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CHAPTER

Recognizing Facial Identity: Prolonged Development During Infancy and Childhood

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Abstract

Adults recognize hundreds of familiar faces at a glance: a neighbor both at the gym and in wedding photos; actors in numerous movies, despite dramatic variability in their appearance; a high school classmate at a twenty-fifth reunion—despite physical changes associated with aging. What makes this ability so remarkable is that faces are a homogeneous class of stimuli—increasing both the challenge of telling faces apart and of recognizing someone despite changes in appearance. Here we focus on the development of the ability to recognize facial identity, underlying mechanisms, and the role of experience. We focus on behavioral development but sample the neuroscience literature when doing so is helpful. We begin with a brief synopsis of adults' abilities, followed by a discussion of changes in these abilities during infancy and childhood.

Keywords: face recognition, face perception, face detection, face learning, cognitive development, role of experience

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Face Detection

Adults readily detect faces; faces capture attention when embedded in complex arrays (Bindemann et al., 2005; Langton et al., 2008) and are even detected in the absence of normal facial features, such as stimuli comprised only of black-and-white contours (Mooney faces: Mondloch et al., 2013b; Schwiedrzik et al., 2018), paintings with objects replacing facial features (e.g., Archimbaldo paintings), and pure-noise images (Liu et al., 2014). Such illusory perception, *pareidolia*, shows how exquisitely the adult perceptual system is tuned to face-like stimuli.

Face detection is associated with two neural markers. The N170 (an event-related potential peaking 170 mos after stimulus onset) is larger for upright faces than for most other stimuli (Bentin et al., 1996; see Eimer, 2011; Rossion and Jacques, 2011, for reviews) and fMRI activation in several regions, most notably the fusiform face area (FFA), is larger for faces than for a variety of nonface objects (Kanwisher et al., 1997; McCarthy et al., 1997,), even when the stimuli are ambiguous (Liu et al., 2014; Tong et al., 1998; Hasson et al., 2001).

Recognition of Facial Identity

Two distinct approaches provide abundant evidence that adults are experts at recognizing facial identity. In one approach, researchers present *tightly controlled* images in which all photos are taken with the same camera, from the same distance and under identical lighting conditions; hair is typically masked and blemishes removed. This approach is ideal for measuring the ability to discriminate unfamiliar faces or recognize a face despite systematic, controlled changes (e.g., in lighting or viewpoint). In the second approach, researchers examine the ability to recognize facial identity in *ambient* images—images that capture natural within-person variability in appearance (across variable lighting, makeup, viewpoint, expression, hairstyle, and even age). This approach precludes image recognition, thereby better capturing the type of face processing necessary in everyday life.

Adults perform very well when asked to recognize faces in an old/new recognition task or in a delayed match-to-sample task, at least when identical images are presented during the study and test phases (Duchaine and Nakayama, 2006; Nordt and Weigelt, 2017; Proietti et al., 2019). When faces are wholly unfamiliar, performance drops when nonidentical images of a face are presented—even when the study and test images are taken only moments apart (Megreya et al., 2013) or when a simple change in lighting, viewpoint, or facial expression is made to tightly controlled images (Duchaine and Nakayama, 2006; Nordt and Weigelt, 2017). When faces are familiar, adults recognize them in ambient images (Jenkins et al., 2011; reviewed in Burton, 2013) and even when they are distorted (e.g., stretched; Bindemann et al., 2008; Hole et al., 2002)—highlighting a fundamental difference between the recognition of familiar and unfamiliar faces.

Underlying Processes

Adults' ability to recognize and discriminate faces has been attributed to three underlying processes. 1) Adults process faces as a gestalt; perception of each feature (e.g., the eyes) is influenced by the rest of the face—a pattern dubbed holistic processing (Hole, 1994; Tanaka and Farah, 1993; Tanaka et al., 1998; Young et al., 1987). 2) Adults are exquisitely sensitive to differences in feature shape and spacing, allowing them to detect very small differences among both unfamiliar and familiar faces (Freire et al., 2000; Mondloch et al., 2002; Ge et al., 2003). 3) Adults engage in norm-based coding; each face is represented based on how (e.g., crooked nose), and how much (e.g., large eyes), it differs from a prototype (Rhodes et al., 2014; Valentine, 1991; Valentine et al., 2016).

Adults' ability to recognize familiar faces despite tremendous variability in appearance has been attributed to their building a robust and abstract representation of facial identity—analogous to Face Recognition Units in Bruce and Young's (1986) influential model. This mental representation likely includes an average representation of each person's face that excludes nondiagnostic cues unique to individual instances (Burton et al., 2005) but includes idiosyncratic variability characteristic of each person (Burton et al., 2016). Exposure to within-person variability in appearance facilitates learning such that new instances are recognized (e.g., Andrews et al., 2015; Baker et al., 2017; Dowsett et al., 2016; Murphy et al., 2015; Ritchie and Burton, 2017).

In the remainder of this chapter we provide evidence that, despite rudimentary abilities being present during infancy, the ability to recognize facial identity develops slowly during childhood—a pattern that is attributable to the slow development of some, though not all, underlying processes. Finally, we provide evidence that face-specific experience plays an important role in the development of these skills.

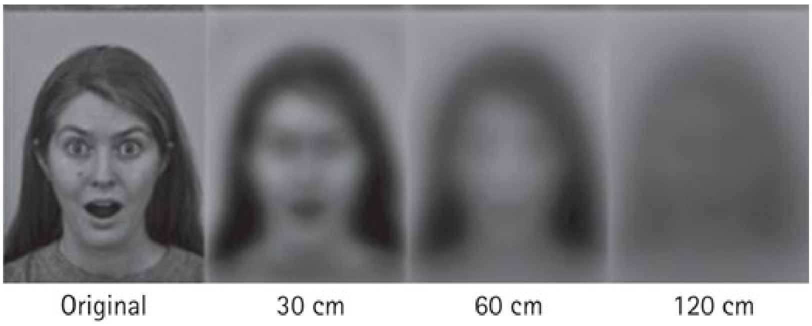
Infancy

All of these skills have been tested during infancy.

Face Detection

Poor acuity and contrast sensitivity limit the information available to newborns from faces. From closeup, newborns can see only the outline and the most contrasty internal features; farther away, only the outline remains visible (Maurer, 2016; von Hofsten et al., 2014) (see Figure 1). Perhaps as a result, newborns fixate mainly on the external contour (Haith et al., 1977; Maurer and Salapatek, 1976). Even when viewing simplified drawings with no bold external contour, newborns look at the internal features only about half the time (Maurer, 1983).

Figure 1



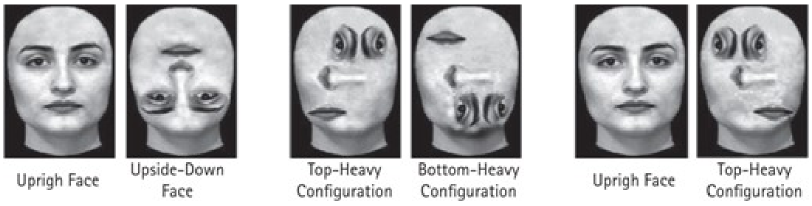
The information visible to a newborn when viewing a face from various distances. Beyond 30 cm, only the outline remains visible.

Source: used with permission from von Hofsten, O., von Hofsten, C., Sulutvedt, U., Laeng, B., Brennen, T., and Magnussen, S. (2014). Simulating newborn face perception. *Journal of Vision*, 14(13):16, 1–9. Doi: 10.1167/14.13.16

Within minutes of birth, newborns orient preferentially toward an oval with three squares located in the positions of eyes and mouth, a stimulus dubbed *config* because of its face-like configuration, in preference to an oval with those squares inverted (Mondloch et al., 1999; Valenza et al., 1996). At 8 months' gestation, the fetus shows the same orienting preference when bright red blobs are projected onto the mother's abdomen (Reid et al., 2017). In a seminal paper, Morton and Johnson (1991) postulated that the early preference for *config* is mediated by a subcortical mechanism, likely involving the superior colliculus. This mechanism called CONSPEC, they argued, guarantees that young babies attend to faces, feeding information about facial structure into developing cortical networks that "take over" control around 1–2 months with a mechanism they called CONLERN. Consistent with this theory, when newborns wear a patch over one eye, the preference for *config* is easier to demonstrate in the temporal visual field (e.g., the right visual field for the right eye, which can be mediated without cortical input) than in the nasal visual field (across the nose, which requires input routed through the visual cortex) (Lewis and Maurer, 1992; Maurer et al., 1991; Simion et al., 1998). Subsequent work with adults and animal models suggests that the subcortical mechanism may remain active in adults, supporting fast orienting toward faces in the periphery, especially if threatening, and that the network likely involves the pulvinar and amygdala in addition to the superior colliculus (Johnson et al., 2015).

The neonatal looking preference likely is not the manifestation of an innate face module *per se*, but rather of more basic preferences that often match a human face. The newborn looks longer at stimuli with an optimal amount of visible energy (Kleiner, 1987; Mondloch et al., 1999), more features in the top than bottom ("top-heaviness") (Macchi Cassia et al., 2004; Simion et al., 2001; Turati et al., 2002; Turati, 2004), and congruency between the widest part of the external contour and of the internal features (Macchi Cassia et al., 2008) (see Figure 2). These features match the shape of the newborn's limited visual field—skinny half-pear shapes in front of each eye, cut off by the newborn's nose (Maurer and Maurer, 2019). The looking preference for *config* disappears if the contrast is reversed (Farroni et al., 2005), reflecting a more general bias to attend to dark details against a lighter background that is evident in 3-month-olds (Dannemiller and Stephens, 2001) and adults (Komban et al., 2011) and that matches the modal characteristics of the environment (Maurer and Maurer, 2019).

Figure 2



Newborns' "face" preference is mediated, in part, by a bias to look at top-heavy figures. They prefer the stimulus on the left in the left and middle panels, but have no preference between the two stimuli in the right-most panel.

Source: used with permission from: Cassia, V. M., Turati, C., and Simion, F. (2004). Can a nonspecific bias toward top-heavy patterns explain newborns' face preference? *Psychological Science*, 15(6): 379–383. Doi:10.1111/j.0956-7976.2004.00688.x.

Improved acuity, contrast sensitivity, and peripheral vision allow babies older than ~ 2 months to receive more information from internal facial features (Lewis and Maurer, 1992; Maurer, 2016). From that age, babies' fixations fall predominantly on the internal features of faces (Hunnius and Geuze, 2004), especially the eyes (Di Giorgio et al., 2013; Haith et al., 1977; Maurer and Salapatek, 1976). At the same time, more complex face preferences develop and override initial structural biases such as top-heaviness: by 3–5 months, babies look at a photograph of a real face in preference to a scrambled image matched in low-level features (Macchi Cassia, Kuefner et al., 2006a; Chien, 2011), a pattern extending to schematic faces (Kleiner, 1987; Mondloch et al., 1999). As in adults, the critical information appears to be in horizontally oriented spatial frequencies (de Heering et al., 2016).

In more complex scenes, older infants orient first and longest toward a face compared to other objects. Though difficult to demonstrate at 3 months, the preference increases over the first year (Kelly et al., 2019). By 6 months, the saliency of faces is so well-established that even in arrays with six stimuli, infants look first and longer toward a face than a body part or an animal (Gluckman and Johnson, 2013; see also Di Giorgio et al., 2012). Inverted faces are as effective as upright faces in capturing first fixations, but not in attracting the longest looking time. Faces with the internal features phase scrambled are ineffective at either (Gliga et al., 2009), suggesting a role for facial structure.

Neural Underpinnings

A variety of techniques have established some overlap between the adult face network and areas active during face detection in older infants. A pioneering study using PET with 2-month-olds found that faces, in comparison to flickering Christmas tree lights, activated a large, distributed network predominantly in the right hemisphere, including the fusiform face area. The network overlapped with the adult face-processing network but extended beyond to include the left superior temporal and inferior frontal gyri, areas that will become specialized for language (Tzourio-Mazoyer et al., 2002).

Only one study has examined the neural basis of newborns' preference for *config.* It did so by slowly turning the stimulus on and off and then examining whether electroencephalogram (EEG) recordings oscillated at the same frequency. EEG recordings did oscillate at the same frequency when newborns viewed *config*, the standard inverted control, and a top-heavy alternative, but the variation in the amplitude of the EEG was largest for *config*, intermediate for the top-heavy alternative, and smallest for the control stimulus (Buiatti et al., 2019). Source modelling indicated that the *config* response emerged in the ventral stream but extended to other regions. Although much of the activity overlapped with the face network in adults, the authors note that they could not measure subcortical processing and hence could not evaluate whether the response was routed via the superior colliculus, as predicted by Morton and Johnson (1991).

Event-related potentials (ERPs) have revealed changes time-locked to faces versus control images, including a negative wave at ~ 290 msec and a positive wave shortly after 400 msecs. By 3 months (the youngest age tested), the N290 is larger for human faces than scrambled images, and, from some electrodes, larger than for inverted human faces or monkey faces (Halit et al., 2003; Halit et al., 2004; but see Peykarjou and Hoehl, 2013). Inversion increases the latency of the N290 for human faces but has no effect for monkey faces. By 3 months of age, a later wave, the P400, is slower for monkey than for human faces and for upright than for inverted faces, as well as larger in amplitude for human faces over the right hemisphere (Halit et al., 2003). Because the effect of species and inversion on the amplitude and latency of the N290 and P400 resemble the effects of those variables on the adult N170, they are thought to be its infant precursors (Halit et al., 2003; de Haan et al., 2003). However, some of the effects of inversion and species on the N290 and the P400 also differ from the adult's N170 later during the first year (de Haan et al., 2002; Halit et al., 2003). In addition, at 3 months of age, the N290 and P400 may be mediated by an early primitive mechanism, because 3-month-olds look longer at human faces than at top-heavy scrambled images, but these stimuli elicit comparable N290 responses (Macchi Cassia et al., 2006a, 2006b), Source localization for the N290 suggests a network overlapping, but not identical to, the adult face network, including the (right) fusiform gyrus and surrounding areas from the youngest age tested (3 months), but also the right superior temporal sulcus and surrounding temporal lobe (Conte et al., 2020; Guy et al., 2016; Johnson et al., 2005), as well as prefrontal and parahippocampal clusters (Guy et al., 2016; Johnson et al., 2005). Along with evidence from the P1 and P400 (Conte et al., 2020) these findings suggest that the entire social brain is at least partially active from early infancy (Johnson et al., 2005).

Specialization of the Right vs Left Hemisphere

The role of each hemisphere in infants' face detection has been studied by presenting faces monocularly to only one hemifield (and hence to one hemisphere) in infants 4–10-months old (deSchonen et al., 1993). Either hemisphere can learn to discriminate a schematic face from one with scrambled features. The right hemisphere is better at learning configural changes and the left hemisphere, local changes. Infants demonstrate discrimination of their mother's face from that of a stranger when tested with the right hemisphere but not the left, suggesting that configural processing is being used (deSchonen et al., 1993). Transfer of learning between hemispheres does not seem to occur until the second year of life (Liégeois et al., 2000). (The lack of integration across hemispheres is inconsistent with an explanation of the preference for *config* based on binocular correlation in stimulation of the two eyes, as is the top-heavy bias (Wilkinson et al., 2014)).

Superior learning by the right hemisphere complements findings using near-infrared spectroscopy (NIRS) that show an increase in total hemoglobin, especially in the right hemisphere, when infants 5–8-months old view intact images of internal facial features, compared to a baseline condition with vegetables, scrambled faces, or inverted faces (Honda et al., 2010; Otsuka et al., 2007). Likewise, when 4-month-olds (the only age tested) watched a rapidly changing stream of natural images (6/second) with faces embedded at a specific temporal frequency, the EEG signal over the right hemisphere contained changes locked to that temporal frequency (de Heering and Rossion, 2015). No such signal emerged for scrambled images or in the left hemisphere. In a similar paradigm, 4- to 6-month-olds' EEG contained distinctive responding to faces versus objects, especially in the right hemisphere, with more overlap with findings from adults in the location of the regions responding to faces than those responding to objects (Farzin et al., 2012). The response to faces in such paradigms is enhanced when the baby is exposed to the mother's body odor (Leleu et al., 2019), a modulation indicating that infants' learning about faces is multimodal.

A Special Role for Eyes?

Newborns look longer at faces with eyes open than closed (Batki et al., 2000) and at upright than at inverted faces, but only if the eyes are not occluded (Gava et al., 2008) or the polarity of the contrast is not reversed (Farroni et al., 2005). In both cases, the preferred stimulus is a better match to *config.* They also look longer at a face with direct rather than markedly deviated gaze, but only if the face is upright and oriented straight ahead (Farroni et al., 2002; Farroni et al., 2004; Farroni et al., 2006). After viewing a video of talking strangers, newborns subsequently look longer at the static image of a novel stranger—but only if the eyes are visible with direct gaze (Gava et al., 2008; Guellai and Streri, 2011). By 3 months (but not at birth), infants prefer to look at the face of a chimp or Barbary monkey when the eyes are replaced by human eyes (Dupierrix et al., 2014). Like their preference for *config*, newborns' attention to eyes and preference for direct gaze might be mediated by low-level biases: a clearly visible black-and-white stripe in the top half of an object with dark features on a light background (Maurer and Maurer, 2019).

By 4 months (the youngest age tested), the N290 is larger when babies view upright (but not inverted) faces with direct rather than averted gaze (Farroni et al., 2002), even when the eyes are within an averted head (Farroni et al., 2004). At 6–10 months, the latency of the N290 is shorter for photos with direct than averted gaze and the P1, N290, and P400 all have a larger amplitude when a live observer begins by looking directly at the baby and then shifts gaze to the side than the reverse (Vernetti et al., 2018). Source localization indicates that the N290 modulated by eye gaze originates, among other regions, from right temporal regions and bilateral fusiform gyrus, as it does in adults (Johnson et al., 2005).

Facial Identity

After only a few hours, newborns prefer to look at their mother over the mother of another baby, even if they have not seen the mother in the preceding 15 minutes (Pascalis et al., 1995; Bushnell, 2001). The preference is evident within 3 hours of birth if the baby has been able to both see *and* hear the mother (Sai, 2005) and increases with exposure up to 8 hours (the longest tested) (Bushnell, 2001). If both the mother and stranger wear identical scarves, all evidence of recognition disappears (Pascalis et al., 1995)—as would be expected from the newborn's limited scanning of internal facial features.

When tested with tightly controlled images, newborns rapidly learn to recognize a new face and discriminate it from another: after familiarization with one face, they look longer at a new one (Pascalis and de Schonen, 1994; Turati et al., 2006), even after a 2-minute delay (Pascalis and de Schonen, 1994) and even if the faces are filtered to contain only low spatial frequencies (0–0.5 cycle/degree) (de Heering et al., 2008). External features dominate newborns' learning. Despite learning from the internal or external features presented alone, newborns demonstrate recognition of the whole face after seeing only the external features, but not only the internal features (Turati et al., 2006). At 5 weeks, babies demonstrate learning even if the mouth and eyes of the familiarized and novel faces are occluded, but covering the hair eliminates it (Bushnell, 1982). Nevertheless, even newborns are able to generalize habituation between a face directly facing them (*en face*) and the same face turned to a 3/4 view. However, habituation does not generalize between a profile and other viewpoints (Turati et al., 2008), a pattern suggesting that viewing both eyes (as a trigger to *config*) supports learning. By 19 weeks, infants can recognize a learned face even if the hair is covered (Bushnell, 1982). Around this time, they also can learn to recognize an upright face shown during habituation even when it changes in expression (smiling or neutral) or point of view (*en face*, 3/4, or profile) (Pascalis et al., 1998; Turati et al., 2004).

Evidence from ERPs parallels behavior. By 3 months (the youngest age tested), the ERP to a novel face is distinctive between 750 and 1700 msec, even when the familiar face has been presented in various viewpoints (frontal, 3/4, profile) and after a 2-minute delay (Pascalis et al., 1998; see Ichikawa et al., 2019 for similar evidence from functional near-infrared spectroscopy (fNIRs). If additional familiarization is provided by sending home a three-dimensional (3D) model of the face, the P400 is larger for the familiar face than a novel face, especially on frontal central electrodes over the right hemisphere (Moulson et al., 2011). Additional evidence from fNIRS indicates that between 5–8 months, the temporal cortex becomes sensitive to facial identity despite changes in viewpoint or facial expressions and to facial profiles (Ichikawa et al., 2019; Kobayashi et al., 2011; 2014).

Underlying Mechanisms

From birth, infants can discriminate differences in shape (Slater et al., 1983). In contrast, it is not until 5 months that infants demonstrate discrimination between upright faces differing only in the spacing of internal features; 3-months-olds show no such evidence even after habituation to exaggerated differences (Bhatt et al., 2005; Hayden et al., 2007b). The discrimination extends to monkey faces but not houses or inverted faces (Hayden et al., 2007b; Zieber et al., 2013), a pattern suggesting a possible role for experience.

From 3 months, infants' recognition memory for faces includes an average of the faces they have seen recently: after familiarization with four faces, they treat their average as familiar, looking less long at it than a novel face or even one of the four original faces (de Haan et al., 2001). This is an important step in the development of norm-based coding. By 12 months (youngest age tested), infants look longer at the member of a pair of faces that is closer to average, matching adults' judgments of attractiveness. Infants' preference for the more-average face is limited to human faces, suggesting a role for experience (Damon et al., 2017).

Nevertheless, it is nearly 1 year before infants integrate facial parts into a gestalt. Cashon and Cohen (2004) used a switch paradigm in which babies are habituated to two faces, then tested with a novel face and a composite comprising the external features of one of the habituated faces and the internal features of the other (see Figure 3). To adults, the upright composite face looks completely novel because the external and internal features are integrated into a novel gestalt; inverted, it is treated as a collection of familiar pieces.

Three-month-olds treat even upright composites as a collection of familiar pieces, showing no recovery of looking. At 4 months, the composite face is treated as novel whether upright or inverted (and whether own- or other-race) (Ferguson et al., 2009). At 5.5 months, the adultlike (upright-only) pattern is shown, but as the baby's perspective changes with sitting up (around 6 months of age), the composite face is again treated as a familiar collection of pieces whether upright or inverted (Cashon and Holt, 2015). At 7 months, the adult-like pattern reemerges and babies also demonstrate holistic processing of their mother's face with the Composite Face Effect (see the following section) (Nakato et al., 2018).

Figure 3

The switch paradigm for measuring holistic processing. After habituation to two faces, the baby is tested with a combination of the external contour of one and the internal features of the other. If processing piecemeal, the baby should find it as familiar as the face on the left that was shown during habituation. But if processing holistically, the baby should find it novel, like the face on the right.

Source: used with permission from: Cashon, C. H., and Cohen, L. B. (2004). Beyond U-Shaped Development in Infants' Processing of Faces: An Information-Processing Account. *Journal of Cognition and Development*, 5(1): 59–80.

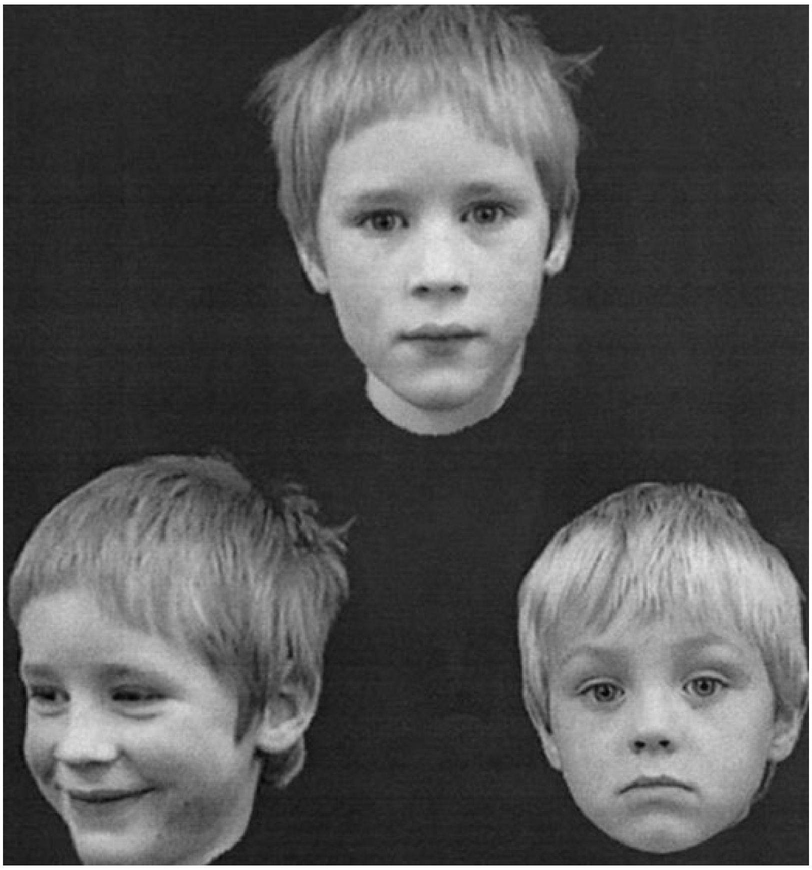
In sum, by their first birthday, infants show at least rudimentary forms of all the specialized skills adults use to detect faces and process their identity, using neural networks that overlap with those of adults, but which remain to be refined.

Recognition of Facial Identity During Childhood

Research with children after infancy has focused on their ability to recognize newly learned faces and match unfamiliar faces when images incorporate limited, systematic variability in appearance (see Figure 4). Children's recognition of previously learned faces shown from a new viewpoint improves between the ages of 5–12 (Croydon et al., 2014), with evidence of additional improvement until age 30 (Germine et al., 2011). The ability to match images of a target across minor changes in lighting, viewpoint, and expression also improves across childhood (Bruce et al., 2000; Carey et al., 1980; de Heering et al., 2012; Megreya and Bindemann, 2015; Mondloch et al., 2003a). as does the ability to recognize an unfamiliar face when paraphernalia (e.g., hats, glasses) is added or removed (Diamond and Carey, 1977; Freire and Lee, 2001).

Performance is better with familiar faces. By age 5, there is an advantage for familiar over unfamiliar faces when matching identity in tightly controlled images and, like adults, children rely on internal features to recognize familiar faces, but external features for unfamiliar faces (Bonner and Burton, 2004; Ge et al., 2008; Wilson et al., 2009; but see Newcombe and Lie, 1995). Familiarity also protects 6-year-olds from making errors based on paraphernalia (Diamond and Carey, 1977).

Figure 4



An example of stimuli used in a match-to-sample task in which children were asked to decide which of the two bottom images depicts the same person as the top image, despite systemic changes in viewpoint and expression.

Source: used with permission from Bruce, V., Campbell, R.N., Doherty-Sneddon, G., Import, A., Langton, S., McAuley, S., and Wright, R. (2000). Testing face processing skills in children. *British Journal of Developmental Psychology*, 18(3): 319–333. Doi: 10.1348/026151000165715

Despite these findings, some researchers have argued that recognition of identity even of unfamiliar faces is *fully quantitatively mature* by the age of 5, with further improvements arising only from general cognitive development (Crookes and Robbins, 2014; McKone et al., 2012; Weigelt et al., 2014). Weigelt and colleagues drew this conclusion based on findings of face-specific improvement in recognition memory throughout childhood (i.e., memory for faces improved more than memory for other categories, such as cars) but no evidence of face-specific perceptual development after 5 years of age (i.e., improvements on perceptual tasks were similar for faces and other categories). In a memory task, Crookes and Robbins (2014) confirmed that error rates increase when newly learned faces are shown from a different versus the same viewpoint. They discounted developmental change because the increase was comparable in 8-year-olds and adults after equating performance in the same-view condition by reducing set size for children. All of these studies used tightly controlled images of unfamiliar (or newly learned) faces with minimal variability, stimuli that are ideal for measuring children’s sensitivity to different types of information, but that do not measure the type of expertise adults use to recognize familiar faces across natural variability in appearance (e.g., changes in lighting, hairstyle, expression, age, weight; see Burton, 2013 for discussion). Recognizing identity in ambient images (i.e., those that capture natural variability in appearance, see Figure 5) is likely a face-specific skill because no other visual category contains so much variability and, for most observers, only faces are recognized at the individual level (see Baker et al., 2017 for discussion). Moreover, adults’ ability to recognize identity in ambient images is limited to familiar faces, but most developmental research has relied on unfamiliar faces. As we will show below, the developmental trajectory for recognizing identity in ambient images is prolonged, especially when faces are unfamiliar.

Figure 5

An example of stimuli that capture natural within-person variability in appearance (i.e., ambient images). All six images are of the same person.

Source: used with permission from Matthews, C. M., and Mondloch, C. J. (2018). Finding an unfamiliar face in a line-up: Viewing multiple images of the target is beneficial on target-present trials but costly on target-absent trials. *British Journal of Psychology*, 109: 758–776. Doi:10.1111/bjop.12301.

Adults make errors when matching identity in ambient images of unfamiliar faces (e.g., Bruce et al., 1999; Bruce et al., 2001; Burton et al., 2010; Jenkins et al., 2011; Kemp et al., 1997; Megreya and Burton, 2006, 2008; Megreya et al., 2013) but recognize ambient images of familiar faces with ease (e.g., Bruce, 1982; Bruce et al., 2001; Jenkins et al., 2011), even when image quality is poor (e.g., in closed-circuit television (CCTV) footage, Burton et al., 1999) and after large distortions (Hole et al., 2002). This stark contrast between familiar and unfamiliar face recognition was highlighted in a sorting task by Jenkins and colleagues (2011). Adults sorted 40 photographs (20 images of two people's faces) into piles based on identity. Whereas participants who were familiar with the people correctly sorted the images into two piles, those who were unfamiliar made about seven piles (i.e., perceived seven people to be present). Representations of unfamiliar faces are limited by the instance in which the image was captured; a change in appearance is often perceived as a change in identity. In contrast, representations of familiar faces are robust to variability in appearance, allowing for recognition in novel instances (see, Burton, 2013; Burton et al., 2005; Burton et al., 2011; Hancock et al., 2000; Johnston and Edmonds, 2009). A strong test of fully quantitatively mature face recognition requires comparisons of familiar and unfamiliar faces and the use of ambient images to examine children's ability to form such robust representations—akin to Face Recognition Units (FRUs) in Bruce and Youngs' (1986) model.

The few studies using ambient images of unfamiliar faces with children have reported age-related improvement and, when adults were tested, significant differences between children and adults (Baker et al., 2017; Laurence and Mondloch, 2016; Matthews et al., 2018; Neil et al., 2016). Accuracy on Jenkins et al.'s (2011) sorting task with unfamiliar faces increases between the ages of 6–14 years (Neil et al., 2016). This prolonged development is evident even when the task is made child-friendly by reducing cognitive demands (Laurence and Mondloch, 2016; Matthews et al., 2018). The inclusion of control trials showed that children's poor performance was not attributable to generally immature cognitive skills. The developmental pattern for familiar faces is quite different. The only study using ambient images suggests that the ability to recognize a familiar face in ambient images is adultlike by 6 years of age (Laurence and Mondloch, 2016): children aged 6 years and older sorted ambient images of their own teacher (nearly) without error. However, many 4- and 5-year-olds recognized only a subset of their teacher's images, despite knowing her for 3–9 months. Young children's errorless performance on control trials indicates their failure to recognize their teacher cannot be attributed to general cognitive skills. Thus, there appears to be improvement in the ability to recognize familiar faces between 5 and 6 years of age, at which point, it is (nearly) adultlike.

Behavioral evidence of prolonged development of identity recognition, at least for unfamiliar faces, is consistent with evidence that face-selective regions in the brain undergo substantial changes during childhood (e.g., Cohen Kadosh et al., 2013a, 2013b; Golarai et al., 2007, 2010, 2017; Scherf et al., 2007). During childhood and adolescence, the fusiform face area (FFA) which, in adults, responds more to faces than nonface objects (Kanwisher et al., 1997) and which is involved in representing invariant aspects of facial identity (i.e., information that does not change across instances; see Haxby et al., 2000), increases in size (Golarai et al., 2007; Peelen et al., 2009; Scherf et al., 2007) and becomes more selective to faces versus nonface objects (Aylward et al., 2005; Golarai et al., 2010; Peelen et al., 2009). This region also becomes increasingly sensitive to facial identity during childhood (Natu et al., 2016; Nordt et al., 2018). For example, when different images of the same person were presented, adults' responsiveness in the FFA decreased across trials, but there was much less change for 7–10-year-olds (Nordt et al., 2018), consistent with children's difficulty recognizing identity across even slight changes in appearance. Collectively, behavioral and neural evidence suggest prolonged development of identity recognition for unfamiliar faces and, in the very few studies to date, faster development for familiar faces.

Underlying Mechanisms

Insights into the source of limitations on children's face processing have been gained from studies of the specific mechanisms used by adults.

Holistic Processing

Holistic processing, a process by which facial features are integrated into a gestalt, is a hallmark of adults' expertise and evident in two experimental tasks. The *composite face effect* occurs when aligning the top and bottom halves of two different faces impairs recognition of individual parts (see Figure 6). When the composite is comprised of familiar faces, adults are slow to recognize the top half, despite being told to ignore the bottom half (Young et al., 1987). When the composite is comprised of unfamiliar faces and the task is to make same/different judgements about the top halves, adults have a high error rate on *same* trials (i.e., when the same top half is aligned with different bottoms, see Hole (1994)). Adults perform better when the two halves are misaligned or the face is inverted, disrupting holistic processing (Hole, 1994; Hole et al., 1999; Le Grand et al., 2004; Young et al., 1987). In the *part/whole task*, participants are asked to recognize facial features when presented in isolation (e.g., Larry's nose, *part* condition) or in the context of the whole face (*whole* condition). Adults more accurately identify the features in the whole than in the part condition (Farah et al., 1998; Goffaux and Rossion, 2006; Pellicano and Rhodes, 2003; Tanaka and Farah, 1993; Tanaka and Sengco, 1997). Both effects are upright face-specific (i.e., not observed for objects such as houses and cars or for inverted faces; Tanaka and Farah, 1993; Macchi Cassia et al., 2009b).

Figure 6

An example of stimuli from the Composite-face task. The top row depicts faces pairs in the misaligned condition and the bottom row depicts faces pairs in the aligned condition. In the left panel, the top halves are identical in each pair, and in the right panel they are different. The bottom halves are different in all face pairs. Aligning the two halves evokes holistic processing; the halves become fused, and adults perceive a novel identity, making it difficult to decide whether the top halves are the same or different.

Source: used with permission from Le Grand, R., Mondloch, C. J., Maurer, D., Brent, H. P. (2004). Impairment in holistic face processing following early visual deprivation. *Psychological Science*, 15(11): 762–768. Doi: 10.1111/j.0956-7976.2004.00753.x

Holistic processing emerges during infancy and is mature by 4 years of age. When making same/different judgments about the top halves of unfamiliar faces, children as young as 3.5 years (Macchi Cassia et al., 2009b) demonstrate a composite face effect and 4- and 6-year-olds show an effect of comparable magnitude to that of adults (de Heering et al., 2007; Mondloch et al., 2007). At age 6 children also show a composite face effect for familiar faces (Carey and Diamond, 1994). By age 4, children are more accurate in the whole than in the part condition of the part/whole task (Pellicano and Rhodes, 2003; Pellicano et al., 2006; Tanaka et al., 1998). Holistic processing is face-specific during childhood—at least to some degree: children as young as 3.5 years do not show a composite effect for cars (Macchi Cassia et al., 2009b), but 8–10-year-olds do show one for watches, albeit a smaller effect than that observed for faces (Meinhardt-Injac et al., 2017). Similarly, children as young as 5 do not show the part/whole effect with inverted faces (Pellicano and Rhodes, 2003; Tanaka et al., 1998). Collectively these studies suggest that immature holistic processing does not contribute to the slow development of face recognition during childhood (see Crookes and McKone, 2009 for a similar conclusion).

Sensitivity to External Contour, Shape of Features, and their Spacing

To discriminate between identities adults can rely on subtle differences in the shape of facial features, the spacing among them and the shape of the external contour. Systematically isolating each of these cues by replacing the original features with those of another face, by moving the eyes and mouth, or by replacing the original exterior contour with that of another face has repeatedly demonstrated adults' sensitivity to each of these cues (see Figure 7). Whether asked to make same/different judgements of unfamiliar faces or detect subtle changes to familiar faces, adults are highly accurate, with > 80% accuracy even when spacing changes are kept within normal limits (Ge et al., 2003; Freire et al. 2000; Mondloch et al., 2002). Sensitivity to feature spacing is tuned by experience: it is reduced for monkey and inverted faces, and for houses (Mondloch et al., 2006b; Robbins et al., 2011).

Figure 7

An example of stimuli created to examine sensitivity to feature shape and spacing, and external contour. The original face is shown as the left-most face in each panel, along with the altered faces in each set. Panel A depicts the spacing set, created by moving the eyes in/out/up/down and moving the mouth up or down. Panel B depicts the feature set, created by replacing the original features with those of another identity. Panel C depicts the external contour set, created by replacing the original exterior contour with that of another face.

Source: used with permission from Mondloch, C. J., Le Grand, R., and Maurer, D. (2002). Configural face processing develops more slowly than featural face processing. *Perception*, 31: 553–566. Doi: 10.1068/p3339

Sensitivity to each of these cues emerges during infancy but the age at which adult-like performance is achieved varies. Six-year-olds are adultlike when making same/different judgments about unfamiliar faces that differ in external contour, and nearly so when such faces differ in feature shape, with little to no statistical difference at age 10 (Mondloch et al., 2002; Mondloch et al., 2010b). When unfamiliar faces differ in feature spacing, accuracy increases between 6–14 years of age and even 14-year-olds make more mistakes than adults (Mondloch et al., 2002; Mondloch et al., 2003a, see Freire and Lee, 2001 for evidence of age-related improvement in a delayed match-to-sample task). Even when the task is adapted to increase the viewing time and exaggerate feature spacing beyond natural limits, 8-year-olds are still not as accurate as adults (Mondloch et al., 2004), although when featural distortions are extreme, children aged 7–11 perform comparably to adults in a memory task (Gilchrist and McKone, 2003). Threshold sensitivity also decreases: the smallest difference in spacing that children are able to detect decreases between 7 and 11 years of age (Baudoin et al., 2010). Although less sensitive to feature spacing than adults, even 6- to 8-year-olds show face-specificity: an adult-like advantage for recognizing feature spacing in upright human over inverted human and monkey faces (Mondloch et al., 2002; Mondloch et al., 2006b).

Although 4-year-olds detect differences in feature spacing under certain circumstances (e.g., when judging distinctiveness, McKone and Boyer, 2006; when asked to recognize facial features in the part/whole task, Pellicano et al., 2006), it is unlikely that they use feature spacing to recognize facial identity. Four-year-olds are at chance at distinguishing familiar(ized) faces from distractors that differ only in feature spacing (Mondloch et al., 2006a), regardless of whether the faces had been learned from a storybook or were personally familiar—best friends from the child's daycare (Mondloch and Thompson, 2008) or even their own face[1] (Mondloch et al., 2006a). Chance performance cannot be attributed to general immature cognition because these same children performed (nearly) without error when the distractor differed in feature shape or external contour. Similarly, 4-year-olds are at chance in a simultaneous match-to-sample task in which they are instructed to find the twins when one member of each triad differed in feature spacing (Mondloch and Thompson, 2008). This is the same age at which children have difficulty recognizing their own teacher in ambient images (Laurence and Mondloch, 2016). Given that sensitivity to feature spacing matures quite late in childhood, while other mechanisms (e.g., holistic processing, sensitivity to feature shape and external contour) are fully developed by age 4–6, immature sensitivity to feature spacing may underlie children's difficulties in recognizing facial identity.

Prototype Formation

One conceptualization of how adults encode individual faces is as unique points in a multidimensional face space. According to Valentine's (1991) influential model, vectors in multidimensional face space represent dimensions along which individual faces vary. The nature of these dimensions remains unspecified, but they might represent features such as the size of the nose or the distance between the eyes (see Turk and Pentland, 1991 for description of eigenfaces). Individual faces are encoded in relation to a prototype—a process known as norm-based coding. This prototype represents the average of all the faces a person has encountered and is constantly updated based on experience. Faces that are located close to the prototype are rated as more typical and attractive than faces located farther away (Potter and Corneille, 2008; Rhodes and Tremewan, 1996; Valentine et al., 2004).

To provide evidence of norm-based coding, researchers use an adaptation paradigm. Repeated exposure (i.e., adaptation) to faces distorted in a similar direction leads to an aftereffect—a temporary shift in the face prototype, influencing the perception of subsequent faces. Researchers have examined figural (i.e., attractiveness) aftereffects by adapting participants to faces with compressed or expanded features. Such distortions lead to the perception of unaltered faces as distorted in the opposite direction and similarly distorted faces as more attractive (Rhodes et al., 2003; Webster and MacLin, 1999). Researchers have examined identity aftereffects by adapting participants to the opposite of an original identity (e.g., "anti-Dan"), derived from a computational face-space; for example, if Dan had widely spaced eyes, anti-Dan's eyes are close together. After repeated exposure to "anti-Dan," participants perceive previously ambiguous faces along the *Dan/anti-Dan* trajectory as more similar to the original identity (i.e., Dan; Anderson and Wilson, 2005; Leopold et al., 2001). These effects are selective such that larger aftereffects are found for opposite faces (e.g., Dan and anti-Dan) than for non-opposite faces (e.g., Dan and anti-Jim) equal in dissimilarity (Rhodes and Jeffery, 2006). The magnitude of identity aftereffects is positively correlated with the ability to recognize newly learned faces (as measured by the Cambridge Face Memory Task), providing evidence of the role of norm-based coding in identity perception (Dennett et al., 2012; Rhodes et al., 2014).

Adults' face space shows evidence of separate prototypes for different face categories (e.g., race, sex, age, upright vs inverted) as shown by opposing (category-contingent) aftereffects. Adapting adults to face categories distorted in opposite directions (e.g., compressed Caucasian and expanded East Asian faces) results in perceptions of normality being shifted in opposite directions for Caucasian versus Asian faces (Jaquet et al., 2008; Little et al., 2008). This suggests that the mature face processing system codes faces relative to category-specific norms; had there been a single prototype, the aftereffects would have cancelled each other out, leading to no shift in the norm.

Children as young as 4 appear to represent faces in a multidimensional face space that shares at least some properties with that of adults (reviewed in Jeffery and Rhodes, 2011). Four-year-olds perceive differences in facial distinctiveness, a judgment that requires reference to a face prototype (McKone and Boyer, 2006). Similarly, 6–10-year-olds rate caricatures (images manipulated to exaggerate differences between a face and the average) as more distinctive than anti-caricatures (images manipulated to enhance similarities between a face and the average; Chang et al., 2002).

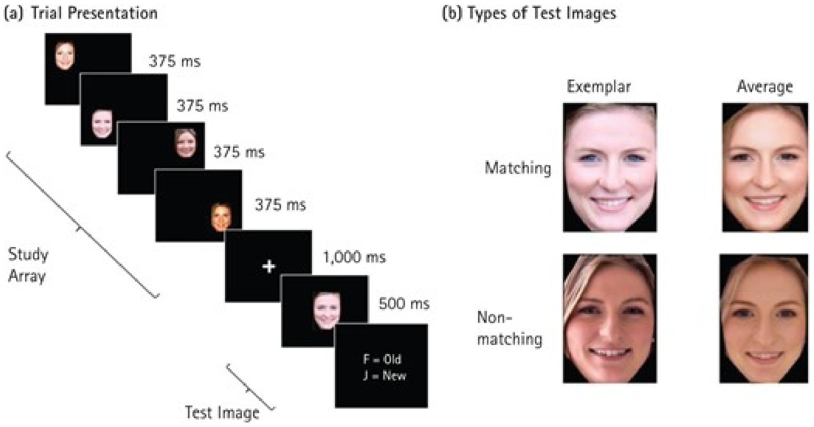
By early childhood, children also show characteristics of norm-based coding. Adaptation produces figural aftereffects in children 4–12 years old (Anzures et al., 2009; Hills et al., 2010; Jeffery et al., 2010; Short et al., 2011) and identity aftereffects in children 5–9 years old (Jeffery et al., 2011; Nishimura et al., 2008; Pimperton et al., 2009). As in adults, these identity aftereffects are selective for pairs of opposite faces (e.g., Dan and anti-Dan: Nishimura et al., 2008). The size of children's aftereffects is comparable to that of adults (Jeffery et al., 2010; Nishimura et al., 2008; Pimperton et al., 2009) and, like adults, children experience stronger aftereffects after adaptation to more extreme distortions (Jeffery et al., 2010, 2011, 2013).

Nonetheless, children are less sensitive to deviations from the norm than are adults. When rating unaltered and distorted (e.g., compressed or expanded) faces based on attractiveness, 8-year-olds require more extreme distortions to reliably rate the unaltered faces as more attractive (Anzures et al., 2009; Crookes and McKone, 2009; Jeffery et al., 2010). Children appear to use the same dimensions as adults when coding facial identity but rely on only one of these dimensions at a time (predominately eye color), whereas adults use multiple dimensions simultaneously (Nishimura et al., 2009). Further, 5-year-olds show no evidence of category-specific norms for race, sex, or age (Short et al., 2014). Category-specific prototypes emerge during middle childhood but are not observed for all categories; 8-year-olds show race-specific aftereffects (Short et al., 2011) but even 10-year-olds do not show orientation-specific aftereffects (Robbins et al., 2012), suggesting that separable norms for faces of different categories continue to develop during childhood. Collectively, this evidence suggests that although children engage in norm-based coding, their face space continues to be refined throughout childhood.

Learning to Recognize Ambient Images of Familiar Faces

The ability to recognize faces in ambient images is the true marker of expert recognition—something that is limited to familiar faces in adults. Within-person variability in appearance makes the recognition of a newly encountered face difficult, but exposure to such variability facilitates face learning in adults (e.g., Andrews et al., 2015; Baker et al., 2017; Dowsett et al., 2016; Ritchie and Burton, 2017). Adults' ability to find an identity in a lineup is improved after viewing multiple images of that person (Dowsett et al., 2016; Matthews and Mondloch, 2018); viewing images captured on different days (i.e., high variability) is more beneficial than viewing images captured on the same day (i.e., low variability; Ritchie and Burton, 2017). Variability may be beneficial because adults can represent multiple versions of a person's face (Burton et al., 2016; Young and Burton, 2017) and/or because they form an average representation that contains reliable diagnostic cues but excludes cues specific to a particular instance (Burton et al., 2005; Kramer et al., 2015). Adults extract average representations rapidly and automatically—a process known as ensemble coding (Davis et al., 2020; Kramer et al., 2015; Matthews et al., 2018); after briefly viewing four images of a person's face they report having seen the average of those four images and the images themselves with comparable frequency (see Figure 8).

Figure 8



(a) Trial presentation in the ensemble coding task. On each trial, a study array comprising four images of a single identity is presented (either sequentially or simultaneously; shown here sequentially). Next, a fixation cross is displayed, followed by one of the four types of test images (see panel b). Once the test image disappears, participants are asked to decide whether the test image was present in the study array. (b) Types of test images. Matching Exemplar: a display image from the array; Matching Average: an average of the display images; Non-matching Exemplar: a new image of the identity; Non- Matching Average: an average of four new images of the identity. Ensemble coding is demonstrated when the matching average (panel B) is perceived as having been seen.

Source: used with permission from Davis, E. E., Matthews, C. M., and Mondloch, C. J. (2020). Ensemble coding of facial identity is not refined by experience: Evidence from other-race and inverted faces. *British Journal of Psychology*. Advance online publication. Doi: 10.1111/bjop.12457

Despite being less accurate than adults at recognizing unfamiliar faces, children aged 6–11, show comparable benefit from viewing multiple images of a newly learned identity in a perceptual task (Matthews et al., 2018). Like adults, they recognize new images of a learned identity more accurately when they had been shown six images of the target identity rather than a single image. Younger children show a slightly different pattern. Although viewing six images increases 4- and 5-year-old's sensitivity to identity, it also leads them to adopt a less conservative response bias (Matthews and Mondloch, 2022). This shift in criterion after viewing six images vs. one image results in children identifying more images of the character but also incorrectly identifying more images of the distractor. This effect of false alarms is not seen in older children or adults, suggesting that the ability to benefit from exposure to multiple images is not fully refined before the age of 6.

Children as young as 6, the youngest age tested, also show comparable ensemble coding to adults (Matthews et al., 2018). After viewing four images of a target identity children recognize the average of those four images (i.e., report the average as having been in the original array) at the same rate at which they recognize the images themselves, regardless of whether the individual instances are viewed simultaneously or sequentially. Formation of such an average was already evident in infancy, from 3 months of age (de Haan et al., 2001).

In contrast, children are less efficient than adults at learning a newly encountered face when the task involves holding a representation in memory—the challenge faced when meeting new people in daily life. Children aged 6–12 show evidence of learning after watching a video that incorporates high variability in appearance (filmed across 3 days), but unlike adults, show no evidence of learning when the variability is low (filmed on a single day; Baker et al., 2017). Evidence of children's prolonged development in face learning in a memory but not a perceptual task is consistent with Weigelt and colleagues' (2014) conclusion that face memory, but not perception, continues to improve after 5 years of age.

Tuning by Experience

We have reviewed a wealth of data documenting prolonged development of face detection, face recognition, and underlying mechanisms during infancy and childhood. Although improvements in general cognitive skills (e.g., memory, attention, executive function) certainly contribute to the developmental changes (see Matthews and Mondloch, 2021; McKone et al., 2012), face-specific experience plays a crucial role. In the language of Gottlieb (1976), experience both induces postnatal change and facilitates the refinement of face processing.

What Infants Experience

Infants are exposed to faces more than any other visual stimulus, ~ 25% of the time they are awake over the first 3 months (Jayaraman and Smith, 2018; Sugden et al., 2014), usually within 2 feet, upright, and enface (Jayaraman et al., 2015; Jayaraman et al., 2017; Jayaraman and Smith, 2018; Sugden and Moulson, 2017). Even in multiethnic Toronto, the faces predominantly match the baby (and mother's) ethnicity (96% in one study) and are mostly adults (81%) and female (70%) (Sugden et al., 2014). The primary caretaker (usually the mother) is seen most frequently and longest (Jayaraman and Smith, 2018; Sugden and Moulson, 2018).

By 3 months, the infant has accumulated about 210 (of 800) waking hours with faces directly in front of the face, a number that increases to 620 (of 3100) by 11 months (Jayaraman et al., 2015). Over the next 1–2 years, faces remain prevalent but their prevalence declines to ~ 8% after 18 months (Fausey et al., 2016; Jayaraman et al., 2017).

Tuning by Biased Experience During Infancy

The clearest evidence of experiential tuning comes from comparisons of human faces with a category rarely seen—nonhuman animals. Newborns can discriminate between two monkey faces and they look longer at an upright than an inverted monkey face, perhaps based on the same cues that attract their attention to *config* (Di Giorgio et al., 2012). When structural cues are matched, newborns look equally long at monkey and human faces. A looking preference for the experienced (i.e., human) category develops over the first 3 months (Di Giorgio et al., 2012; Di Giorgio et al., 2013), a preference revealed even with complex arrays at older ages (Jakobsen et al., 2016; Simpson et al., 2020).

Nevertheless, infants continue to be able to discriminate between monkey faces after 3 months of age. For example, at 6 months, 20 seconds of exposure to a human *or* monkey face is sufficient to elicit a subsequent novelty preference. At 9 months it is sufficient only for the human faces (Pascalis et al., 2002), an effect replicated with different animal species (Pascalis et al., 2005; Scott and Monesson, 2009; Simpson et al., 2011). Thus, monkey faces become harder for infants to discriminate between 6 and 9 months of age, such that they fail the novelty test they "passed" at 6 months. This pattern, a hallmark of biased experience during infancy, has been called perceptual narrowing (Maurer and Werker, 2014).

Longer exposure time to the familiarized monkey face or the insertion of human eyes can prevent the loss of discrimination at 9 and sometimes 12 months (Damon et al., 2015; Fair et al., 2012; Zieber et al., 2013; but see Scott and Monesson, 2009); so can calling attention to the individuality of six monkey faces by giving them different names in a storybook read ~ 30 times between 6 and 9 months (Pascalis et al., 2005; Scott and Monesson, 2009). Mere exposure or a story without individual names is insufficient (Scott and Monesson, 2009). After hearing individual names, the N290 and P400 waves of the ERP also differentiate upright from inverted monkey faces (Scott and Monesson, 2010). Without such training, ERPs at 8–9 months suggest that infants do not process monkey faces at the individual level, are insensitive to whether the monkey's face is upright or inverted, and to whether the monkey's vocalization is congruent with the observed facial movements (Dixon et al., 2019; Grossmann et al., 2012; Scott and Monesson, 2010). Nevertheless, at 9 months, infants' ERPs differentiate repeated from novel monkey faces, with a response even greater than at 6 months, especially in right occipital, right occipitocentral, right central, and left central regions (Barry-Anwar et al., 2018). Those results imply that at the transitional age of 9 months, there is still neural differentiation of individual monkey faces that is not strong enough to be manifest in typical behavioral paradigms.

The results for ethnicity/race[2] are similar and directly correlated with the infant's biased diet of faces. At 3 months, a looking preference for own-race faces emerges despite a continuing ability to discriminate among other-race faces (Bar-Haim et al., 2006; Kelly et al., 2007a; but see Hayden et al., 2007a; Sangrigoli and De Schonen, 2004; and Tham et al., 2015 for evidence of an emerging own-race advantage). By 6–9 months, babies fail to show discrimination with paradigms that they "pass" at younger ages and continue to pass with own-race faces (Kelly et al., 2007b; Kelly et al., 2009; Vogel et al., 2012). This pattern emerges first with female faces (Sugden and Marquis, 2017) and extends to infant faces (Macchi Cassia et al., 2014; Kobayashi et al., 2018). The falloff in discrimination can be prevented at least temporarily by using photographs of expressive faces (with happy or angry expressions; Quinn et al., 2020), encouraging individuation of other-race faces (Anzures et al., 2012; Heron-Delaney et al., 2011; Markant et al., 2016), or living in a multiethnic environment (Tham et al., 2019).

By 8–9 months, babies seem to process other-race faces at the categorical (what is it?) rather than the individual level (whose face is it?) (Anzures et al., 2010; Hayden et al., 2009) and in a piecemeal rather than holistic fashion (Ferguson et al., 2009). They also spend more time fixating the features that differentiate among faces of their own race (for Caucasian faces, the eyes; for Asian faces, the nose) (Liu et al., 2011; Pickron et al., 2017; Wheeler et al., 2011) and shifting fixation between two individual faces of their own race (Fassbender and Lohaus, 2019). ERPs and fNIRs reveal a change in processing coincident with perceptual narrowing, but the use of different paradigms, seemingly inconsistent results (greater for own-race or for other-race) and lack of crossover studies make the findings difficult to interpret (Balas et al., 2011; Timeo et al., 2019: Vogel et al., 2012).

Similar perceptual tuning is seen for age and gender: by 3 months, a looking preference emerges for own-race faces that are adult rather than infant and for own-race faces that are female rather than male (Heron-Delaney et al., 2017; Tham et al., 2015), unless the baby is being raised by a male (Quinn et al., 2002; Quinn et al., 2008). At 9 months, adult faces evoke an increase in oxyhemoglobin in the right temporal area and a decrease in deoxyhemoglobin in the left temporal area, but infant faces do not (Kobayashi et al., 2018). At 3 months, the infant also fails to show discrimination between (own-race) male faces (Quinn et al., 2002), despite continuing to discriminate between faces from unfamiliar species, races, and ages. By 7–9 months, the effect of sex of face has vanished, likely because of increasing exposure to a mixture of male and female faces (Tham et al., 2015). Nevertheless, even at this point, female faces elicit a larger N290, which is also uniquely sensitive to the novelty of the individual female face (Righi et al., 2014).

Persistent Effects of Early Experience

The own-race advantage persists into adulthood on the very tasks that show prolonged development during childhood: recognizing learned unfamiliar faces in memory tasks (e.g., Golby et al., 2001; MacLin and Malpass, 2001; Meissner and Brigham, 2001, Wright et al., 2003, Zhou et al., 2018), matching identity across images of unfamiliar faces (Laurence et al., 2016; Megreya et al., 2011; Meissner et al., 2013; Proietti et al., 2019), and detecting changes in feature shape and spacing (Hayward et al., 2008; Mondloch et al., 2010a; Rhodes et al., 2009; Zhao et al., 2014).[3] Although social cognitive factors might contribute to these effects (Hugenburg et al., 2010; Young et al., 2012) and the ORE is reduced when perceived threat increases (e.g., with angry expressions; Ackerman et al., 2006), the fact that these effects emerge during infancy (i.e., before developing the classic outgroup homogeneity bias) suggests experience is critical (Anzures et al., 2013; Kelly et al., 2005, 2007b; Tanaka et al., 2013). In contrast, adults do not show an own-race advantage on the tasks that mature early: when recognizing highly familiar faces (Zhou and Mondloch, 2016), ensemble coding (Davis et al., 2020) or learning faces from ambient images in a perceptual matching task (Matthews and Mondloch, 2018).

Exposure to siblings' faces also alters development. By 3 years of age, children without a sibling show superior discrimination and a selective inversion effect for adult relative to child or infant faces. Three-year-olds with a sibling (younger or older) and 6-year-olds with a younger sibling show comparable discrimination and inversion effects for both infant/child and adult faces (Macchi Cassia et al., 2009a, 2012, 2013, 2014). This sibling effect persists into adulthood: only mothers who had a younger sibling show an inversion effect for infant faces (Macchi Cassia et al., 2009a).

The number of faces encountered during development also influences face processing. Adults raised in small towns are less accurate at recognizing faces learned in a memory task and at matching the identity of unfamiliar faces than adults from large towns (Balas and Saville, 2015, 2017). Small-town adults also demonstrate an N170 that is less specific to faces (Balas and Saville, 2015). Similarly, adults who were home-schooled are poorer at sorting ambient images of unfamiliar faces than adults who encountered many more faces by attending school (Short et al., 2017).

When early visual experience is completely lacking —because an infant was born with dense central cataracts in both eyes, the developmental trajectory is altered more profoundly. When first treated during infancy, their face preferences resemble those of newborns and not age mates: they look preferentially toward *config*, even at ages when that preference has disappeared in babies with normal eyes (Mondloch et al., 2013a) and their face preferences change with accumulated experience, rather than their chronological age. Despite the early visual deprivation, as adults (i.e., after years of [nearly] normal visual input following treatment) they perform normally in detecting faces even when local featural cues are eliminated

(Mondloch et al., 2013b) and in recognizing identity based on differences in the shape of the external contour or of the internal features (Le Grand et al., 2001a; Le Grand et al., 2001b).

Nevertheless, the early visual deprivation has prolonged effects. As adults, these patients are worse than controls in recognizing upright human faces differing only in the spacing of internal features—a deficit not evident for inverted faces, monkey faces, or the windows and doors of houses (Le Grand et al., 2001a; Le Grand et al., 2001b; Mondloch et al., 2003b; Mondloch et al., 2010b; Robbins et al., 2010). In other words, the deficit is restricted to the category on which adults excel and for which development is protracted. Follow-up experiments indicated that early input to the right hemisphere is critical (Le Grand et al., 2003; see also Dalrymple et al., 2020). Cataract-reversal patients also fail to show evidence of holistic processing of upright human faces: in the composite face task, they are *better* than controls in recognizing that the top halves of two faces are identical when aligned with different bottom halves (Le Grand et al., 2004). Given the lack of these two markers of expert processing, it is not surprising that they also have difficulty recognizing famous faces (de Heering and Maurer, 2014) and learning or discriminating new faces when picture encoding is prevented by adding variable noise or introducing changes in point of view or lighting (Geldart et al., 2002; de Heering and Maurer, 2014; Putzar et al., 2010).

fMRI analyses indicate that cataract-reversal patients use the normal face network when processing faces versus objects or houses, but with reduced activity and specialization in both the core and extended face networks and a different pattern of connectivity, particularly with the left fusiform gyrus. The extent of these changes correlates with performance in recognizing facial identity based on the spacing of internal features (Grady et al., 2014). There are also changes in the neural underpinnings of face detection, despite normal behavioral performance. As in controls, the N170 is larger for faces than other categories (scrambled faces, objects, houses), but it has a much greater amplitude, as does the preceding P100, with the size of the amplification correlated with the duration of the visual deprivation during infancy (Mondloch et al., 2013b). That pattern suggests that patients achieve normal accuracy by recruiting additional neural processing. (When the deprivation lasts past infancy, until an average age of 4 years, the N170 no longer differentiates faces from other categories (Röder et al., 2013).)

Of course, these studies do not distinguish between the necessity for *face* experience versus patterned visual input more generally, but a study of monkeys raised in a rich visual environment but without exposure to faces suggests that it is face experience that is critical (Sugita, 2008).

Summary

The ability to detect faces and the mechanisms underlying the recognition of facial identity emerge during infancy. Whereas some face recognition mechanisms mature relatively early in childhood (i.e., holistic processing, sensitivity to feature shape and external contour, norm-based coding, ensemble coding, perceptual learning from ambient images), others show prolonged development (i.e., sensitivity to feature spacing, refinement of multidimensional face space, forming identity representations in memory). The accumulation of experience during infancy and childhood is critical for these developments.

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Notes

1 Although Freire and Lee (2001) reported that 4-year-olds were capable of using differences in feature spacing to identify faces in a delayed match-to-sample task, subsequent analyses (McKone and Boyer, 2006) revealed that performance in this age group was not above chance.

2 We use the term “other-race” because it is the traditional label even through it actually refers to an unfamiliar ethnicity since there are no biologically distinct races.

3 The results for holistic processing are mixed (Crookes et al., 2013; Hayward et al., 2013; Michel et al., 2006a, b; Mondloch et al., 2010a; Tanaka et al., 2004).