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Attention and Perceptual Learning Interact in the Development of the Other-Race Effect

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Abstract
Face-processing abilities are biased such that some faces are differentiated, recognized, and identified more readily than others. Across the first year of life, experience with faces shapes the development of face-processing biases. However, the developmental trajectory of face processing and important contributing factors are not well understood. In order to better characterize the development of face processing during infancy, we propose a model involving repeated interactions between attention and perceptual learning. This interactive framework predicts that bottom-up attention orienting to faces leads to rapid perceptual learning about frequently experienced faces, top-down selective-attention biases for familiar faces, and increasingly refined neural representations across the first year of life.

Keywords
perceptual learning, other-race effect (ORE), attention, face processing, infancy

Attention is a fundamental mechanism that is available from birth and supports the emergence of complex perceptual and cognitive skills. Face processing is among these skills. Between approximately 3 and 9 months of age, infants maintain their sensitivity to differentiate faces within frequently experienced groups (e.g., their own race). However, differentiation of faces from within unfamiliar groups (e.g., other races) becomes more difficult (e.g., Kelly et al., 2009; Vogel, Monesson, & Scott, 2012). This decline in sensitivity to discriminate faces within unfamiliar groups, called *perceptual narrowing* (Scott, Pascalis, & Nelson, 2007), is hypothesized to be the origin of adult biases in face recognition, including the *other-race effect* (ORE). Although several hypotheses have been proposed to explain perceptual narrowing (e.g., Hadley, Rost, Fava, & Scott, 2014; Lewkowicz, 2014; Maurer & Werker, 2014; Scott et al., 2007; Simpson, Jakobsen, Fragaszy, Okada, & Frick, 2014), researchers continue to debate what type of experience is critical for the development of face processing and how experience shapes emerging face expertise and biases. Here, we propose a mechanistic model that involves continuous, reciprocal interactions between attention and perceptual learning and accounts for the development of face biases.

Attention influences what we learn as we orient to information in the environment. Attention can be mediated by different mechanisms. Bottom-up orienting is primarily driven by perceptual salience, whereas top-down selective attention shifts attention in a controlled manner on the basis of prior experience and current goals (Moore & Zirnsak, 2017). Selective attention modulates neural signaling in sensory brain regions to enhance processing of attended information and suppress processing of irrelevant information (Moore & Zirnsak, 2017). As a result, selective attention improves vision (e.g., acuity, spatial resolution; Moore & Zirnsak, 2017), enhances perceptual representations of attended information, and promotes learning (Markant, Worden, & Amso, 2015).

Perceptual learning involves long-lasting changes to perceptual systems that improve the ability to respond to the environment (Goldstone, 1998). Goldstone (1998) proposed four components of perceptual learning. First, *attentional weighting* is the degree to which attention

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is directed toward information that is environmentally relevant, is experienced frequently, predicts reward, or supports identification and discrimination. Second, *imprinting* is the brain's ability to perceptually encode repeated stimuli in an increasingly fast, efficient, and accurate manner. Finally, *differentiation* occurs when previously undifferentiated stimuli are now readily distinguishable. Conversely, *unitization* occurs when multiple features or parts are fused and perceived as a whole.

We propose that understanding the development of face-processing biases in infancy requires a model of attention and perceptual learning that operates via reciprocal interactions. An initial bottom-up orienting bias drives infants' attention to faces and promotes early perceptual learning. This enhanced perceptual learning in turn biases subsequent orienting toward familiar faces. Continued perceptual learning coupled with increasing endogenous control over attention contribute to the development of top-down selective-attention biases that support greater sustained attention to familiar faces, perceptual learning, and generalization of learning. This proposal is consistent with the view that infant perceptual narrowing reflects a shift from primarily bottom-up processing to a combination of bottom-up and top-down influences (Hadley et al., 2014). Here, we use bottom-up to refer to exogenous stimulus-driven attention and top-down to describe attention mechanisms that are goal-oriented or shaped by prior experiences but not necessarily under voluntary control. The proposed model is also consistent with Oakes's (2017) argument that infants' experiences with faces generate attention biases that dynamically shape input to the developing face-processing system. The current model builds on these previous proposals by suggesting specific interactions between attention and perceptual learning during infancy.

The Development of the ORE in Infancy

Between birth and 3 months, infants begin to prefer to look at frequently experienced faces (e.g., own-race faces; e.g., Kelly et al., 2005). Despite this early preference, infants continue to discriminate both own- and other-race faces until approximately 9 months, when infants no longer show evidence of visual discrimination of faces within unfamiliar races (Kelly et al., 2009; Vogel et al., 2012). However, extended exposure to other-race faces (e.g., through adoption, training, or living in racially diverse communities) attenuates ORE biases (Anzures et al., 2012; Ellis, Xiao, Lee, & Oakes, 2017; Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005).

However, mere exposure is insufficient to support face identification and recognition (Balas, 2012; Scott & Monesson 2009). In one study, 6-month-old infants received 3 months of experience hearing multiple faces being labeled with individual-level names during parent-infant shared book reading (Scott & Monesson, 2009). Later, infants successfully discriminated new faces within the trained face group. However, infants did not discriminate faces within the trained face group when they were read books with the same faces but heard only a single category label or no label. These findings suggest that labeling or naming impacts perceptual learning above and beyond exposure alone. However, the mechanisms that link frequent exposure, individual-level learning, and the development of face-processing biases remain unclear.

Interactive Model of Attentional and Perceptual Face Learning (I-MAP)

We argue that the development of face processing during the first year of life is shaped by continuous interactions among attention orienting, selective attention, and perceptual learning (Fig. 1). These interactions are predicted to change dynamically over time as infants encounter changing developmental tasks (Scherf & Scott, 2012).

Developmental Tasks That Impact Attentional and Perceptual Systems

Salient developmental tasks (Fig. 1) are specific to different stages of development and defined by sociocultural and historical expectations about developmental adaptation (e.g., Havighurst, 1972). Scherf and Scott (2012) proposed that developmental tasks drive face-processing biases. Following this view, we argue that improving visual skills (Mayer & Dobson, 1982), the multisensory qualities of faces (Lewkowicz, 2014), motor development (Libertus & Needham, 2011), the development of early attachment (proposed by Scherf & Scott, 2012), and the increasing utilization of language (e.g., Lewkowicz & Hansen-Tift, 2012) bias attention and impact perceptual learning about faces.

Levels 1 and 2: Bottom-Up Preferences for Facelike Stimuli and Early Perceptual Learning

Faces robustly capture newborn infants' attention over non-face stimuli (e.g., Johnson, Dziurawiec, Ellis, & Morton, 1991). This initial bias may be mediated by domain-specific mechanisms that are selectively tuned to detect faces (Johnson et al., 1991) or a general attention bias for

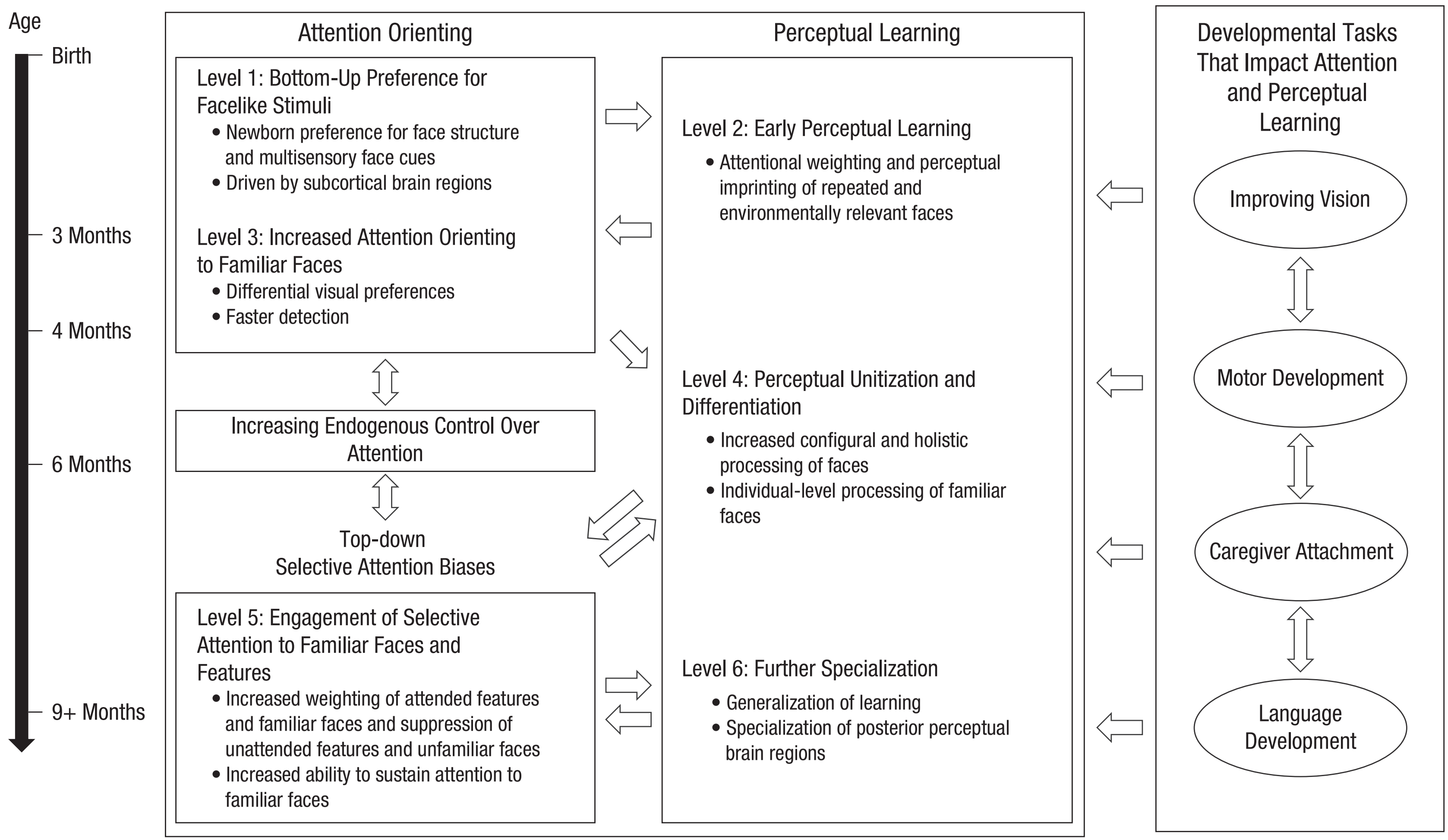

Fig. 1. Proposed model of reciprocal interactions between attention and perceptual learning driving the development of face learning in infancy: the interactive model of attentional and perceptual face learning (I-MAP). An initial bottom-up attention bias to facelike stimuli (Level 1) ensures rapid learning about frequently experienced faces and shifts attention biases to favor repeated and familiar faces (Level 2). Increased attention to familiar faces (Level 3) supports continued perceptual learning about the most informative features of familiar faces and results in perceptual unitization and differentiation (Level 4). As learning progresses, infants concurrently develop increasing endogenous control over attention. Increased endogenous control combined with continued perceptual learning supports the emergence of top-down selective-attention biases toward familiar faces (Level 5). Selective attention then weights informative faces and features, suppresses uninformative information, and increases sustained attention to familiar faces. These selective-attention biases lead to generalization of learning and specialization of posterior perceptual brain regions (Level 6). Finally, the developing visual, motor, and language systems and emerging attachment relationships converge with developing attention and perceptual learning systems to shape the processes involved in the development of face processing and biases such as the other-race effect. Arrows indicate directional and bidirectional influences, and development across the first year of life is depicted by the downward arrow on the left side of the figure.

perceptual properties that are common to faces (e.g., high-contrast areas, more information in the top half, congruency; see Simion & Di Giorgio, 2015). Neonates also readily orient toward perceptually salient information, such as moving or multisensory stimuli (Lewkowicz, 2014). An initial bottom-up attention-orienting bias toward facelike and multisensory stimuli is predicted to increase attentional weighting and perceptual imprinting of repeated and environmentally relevant faces.

Level 3: Increased Attention Orienting to Familiar Faces

Shifting attentional weights and perceptual imprinting based on prior learning about familiar faces are predicted to guide infants' subsequent attention orienting. For example, by 6 months, infants orient more quickly and spend more time looking at human faces compared with faces of other species when they are embedded in an array of objects (Jakobsen, Umstead, & Simpson, 2016). Coupled with repeated exposure to the same or similar faces, shifts in attention weighting may lead infants to differentially reallocate attention to some faces over others. While 3-month-old infants show increased looking at own-race versus other-race faces, by 9 months, infants instead looked longer at other-race faces (Liu et al., 2015). Nine-month-old infants also oriented toward a single other-race face embedded among an array of own-race faces but not to a single own-race face embedded among other-race faces (Hayden, Bhatt, Zieber, & Kangas, 2009). These changing patterns of attention over the first year of life likely reflect infants' exposure to own- and other-race faces and their ability to efficiently process these faces in specific task contexts.

Level 4: Perceptual Unitization and Differentiation

Increased attention weighting and imprinting of familiar faces coupled with differential attention orienting lead to both perceptual unitization and differentiation beginning by 6 months of age. It is predicted that perceptual unitization occurs as faces begin to primarily be perceived holistically and that perceptual differentiation occurs as infants learn to individuate familiar faces.

Holistic face processing is a hallmark of adult face perception. We define holistic face processing as the ability to integrate internal and external face features, sensitivity to face inversion, and sensitivity to changes in face spacing or configuration. Prior to 7 months, infants show little evidence of adultlike holistic face processing. Scott and Nelson (2006) found that adults and 8-month-olds, but not 4-month-olds, exhibited sensitivity to the difference between configural (e.g., eye and mouth spacing) and featural (e.g., replaced eyes and mouth) changes. In another study, 9- to 12-month-olds, but not 4- to 6-month-olds, successfully discriminated faces that varied only in their internal features (Simpson et al., 2014). Face familiarity and the ORE also impact holistic face processing. For example, both 6- and 9-month-olds discriminated between own-race faces that varied only in the eye region but were unable to discriminate these changes within other-race faces (Chien, Wang, & Huang, 2016).

Concurrent with the development of holistic processing, infants also begin to individuate faces when paired with individual-level names. As described above, labeling faces with individual-level names, relative to a category label or no label, differentially impacted visual perceptual narrowing from 6 to 9 months (Scott & Monesson, 2009). Both 6- and 9-month-old infants also neurally differentiated faces labeled with individual-level names from those paired with a nonspeech noise (Barry-Anwar, Hadley, & Scott, 2018). However, 6-month-olds required more exposure to name-face pairs to exhibit this effect. Overall, results suggest that perceptual differentiation of individuals through naming begins by 6 months and that language development impacts perceptual learning of faces.

Level 5: Engagement of Selective Attention to Familiar Faces and Features

Infants develop increasing endogenous control over attention between 3 and 6 months, reflecting changes in frontoparietal brain regions (Posner, 2001). Increasing voluntary control over attention supports infants' ability to attend to relevant information while ignoring irrelevant information and, in turn, supports the development of top-down selective-attention biases toward familiar faces. Thus, what began as a bottom-up orienting bias to facelike stimuli shifts to selective-attention biases toward frequently experienced faces that are based on both prior perceptual learning and top-down, goal-oriented feedback.

Emerging selective-attention biases for familiar faces and features is supported by results showing that from 3 to 9 months, infants' scanning of own-race faces becomes increasingly focused on the features that support face recognition (e.g., eye region; e.g., Liu et al., 2015). These changes in infants' selective attention to face features impact their ability to extract meaningful information from faces and are influenced by developmental tasks. For example, infants shift their attention from the eyes to the mouth during early language learning from 4 to 8 months (Lewkowicz & Hansen-Tift, 2012). We predict that shifting attention to the mouth should differ in magnitude, timing, and duration for faces from unfamiliar groups.

Infants' developing ability to maintain attention while suppressing distraction also supports enhanced learning and memory (Markant & Amso, 2013). Markant, Oakes, and Amso (2016) used a spatial cuing task to bias 9-month-old infants' selective attention to own- or other-race faces. Results suggested that inducing a selective-attention bias toward other-race faces promoted successful discrimination, underscoring the importance of top-down selective-attention biases for perceptual learning.

Level 6: Further Specialization

The emergence of selective-attention biases toward faces within familiar groups is expected to support increased generalization of learning and further specialization of posterior perceptual brain regions. Here, it is predicted that perceptual learning for familiar faces generalizes to unfamiliar faces that are similar to previously learned faces (e.g., in race, sex, or age). For example, 5- and 10-month-old infants showed effective learning of an object when its location was cued by the gaze of a personally unfamiliar own-race, familiar-sex face but not when it was cued by faces with less familiar characteristics (other-race, less familiar sex; Pickron, Fava, & Scott, 2017). Seven-month-old infants were similarly biased to rely on eye gaze cues from unfamiliar own- over other-race faces when anticipating the appearance of an unpredictable target (Xiao et al., 2017). These findings suggest that face biases, such as the ORE, begin with perceptual learning about familiar individuals and generalize to unfamiliar individuals.

Increasingly efficient, but biased, face processing during the first year may reflect changes in the underlying neural systems supporting perceptual processing of faces. Electrophysiological markers and functional-near-infrared-spectroscopy measures of face processing in posterior brain regions emerge gradually over the first year of life (e.g., Scott & Nelson, 2006; Timeo, Brigadoi, & Farroni, 2017; Vogel et al., 2012). Two specific topographic changes are also reported in infants. First, neural responses for face categorization (de Heering & Rossion, 2015) and face individuation (Barry-Anwar, Hadley, Conte, Keil, & Scott, 2018) become right-lateralized by 9 months of age. Second, 5-month-old infants' processing of congruent and incongruent own- and other-race face-voice pairs was recorded over anterior brain regions, whereas 9-month-old infants' processing was recorded over posterior brain regions and was specific to own-race pairs, suggesting a shift with development (Vogel et al., 2012). Younger infants may primarily engage anterior attention systems during face discrimination, whereas older infants rely on posterior perceptual representations, accounting for observed perceptual narrowing effects. Therefore, we propose that as posterior brain regions specialize, anterior attention networks are less engaged for general face discrimination and recruited instead to meet changing task demands.

Future Directions

We propose a mechanistic model for experienced-based tuning of face processing that involves repeated reciprocal interactions between developing attention and perceptual learning systems. Our goal was to provide a testable framework for refining the understanding of the development of biased face processing. However, this framework may also be generally useful for understanding learning about nonface objects, categories, and sounds. Many aspects of the proposed model remain to be tested empirically. For example, although it is understood that infants' experiences shape their subsequent attention behavior, the specific mechanisms through which learning changes attentional weighting for individual stimuli are unclear. Research with adults has shown that attentional weighting can shift so that individuals are more likely to attend to stimuli that were previously selected or reliably rewarded (Awh, Belopolsky, & Theeuwes, 2012). Research is needed to determine whether similar reward-learning and selection-based mechanisms shift attentional weighting in infancy. Dynamic neural field models of infant eye movement planning (e.g., Ross-Sheehy, Schneegans, & Spencer, 2015) may be useful in examining these mechanisms in the context of the current model. For example, computational models may be able to simulate changes in attentional weighting of and orienting to familiar faces that occur as perceptual learning and brain development progress.

In addition, although I-MAP can account for individual differences in development, it is unclear whether the timing and nature of these differences may have a greater impact at different levels of the model. For example, infants may vary in the timing of the development of endogenous control over attention, and therefore the impact on perceptual learning may vary. It is also unclear how individual differences in developmental tasks specifically impact attention and perceptual learning. Developmental delays (e.g., motor, language) may also influence multiple levels of this model. Finally, previously reported neural specialization that occurs across the first year of life needs to be tested using a variety of computational and neuroscience techniques and by examining age-related changes in neural connectivity and coherence.

Recommended Reading

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