Also, there is some evidence that social categorization of faces can modulate the race bias in children, which is consistent with the social-cognitive version of the Contact Hypothesis.

However, the patterns of developmental change indicating that infants and young children have a fairly undifferentiated representational space for faces (with respect to species or race) that maintains sensitivity (as opposed to increasing sensitivity with increasing experience) to the holistic and/or configural properties of faces in their local environment, but loose sensitivity to such properties in faces that they do not observe regularly, is in direct contrast with predictions from either version of the Contact Hypothesis. Also, it is unclear whether there is a long-term consequence of early experiences for setting up race biases, as may be the case with species biases. Neither the perceptual learning/expertise nor the social-cognitive theories have

clear predictions about the timing of experience in shaping the race, or any other, bias in face processing.

DEVELOPMENTAL TRAJECTORY OF AGE BIASES

There is very little work investigating the developmental trajectory of an age bias (own or otherwise) and/or the relative plasticity in this bias across the life span. The findings that do exist are not well explained by either the perceptual learning/expertise or the social cognitive theories of face-processing biases.

The strongest evidence for an OAE in face recognition abilities comes from studies in adults (Anastasi & Rhodes, 2006; Bäckman, 1991; Fulton & Bartlett, 1991; Perfect & Moon, 2005; Wright & Stroud, 2002). Across several different kinds of face-processing tasks with unfamiliar faces (e.g., identifying a perpetrator from a lineup following observation of a video crime scene, old/new recognition tasks), adults seem to exhibit better recognition for faces within their own-age group compared to both younger and older adult faces. It is difficult to evaluate whether and how these findings are consistent with the current theories of face-processing biases, particularly without being able to quantify the amount of exposure adults have to same-age versus other-age faces. In fact, both the social cognitive and perceptual learning/expertise contact theories might predict that learning to recognize same-age peer faces throughout one's life would result in the weakest own-age bias in older adults who have had the benefit of many years individuating faces across a variety of same-age peer groups (e.g., Wiese, Schewinberger, & Hanson, 2008). However, there are no consistent data to support this hypothesis. Although there are a handful of studies that report a less reliable or non-existent age bias in older adults relative to younger adults (Bäckman, 1991; Fulton & Bartlett, 1991; Wiese et al., 2008; Wright & Stroud, 2002), there are other studies that find that magnitude of the OAE is comparable in younger and older adults (Perfect & Harris, 2003), is strongest in middle adulthood (Anastasi & Rhodes, 2006), and is strongest in older adults (Perfect & Moon, 2005).

On one hand, much of the work investigating age biases (or lack thereof) in face processing in adults is largely consistent with the Contact Hypothesis, meaning that experience observing other age faces in one's local environment influences the magnitude of the OAE. For example, in a series of three studies, Kuefner et al. (2008) found that young men and women (mean age 21 years) who do not report extensive experience with infants in the preceding 5 years only exhibit a

face inversion effect for adult, but not newborn, faces indicating an OAE. However, preschool teachers tested in the same paradigm showed inversion effects for both adult and child faces, indicating no OAE. Similarly, Harrison and Hole (2009) tested trainee teachers and age-matched adults in a recognition memory paradigm on both child (ages 8–11 years) and adult (ages 19–33) faces. Although the control adults exhibited an OAE in their recognition memory, the teachers in training did not. In another study, both maternity ward nurses and adults who were novices at identifying newborn babies completed a recognition paradigm with both upright and inverted adult and newborn faces (Macchi Cassia, Picozzi, Kuefner, & Casati, 2009b). The novices exhibited a classic OAE in overall accuracy and with respect to the face inversion effect. In contrast, the nurses showed inversion effects for both the newborn and adults faces, even though they were more accurate overall when identifying the adult faces. These findings suggest that increased experience with certain aged faces may increase holistic processing of those faces.

Unfortunately, it is difficult to evaluate the developmental trajectory of an own-age bias from infancy to adulthood. Presently, there are no studies specifically investigating age (own or otherwise) biases in infants and there is very little consistency in the pattern of results with children and adolescents. To our knowledge, there are only a handful of developmental studies that were specifically designed to evaluate recognition memory skills for same-age peer faces in children, most of which failed to find an own-age bias in preadolescent children. For example, Chung (1997) tested 7- to 12-year-old children and adults in a recognition memory task with faces from both age groups. Only the adult group exhibited an own-age bias. Rehnman and Herlitz (2006) also failed to find an own-age bias in the recognition skills of 9-year-old girls and boys for either same or OR child and adult faces.

Several studies have produced a mixed pattern of results concerning a potential own-age bias in children. Goldstein and Chance (1971) tested recognition abilities of children in kindergarten, third, and eighth grade on images of children faces from each of the three age groups in an old/new recognition memory paradigm. Although they found that recognition abilities improved with age across the whole sample, they reported a mixed pattern of results concerning a potential own-age bias. More recently, Crookes and Mckone (2009) evaluate the potential age biases in both explicit and implicit memory paradigms. Children (ages 5–6 years), young adolescents (ages, 10–11 years), and young adults (ages 18–30 years) performed the memory tasks with both child (ages 5–7 years) and adult (ages 18–31

years) faces.[3] The authors reported very weak evidence of an own-age bias when the two younger age groups were combined in the explicit memory task, and no evidence of any age bias in the implicit memory task. Note that these results are difficult to interpret since the adults also failed to show an own-age bias in both memory paradigms. In another investigation, children (ages 5–8 years) and older adults (ages 55–89 years) completed an old/new recognition memory task for faces from four different age groups (5–8, 18–25, 35–45, and 55–75 years; Anastasi & Rhodes, 2005). Results revealed that children exhibited no clear own-age bias in that they showed superior recognition performance for peer compared to young adult faces, but comparable recognition performance for the peer and oldest adult faces. Finally, 4- to 6-, 7- to 9-, and 9- to 12-year-old children were tested on their recognition for faces of young adults, older adults, and 8-year-old children (Hills & Lewis, 2011). Only adults and children aged 7–9 years but not the 4- to 6-year olds nor the 9- to 12-year olds showed an own-age bias in their recognition abilities. Unfortunately, there appear to be no studies tracking the developmental progression of such a bias with truly age-matched faces for each age group from early childhood, through adolescence and into adulthood. The existing data are consistent with the interpretation that an own-age bias in preadolescent children is much less robust than in adults.

As in the adult literature, there are some findings indicating that the strength of an own-age bias is specifically related to the age range of the faces in a child's immediate environment.

Macchi Cassia et al. (2009a) evaluated the potential influence of infant siblings on preschoolers' (3-year olds) face recognition skills for both adult and infant faces. The group of preschoolers without infant siblings exhibited an age bias in accuracy and inversion effects for *adult* faces.[4] Interestingly, the group of preschoolers with infant siblings did not exhibit this age bias toward adult faces. The authors concluded that without younger siblings, the 3-year-old face-processing system is tuned to adult (as compared to infant) faces. This conclusion is consistent with reports that infants' experience with faces during the first year of life is largely with their primary caregiver (typically the mother), females, and individuals of the same age and race as the primary caregiver (Rennels & Davis, 2008).

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[3]Note that the "own" age bias can only be evaluated in the youngest and oldest age groups given the nature of the stimuli.

[4]Note that this finding does not speak to an OAE in these children since neither of the stimulus sets included children from their own age group.

However, in a second experiment, Macchi Cassia et al. (2009a) found that women who are first time mothers and who have younger siblings fail to exhibit an OAE for adult compared to infant faces. In contrast, women without younger siblings, regardless of whether they have their own children or not, show a classic OAE for adult faces. The authors explained this interesting and complicated set of findings by arguing that experiences in adulthood (including that of individuating your own child) does not readily modulate the OAE unless one had early childhood experiences with infant faces that become "reactivated" in adulthood. These findings are especially difficult to reconcile with either a perceptual learning/expertise or a social cognitive theory of face recognition biases because, like in the monkey deprivation studies (Sugita, 2008), they suggest that early life experiences can have a lasting effect on the representational space of faces with respect to the way age is encoded.

Together, these studies suggest that the OAE may be somewhat plastic in adulthood, but that this plasticity is related to previous experience. However, it is not clear what kind and timing of experience is required to induce this plasticity. Recall that the training studies with both infants and adults demonstrate that the experience of *individuating*, but not categorizing or passively viewing, faces is critical to induce plasticity in the ORE. This work might be extended to the OAE to hypothesize that similar experiences individuating faces outside one's own-age group are required to induce an age bias in face recognition abilities. However, there are no such training studies investigating the specificity of the experience required to induce plasticity in the OAE. Much work needs to be done to evaluate the full developmental trajectory, relative plasticity, and critical experiences that shape the age-related biases in face processing more generally.

Although, several groups have specifically argued that the amount of exposure with other age faces will predict the magnitude of the OAE in recognition memory (Anastasi & Rhodes, 2006; Ebner & Johnson, 2009; Harrison & Hole, 2009; Kuefner et al., 2008; Mason, 1986), there is only one study, to our knowledge that speaks to this critical evaluation of various forms of the Contact Hypothesis. Ebner and Johnson (2009) evaluated the relation between self-reported frequency of contact with one's own and another age group (younger and older adults) and the magnitude of the OAE for both emotional expression and identity recognition abilities in adults. For emotional expression recognition, only the frequency of contact with one's own-age group (not other age group) predicted the OAE, particularly for younger adults. In contrast, frequency of contact with own or other age group did not predict an OAE in recognition memory. This pattern of results suggests that exposure (i.e., contact) alone is not sufficient to induce plasticity in the OAE in adulthood. Note, that the authors did not evaluate the kind of exposure, only the frequency of contact. It may be the case, that high frequency exposure coupled with the process of individuating the faces is critical for shaping age-related biases in face recognition. This assumption may be less appropriate for some developmental stages (e.g., infancy) relative to others (e.g., adolescence) when individuation of similar-aged individuals is more relevant. Finally, it is difficult to apply the social-cognitive theories to understand age-related biases in face recognition because it is not clear that age is as relevant a defining variable for in/out group status at all developmental levels.

In sum, the overwhelming majority of the work on age biases in face-processing abilities has been conducted with adults and addresses questions regarding the relative plasticity of the bias. Some of this work, especially the work of Cassia et al., is largely consistent with the Contact Hypothesis, suggesting that a lifetime of experience individuating faces from a different age-group than one's own will mitigate some aspects of the age bias. However, it is not at all clear whether and to what extent early life experiences shape the long-term developmental trajectory of these biases. Furthermore, the developmental trajectory of age biases in face processing is very much under studied, and inconsistent making it difficult to draw strong conclusions about how such biases change with age.

DEVELOPMENTAL TRAJECTORY OF OWN GENDER BIAS IN FACE PROCESSING

As with the previously described face recognition biases, the strongest evidence of an own gender bias in face processing is in adults (Shaw & Skolnick, 1994, 1999; Wright & Sladden, 2003). However, many studies investigating this bias in adults have reported an asymmetry in the own gender bias across the sex of the observers. Women tend to exhibit a stronger own-gender bias (i.e., enhanced recognition performance for other female compared to male faces) than do men (Armony & Sergerie, 2007; Cross et al., 1971; Lewin & Herlitz, 2002; McKelvie, 1987). These reports of asymmetric own-gender biases may also be confounded by the consistent finding that females tend to outperform males on face recognition and emotion expression identification tasks in general (Cross et al., 1971; Ellis et al., 1973; Feinman & Entwisle, 1976; McClure, 2000; Rehnman & Herlitz, 2006, 2007; Temple & Cornish, 1993). This is a complicated set of findings,

which are not clearly consistent with any of the existing theories about the role of experience in shaping face-processing biases.

In contrast, a body of work investigating gender biases in face-processing abilities in infants is much more consistent with the various forms of the Contact Hypothesis. For example, by 2 days of age, infants can perceptually discriminate their mother's face from that of another (dissimilar looking) woman's face (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995; Walton, Bower, & Bower, 1992). Also, newborns can discriminate between two unfamiliar female faces when the external features are sufficiently different (Turati et al., 2006). If given ample familiarization to a stranger's face, 3-month-old infants discriminate between two similar-looking female strangers (Barrera & Maurer, 1981). Interestingly, they do not have these same perceptual discrimination abilities when it comes to their father's face (Walton et al., 1992), even by the age of 4 months (Ward, 1998). At 7 months of age, infants still have difficulty discriminating among similar-looking adult male faces (Fagan, 1976). Note that these findings reflect a gender bias toward better recognition of female faces across both male and female infants.

To date, there is no evidence of an "own-gender" bias in infant face discrimination abilities. This is actually quite consistent with the notion that an infant's immediate environment is typically dominated by female faces of the same demographic characteristics (e.g., age, race) as the infant's mother's face (Rennels & Davis, 2008), making these findings very consistent with all forms of the Contact Hypothesis. In support of this notion, a recent set of studies has found a more direct link between the sex of the primary caregiver and an infant's gender bias in face recognition abilities. At birth infants do not exhibit a preference for female or male faces (Quinn et al., 2008); however, Quinn, Yahr, Kuhn, Slater, and Pascalis (2002) reported a spontaneous preference and better individual recognition for adult female faces in 3- to 4-month-old infants who had a female adult primary caregiver. In contrast, infants who had male adult primary caregivers tended to show a spontaneous preference for adult male faces. In a subsequent study, Quinn et al. (2010) reported that the same infants reared with a female caregiver exhibited a gender bias toward female faces that extended to child face stimuli as well, and by 3 months of age this gender preference is specific to own-race female faces (Quinn et al., 2008). Critically, the tendency to exhibit this gender bias in face processing was not related to whether the infants had an older sibling (boy or girl) in the house, leading the authors to argue that the gender

bias is mediated by the social category of the face of the *primary* caregiver, which appears to be in contrast with the observed effects of siblings in the early environment on age biases in face processing (Macchi Cassia et al., 2009a). However, in a recent review of the infant gender bias literature, Ramsey et al. (2005) argued that these biases are multiply determined in infants and can be influenced by not only differential experience observing the primary caregiver's face but also qualitative differences in the nature of the interactions with the primary compared to the secondary caregiver.

Importantly, beyond evaluating the general sex differences in face-processing abilities (i.e., females tend to be better in general than males), there are no studies, to our knowledge, investigating gender biases in face-processing abilities across development, particularly during childhood and adolescence. Therefore, it is very difficult to even speculate about how a gender bias in face processing in infancy that appears to be very tied to the social category (and thus the perceptual characteristics) of the primary caregiver then morphs into an asymmetric own-gender bias in adult females but not adult males. Also, the role of early experience appears to be very different, and potentially much less influential, with respect to gender biases in face processing.

COMPARING DEVELOPMENTAL TRAJECTORIES OF THE FACE-PROCESSING BIASES

This review of the existing work on face-processing biases leads to many unanswered questions, particularly with respect to the explanatory power of the various forms of the Contact Hypothesis. There seems to be an implicit assumption in the Contact Hypothesis that similar mechanisms drive and shape all of these biases. This leads to a prediction that they should all follow a similar developmental trajectory. Our review of the literature suggests that this is not the case. For example, the species bias appears to emerge as a result of perceptual narrowing in the second half of an infant's first year of life and may not be very plastic throughout the rest of life. In contrast, there do not appear to be strong biases with respect to the age of a face, particularly with respect to an overrepresentation of own-age faces, until adulthood, but these biases may be very plastic and representative of the age of faces in an adult's early and immediate environment. This comparison of the developmental trajectories of the different face-processing biases has led us to suggest that the nature of these biases might actually be qualitatively different from one another, leading the search for a single underlying

mechanism (e.g., meaningful social contact, perceptual expertise) to explain the developmental trajectories of these biases difficult and even unfruitful.

Second, this review has demonstrated that the biases differ with respect to the role of early experience in shaping the developmental trajectory of the bias. On one hand, early experiences appear to be critical for organizing face-processing biases (e.g., individual-level learning to modify species biases, demographic characteristics of primary caregiver in race and gender biases), while other early experiences are not (e.g., the sex of siblings and gender-related biases). Additionally, the specificity of the timing of particular experiences appears to differentially influence the developmental trajectories of the various face-processing biases. For example, perceptual narrowing may be particularly relevant to shaping some (e.g., species, race), but not all (e.g., age, gender) of the biases within a limited age range in infancy.

Third, the quality/kind of experience that is needed to shape face-processing biases is not explained well by the various versions of the Contact Hypotheses. For example, several investigators have shown that frequency of exposure is not sufficient to explain the developmental plasticity (or lack thereof) in these biases. The individuation hypothesis (i.e., experience individuating faces) has explained much of the pattern of results of the species and race effects, but has not been systematically applied to study the other face recognition biases. Therefore, it may be a potential contributing mechanism for all face-processing biases. However, there is a wealth of data suggesting that the behavioral and neural foundation of individual recognition for faces continues to improve through and beyond adolescence (e.g., Germine et al., 2011; Scherf et al., 2011), which seems to be inconsistent with the early emergence of the other species and other race biases in infancy.

Although both the perceptual learning/expertise and social cognitive theories of face-processing biases have motivated seminal work in the area, it is clear that neither of these frameworks can account for the full range of developmental findings in their current form nor can they address these unanswered questions. A particularly good example of this failure comes from the social theories about depth/strategy of processing for in-group and out-group faces (e.g., Sporer, 2001). While this account may explain why the ORE develops early and remains quite malleable throughout development as individuals move in and out of social groups, it cannot explain what is currently known about the developmental trajectory of the age biases. In fact, this account would seem to predict that young children should have the largest own-age bias given their limited exposure being in older age groups, and that older adults should

have the smallest own-age bias because they have had the experience of being a member of all younger age groups. This is not the developmental trajectory that age biases appears to follow.

Comparing the developmental trajectories of these face-processing biases reveals that no existing theoretical framework can simultaneously and parsimoniously explain these open questions. In the following section, we introduce an alternative hypothesis that we argue will begin to link this seemingly disparate set of results to explain the full range of data on developmental trajectory of biases in face processing.

NOVEL HYPOTHESIS: DEVELOPMENTAL TASKS/GOALS DRIVING FACE-PROCESSING BIASES AND BEHAVIOR

We offer an alternative/additional explanation. We argue that there are both continuous and discontinuous aspects of the developmental trajectory for face-processing skills from infancy through early adulthood. Our theoretical contribution in this paper largely relates to the abrupt discontinuities in face-processing abilities (e.g., transition from a primary caregiver-based gender bias in infancy to a own-gender bias in adulthood). We argue that these discontinuous, qualitative changes in face processing are largely influenced by transitions in age-appropriate *developmental tasks* or goals.

Developmental tasks are salient measures by which adaptation to life can be judged (Havighurst, 1972; Masten et al., 1995). They are specific to an ontogenetic period and are contextualized by prevailing sociocultural and historical expectations (Havighurst, 1972). Moreover, success in mastering developmental tasks in one ontogenetic period is probabilistically associated with mastery on subsequent developmental tasks (Roisman, Masten, Coatsworth, & Tellegen, 2004). For example, social competence with peers in late adolescence/early adulthood predicts work and romantic competence in young adulthood (Roisman et al., 2004). We predict that specific developmental tasks (e.g., forming an attachment relationship with a primary caregiver in early infancy; the social reorientation toward peers in adolescence) fundamentally influence the "computational goals" of the perceptual system (Marr, 1982), which are ultimately reflected in these face-processing biases. In other words, developmental tasks are derived from the social, emotional, contextual milieu of an individual's environment, and the computational goals of the perceptual system are instantiations of the solutions to these tasks/problems.

Our developmental tasks/computational goals hypothesis also draws from dynamic systems (DSs) theories

of developmental change (e.g., Smith, 2005; Smith & Thelen, 2003; Thelen & Smith, 1994; Van Geert, 1994). In our view, face-processing abilities go through periods of relative stability and instability as development proceeds and environmental demands induce new developmental tasks that must be accomplished with computational goals of the perceptual systems. Thus, face-processing abilities *self-organize* as developmental tasks change. In DSs theories, *self-organization* is a process through which higher-order components of development emerge through recursive interactions from simpler components to spontaneously induce new developmental outcomes. Lewis (2000) articulated several characteristics of self-organizing systems in DSs theories. First, they permit true novelty in developmental outcomes. Second, new outcomes *emerge* during periods of phase transitions; points of instability in the system when old patterns break down and new ones appear. Third, these transitions are global and abrupt, indicating that new outcomes require the cooperation of all existing system components and that they appear discontinuously. As a result, small effects can strongly influence development during these transition phases. Finally, self-organizing systems are exquisitely sensitive to aspects of their environments because of their propensity for feedback and coupling with other systems. It is with these principles in mind that we argue that both infant-specific and adolescent-specific developmental tasks instigate periods of relative instability in the existing face-processing system. Importantly, this instability leads to abrupt change and re-organization to accommodate the new demands and, thus, new components of face processing are expressed as new computational goals of the perceptual system. In this way, the dynamics of face-processing abilities are embedded in the dynamics of broader developmental tasks/demands. This approach leads us to argue that there are actually important differences, and potentially different mechanisms, that support the emergence and shaping of the various face-processing biases.

A strong empirical evaluation of our hypothesis will require future large-scale cross-sectional and longitudinal studies of multiple aspects/biases of face-processing behavior from infancy through early adulthood. Here, we use this hypothesis to generate several predictions about the developmental trajectory of face-processing biases. Importantly, our hypothesis may be able to simultaneously explain the perceptual narrowing data from infant studies of face biases and the potential primacy and long-lasting effects of early experiences on establishing face-processing biases, which were two difficult sets of findings for the existing theoretical accounts to reconcile.

DEVELOPMENTAL TASKS OF INFANCY SHAPING FACE-PROCESSING BIASES

We predict that face-processing biases and behavior in infancy are functionally related to the developmental tasks of infancy, and are not yet complicated by the many subtle and nuanced social aspects of face processing that emerge with later stages of development, like adolescence. More specifically, we argue that forming attachment relationships with caregivers and learning to physically navigate the world apart from caregivers are two specific developmental tasks that are likely to shape the computational goals of the visuoperceputal system, resulting in measurable face-processing biases.

For example, we predict that infants over-represent faces with demographic/social characteristics of the primary caregiver(s) *with whom they are forming an attachment relationship(s)*. Forming at least one attachment relationship is an essential developmental task of infancy in which infants come to focus their bids for attention on a single (or small number of) familiar individual(s) (Bowlby, 1969). During the first 2 months of life, infants are somewhat indiscriminate with respect to their bids for attention. Between 2 and 7 months of age, infants direct these bids more selectively toward specific people and by 7–24 months of age, they take responsibility for attaining proximity to the caregivers with whom they are attached. We predict that the need to form an attachment relationship with a caregiver drives the perceptually difficult computational goal of individuating faces, and therefore, the strength and magnitude of face recognition biases in infancy will follow a similar developmental trajectory as that of the formation of attachment relationships.

There are several expected empirical findings from this prediction. First, within a single infant, species-, race-, gender-, and age-related biases in face recognition will emerge along a similar developmental trajectory and will reflect the demographic characteristics of the primary caregiver(s) with whom the infant is forming an attachment relationship(s). In other words, infants' needs to form an attachment relationship with a primary caregiver will lead them to attend and respond to the caregiver's face (very often the mother's face) and may also lead to an initial categorization of all faces that are perceptually dissimilar to the caregiver's face as "other." Since infants are exposed to their mother's face and the faces of her peers (Rennels & Davis, 2008), we predict that the characteristics of the mother's face as well as those of her peers will shape the formation of infants' initial biases in face processing.

Furthermore, this early familiar versus other categorization of faces could support the initial species, gender, age, and race biases that have been reported in infants' looking behavior. It may also be the case that the quality of the attachment relationship will influence the magnitude to which the perceptual characteristics of the caregiver's face dominate the representational space for faces in a particular infant. For example, infants with disorganized attachment profiles may not exhibit a strong bias toward the perceptual characteristics of their caregiver, given the lack of organized focus of attachment behaviors toward a specific individual. Some evidence in support of this prediction comes from the study of institutionalized children in Romanian who have almost no opportunity to form stable, emotional attachments to caregivers. The neural responses of institutionalized infants fail to discriminate between the faces of the "primary" caregiver and a stranger (Parker, Nelson, & Group, 2005; Moulson, Westerlund, Fox, Zeanah, & Nelson, 2009) and this failure is only moderately modulated following placement in foster care homes where children have more opportunity to develop a stable attachment relationship with a small number of primary caregivers (Moulson et al., 2009).

Second, faces of individuals in infants' environments with whom they have not formed an attachment relationship, despite the frequency of exposure to these faces, are not expected to influence the representational space of faces in these infants. This may explain the early gender bias toward female faces in infancy, particularly for those who are primarily raised by a female versus a male caregiver. It could also explain why infants raised by fathers tend to show a gender bias toward male faces. In order to evaluate this claim, it will be important to differentially quantify exposure time versus the magnitude of the attachment relationship, which are most certainly confounded in many circumstances.

Third, we predict that if infants establish attachment relationships with multiple caregivers, their representational space for faces, and therefore, biases in face perception, will reflect the range of perceptual characteristics of all the caregivers with whom they are attached. Relatedly, as infants develop additional attachment relationships with other individuals (e.g., day care providers, older siblings), their representational space for faces will self-organize to increasingly reflect the perceptual characteristics, including age, of these other individuals. Interestingly, this may result in a *reduction* of some face-processing biases. For example, if an infant forms an attachment with a caregiver who is of a different race than the infant and her immediate family, a previously established own-race bias

may decrease. Similarly, if an infant forms an attachment relationship with an older sibling, the magnitude of the age-related bias is predicted to shift to reflect the ages of both the parent and sibling.

Fourth, the emerging abilities in face recognition will also interact with (and may facilitate) other social–emotional components of face processing (e.g., emotional expression perception, production of imitative expressions) that represent some of the earliest attachment behaviors. There is some evidence that the development of a race bias in face recognition in infancy specifically interacts with other aspects of social–emotional processing of faces. For example, Vogel et al. (in press) recorded ERPs while an emotion sound (laughing or crying) was presented prior to viewing an image of a static African-American or Caucasian face expressing either a happy or a sad emotion in both 5- and 9-month-old Caucasian infants. As in previous investigations, only the 9-month-olds exhibited an own-race bias in face recognition. More importantly, the ERP findings revealed race-specific perceptual processing of emotional face stimuli at 9 months as well, indicating that the enhanced perceptual processing of own-race faces influenced the ability to process emotional expressions in these same faces. The 5-month-old infants did not show this effect. The authors found a corresponding developmental shift between 5 and 9 months of age in the neural networks that were activated when detecting a sound/face congruency. These findings are consistent with previous accounts of perceptual narrowing and the development of the other-race bias. Critically, they also suggest that the development of the other-race bias influences face-related emotion processing and 5- and 9-month-old infants may be using different neural networks when attempting to integrate perceptual and social/emotional components of face processing.

Finally, as infants' motor abilities develop and they begin to independently navigate their environment, thereby increasing the physical distance from their attachment figure, we predict that the pressure to individuate faces increases, which encourages infants to build individual-level representations of socially important people. A positive correlation between the amount of time infants are not in physical contact with the primary attachment figure and the magnitude of face-processing biases in favor of the perceptual characteristics of the attachment figure's face would lend support to this hypothesis.

Importantly, there is some existing support for notion that developmental tasks in the motor domain influence face-processing abilities, particularly in infants (Cashon, Ha, Allen, & Barna, 2009; Libertus & Needham, 2011). For example, from 3 months of age,

learning to reach and manipulate objects is a critical developmental task. In one study, reaching experience in 3-month-old infants was positively related to spontaneous orienting toward faces (Libertus & Needham, 2011). In another study, the developmental task of learning to sit in 5- to 7-month-old infants was examined in relation to their face-processing abilities (Cashon et al., 2009). In this investigation, infants who were nearly sitting exhibited *decreased* holistic face processing relative to non-sitters and to sitters. In other words, as infants began to master the developmental task of learning to sit, the instantiation of the computational goals of the face-processing system was disrupted. This is consistent with the notion that developmental tasks instigate a period of instability in the organization of computational goals within the face-processing system as it re-organizes to accommodate new demands. Although these results do not examine specific face-processing biases, they do highlight the embodied nature of face processing and suggest that development might follow a nonlinear developmental trajectory, influenced by developmental tasks, in line with DSs theory (Smith & Thelen, 2003).

Our proposed framework can also be used to predict that infants and young children are not likely to exhibit an "own" age bias in face recognition abilities. If the essential developmental tasks for face processing of infancy and early childhood revolve around perceptually discriminating the primary caregiver(s) from all others, then the prediction is that there will be a bias to represent faces of the same age, race, and sex of the primary caregivers. In fact, this hypothesis is consistent with the findings that the 3-year-old face-processing system is tuned to adult faces (Macchi Cassia et al., 2009a).[5] It would be interesting to evaluate whether the infant face-processing system can be trained to discriminate other infant faces as well as it can be trained to discriminate adult monkey faces (Pascalis et al., 2005; Scott & Monesson, 2009, 2010). One possibility is that infants are so motivated to look at adult faces, which have very different structural and configural components than infant faces (e.g., sexual dimorphism in both overall shape and in features, features more spread out across width and length of face), that they cannot be trained to discriminate infant faces. In other words, the developmental tasks of infancy that drive attention to adult faces may constrain the kinds of plasticity that can be induced in the computational goals of the visuo-perceptual system.

Importantly, our hypothesis makes predictions about the phenomenon and developmental timing of perceptual narrowing in infant face biases, which neither the perceptual-learning/expertise theories nor the social-cognitive theories of the Contact Hypothesis can accommodate. Recall that the representational space for faces in very young infants appears to be quite undifferentiated. In other words, they do not exhibit biases that favor or inhibit their ability to perceive, discriminate, or recognize faces until about the age of 9 months. This is true despite the fact that they are exposed to faces quite often in their natural environment. In fact, face-to-face interactions dominate mother–infant interactions by approximately 2 months of age (Lavelli & Fogel, 2002). In other words, the emergence of face-processing biases does not reflect this early, intensive experience with faces.

We predict that the developmental task of forming an attachment relationship fundamentally drives much of early face-processing biases and behaviors and that the developmental trajectory of these biases follows the formation of an attachment relationship. Recall that it is not until the middle to end of the first year (i.e., approximately 9 months of age) that infants come to focus their bids for attention on a small number of familiar individuals and thus, begin the process of attachment formation. Similarly, face-processing biases, like the race and species biases, are not consistently observable in infants until 9 months, a developmental period in which they are mostly likely to have begun to form attachment relationships with specific caregivers. We suggest that this similarity in timing is not a coincidence. We argue that infants' representational space for faces should remain fairly undifferentiated as they are learning who to direct their attachment behaviors toward and then quickly self-organize around the characteristics of the individual faces who are becoming socially and emotionally essential in their world. Furthermore, this initial carving up of the representational space for faces in infants may become foundational for setting up some of the face-processing biases that have a life-long influence. Further work investigating the range and timing of plasticity that truly exists in adult face-processing biases and its relation to early life environments (as a proxy of early face-processing biases) would help evaluate this possibility.

DEVELOPMENTAL TASKS OF ADOLESCENCE SHAPING FACE-PROCESSING BIASES

Our framework for considering the influence of developmental tasks on modifying the computational goals of face processing can also be used to make predictions

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[5]Note that Macchi Cassia has made a similar argument in a recent review paper characterizing age biases in face processing across development (Macchi Cassia, 2011).

about developmental discontinuities in face-processing abilities that are unique to adolescence. Our review of the literature suggests that the age-related bias may follow a very different developmental trajectory than do either the species-related and race-related biases. For example, although it has yet to be specifically tested, we predict that it is likely that infants over-represent the age of faces that approximates the primary caregiver's age, resulting in an other-age bias, whereas, adults generally exhibit a same-age bias. We suggest that a discontinuous developmental trajectory of this nature would indicate that the transition to an own-age bias in face processing is more likely to occur in particular developmental stages when individuation of same-age individuals is more relevant (e.g., adolescence, adulthood).[6]

Specifically, we hypothesize that future work will confirm the onset of an own-age bias to be in adolescence, when the developmental tasks of forming confiding friendships and romantic relationships with peers become central. These adolescent-specific developmental tasks, which are likely to be initiated by the process of pubertal maturation, drive a dramatic *reorientation* away from parents and toward peers that enhances the primacy of peer interactions. Adolescent peer relationships are more elaborate than friendships at any earlier developmental period (for review see Brown, 2004). Peers become a critical source of social support (Brown, Eicher, & Petrie, 1986; Brown & Klute, 2006) as well as the focus of new romantic and sexual interests (see Collins, Welsh, & Fruman, 2009). We predict that future cross-sectional and longitudinal studies investigating a wide range of ages for face stimuli and for participants will demonstrate that an own-age bias in face recognition does not emerge until social re-orienting begins in early adolescence (which could be measured as a relative change in proportion of time spent with parents to that spent with peers).

Another prediction from our new model is that, as in infancy, the increased computational demands of these new biases of face processing that emerge as a result of age-appropriate developmental tasks will induce a re-organization within the existing face-processing system. Again, drawing on DSs theories of developmental

change, we suggest that this re-organization will be manifest behaviorally initially as a *disruption* in existing face-processing abilities, such as identity recognition and emotional expression recognition, to accommodate the new task demands of face processing in adolescence.

There is some evidence that the developmental trajectory of face expression and identity recognition abilities is actually *temporarily disrupted* during adolescence, especially during puberty (Carey et al., 1980; Diamond & Carey, 1977; Diamond, Carey & Black, 1983; Flin, 1980). In a study of 210 children and adolescents (8–16 years), Diamond et al. (1983) identified a stasis in face identity recognition, with an actual decline in performance at age 12. In two follow-up studies, they evaluated the contribution of pubertal status to performance differences on the same face identity task in more than 200 girls ages 10–14 years. Across both studies, the authors found that girls in the midst of pubertal change make more errors in the face identity task than do pre- or post-pubescent girls (Diamond et al., 1983). They argued that this temporary developmental disruption appears to be specific to faces since performance on another visuospatial task, the Embedded Figures Task, was not related to pubertal status.

More recently, a large-scale study of approximately 500 participants ages 6–16 years found a similar developmental trajectory and plateau in adolescence (Lawrence et al., 2008). Lawrence et al. (2008) reported a linear improvement in face recognition skills (as assessed using the Warrington Recognition Memory for Faces test) from ages 6 to 10 years, followed by a plateau in performance from ages 10 to 13 years, and later by additional improvement from ages 13 to 16 years. In this same study, performance on emotion classification tasks correlated with face recognition performance across the age range.

Carey et al. (1980) suggested that this adolescent-specific disruption in face-processing skills may be directly tied to pubertal changes via hormonal changes that influence the neural substrate for face processing. Recent developmental neuroimaging findings support for the notion that the neural substrate for face processing emerges slowly over the course of childhood and adolescence, and does not reach mature levels until early adulthood (Golarai et al., 2007, 2010; Scherf et al., 2007, 2011). Unfortunately, very little is known about the relation between gonadal hormones and neural or behavioral development in humans (see Scherf, Behrmann, & Dahl, in press for a discussion of the relation between pubertal hormones and adolescent-specific changes in the face-processing behavior and its underlying neural architecture).

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[6]In some ways this argument is compatible with Hugenberg et al.'s (2010) categorization-individuation model of the other race effect, which argues that motivated individuation focuses an observer's attention to encode the identity-diagnostic characteristics of a face. In other words, adolescents may become especially motivated to individuate peer faces. However, we extend this argument by suggesting that this increased motivation is specifically linked with the developmental tasks of adolescence, namely initiating a social reorientation away from parents and toward peers in the service of forming intense friendships as well as romantic and sexual relationships.

Given the strong developmental tasks of adolescence that drive social re-orientation toward peers, adolescence may also be a time when in/out group categorizations become especially important and relevant to the task of determining social status. Therefore, investigating potentially abrupt changes in race and gender face-processing biases in addition to the age-related biases during adolescence may provide a unique opportunity to understand how developmental tasks influence the emergence of qualitatively new kinds of social-information processing, and, furthermore, how the adolescent brain re-organizes to accommodate these changes.

CONCLUSIONS

We have argued that discrepancies in the literature about the nature and timing of the developmental trajectory for various face-processing abilities can be greatly informed by taking a more functionalist approach in which the influence of age-appropriate developmental tasks and the computational goals of the perceptual system are considered. This perspective is consistent with DSs theory approaches to development (Smith & Thelen, 2003), in which self-organized learning is featured. We suggest that developmental tasks influence the content and description of information (i.e., computational goal) that individuals need to extract from faces. As a result, these tasks directly affect the emergence of various face-processing behaviors and biases. Differences in the developmental trajectories of various biases of face processing (i.e., species, race, gender, and age biases) can be rectified within this account quite parsimoniously. We suggest that future studies testing this hypothesis in the face-processing domain may reconcile many apparently discrepant findings in the literature as well as reflect more broadly on mechanisms of developmental change across many systems. Finally, we propose that this approach may provide a unique opportunity to study the role of early experience in (i.e., age of acquisition effects) and the quality and range of experiences that are critical for shaping behaviors through the course of development, from infancy to adulthood.

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