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Perceptual Narrowing During Infancy: A Comparison of Language and Faces

ABSTRACT: *In this article, we begin with a summary of the evidence for perceptual narrowing for various aspects of language (e.g., vowel and consonant contrasts, tone languages, visual language, sign language) and of faces (e.g., own species, own race). We then consider possible reasons for the apparent differences in the timing of narrowing (e.g., apparently earlier for own race than for own species). Throughout we consider whether the evidence fits a model of maintenance/loss or is better characterized as enhancement/attunement to exposed categories. Finally, we consider evidence on the malleability of the timing and its implications for the role of endogenous factors versus learning in controlling when narrowing occurs. Overall, the comparison across domains revealed many similarities but also striking differences which lead to suggestions for future research.* Dev Psychobiol 56: 154–178, 2014.

Keywords: *infant; language; early experience; auditory; vision*

WHAT IS PERCEPTUAL NARROWING?

When first introduced, the term perceptual narrowing was seen by many as a useful, but merely descriptive phrase that helped draw attention to a number of findings that have common elements. This use of the term is undeniably useful. It helps draw attention to the commonality of the finding that young infants often show greater preparedness to respond to any potential social signal, as reflected in greater sensitivity to non-native speech sounds, unfamiliar facial speech gestures, and the features of unfamiliar faces, than do older infants. It is important to draw attention to this fact, as it is surprising to a scientific community that typically assumes that developmental advance comprises only increased sensitivity. Perceptual narrowing studies show one way in which infants and children become more adept members of their community by showing a decline in sensitivity to distinctions not featured in their linguistic and social environments.

More problematic is whether the descriptive phrase, "perceptual narrowing" carries with it a mechanistic explanation. While several different mechanistic explanations have been offered, many of which are reviewed in this volume, the most common interpretation is that "perceptual narrowing" refers to a set of evolved (and/or experience-expectant) initial sensitivities that prepare the infant for learning about aspects of their world that have adaptive significance, and that minimal input is needed to maintain these initial sensitivities. This interpretation fits well into a framework laid out by Gottlieb (1976) on possible effects of perceptual experience. As shown in Figure 1, one possibility is maintenance/loss wherein sensitivities are present prior to specific experience and the role of experience is simply to maintain that which is already present. That contrasts with induction, wherein experience is necessary to induce the development of perceptual sensitivity and two intermediate patterns, facilitation and enhancement, which refer to an experiential effect on the speed of development or the level attained, respectively. In an elaboration of Gottlieb's framework in 1980, Aslin and Pisoni suggested the term "perceptual attunement" to

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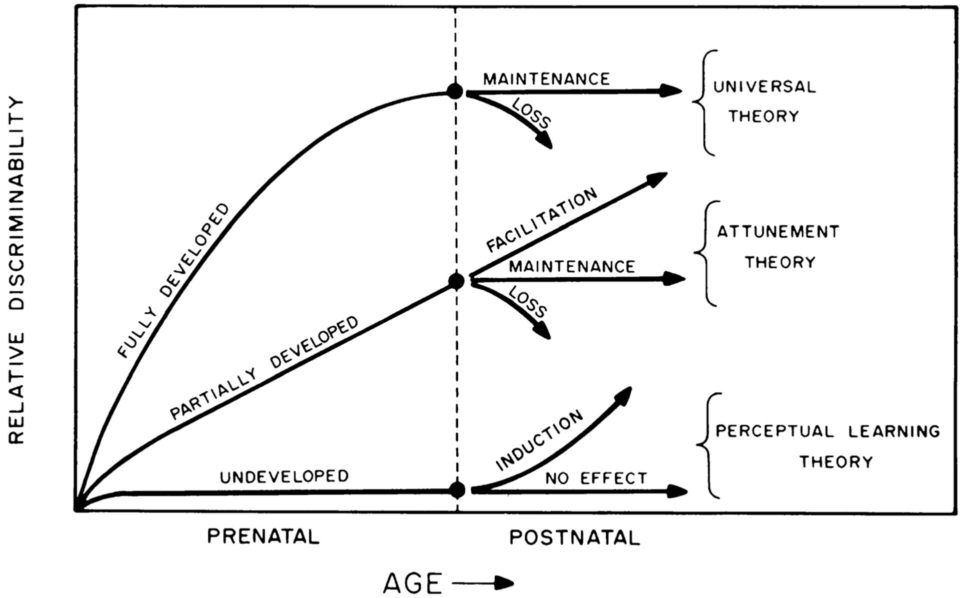

FIGURE 1 Possible effects of experience on speech perception development. Figure 5.4, p. 77, from Aslin and Pisoni (1980).

apply to a pattern in which substantial organization is evident prior to specific experience, but experience serves not only to "maintain" initial sensitivities, but also to enhance, or sharpen, those sensitivities.

The interpretation of "perceptual narrowing" as evidence for an underlying mechanism involving maintenance/loss was bolstered by the similarity in timing of many of the examples. This has led to the idea that there is a "critical" or "sensitive" period during which sensitivities are affected by listening or viewing experience with the timing determined more by maturation than by the amount or type of input. Experience by this view acts to merely "trigger" rather than "sculpt" the resulting organization and can do so only, or most easily, during the sensitive period. Finally, as in any "critical" or "sensitive" period phenomenon, the implication is that the system will not be open to, or at least will be more resistant to, reorganization or retuning at a younger or older age.

Many of the articles in this issue challenge this set of assumptions, and offer alternate accounts. Below, we attempt to address the usefulness of the initial formulation of "perceptual narrowing" as well as the limits of its applicability. We do so by reviewing the reported examples in the domains of language and faces and carefully considering some of the reported exceptions. We work from a framework in which we assume that in both the domains of language and face processing, the capabilities and biases infants show at any particular point in development reflect a prior developmental history. This developmental history reflects the combination of biological proclivities (e.g., the response properties of individual neurons, or the initial projections between different brain regions; what we call "preparedness") and experiential influences up to that point. We hope to advance understanding about two aspects of perceptual narrowing: (1) the extent to which both the (a) broader sensitivities shown in the young infants, and (b) the more specific ones shown in the older infant, reflect specific versus more general types of experience: and (2) the extent to which experiential influences, particularly "specific" ones, can change perceptual biases at any age versus the extent to which the perceptual bias in question is most open to specific experience in a constrained age range (i.e., a "sensitive" or "critical period"). An example of specific experience is hearing a particular speech sound or seeing a face of a particular race. An example of a more general experience is hearing language cum large, that is, experiencing the kinds of sounds that can be produced by a human (or other primate) vocal tract, or for example, seeing faces in general, not the face of any particular individual or any particular race. An example of specific experience being equally effective at any age would be, for example, creating or erasing an other race bias equally well at 5 months as at 5 years, assuming the amount of experience was equivalent. An example of what we call a critical period would be the other race bias requiring only minimal exposure to be set (or eliminated) at 5 months in comparison to a requirement for much, much more exposure to lead to equal change at an older age.

LANGUAGE

Processing of Speech Versus Non-Speech

Human infants respond preferentially to speech over non-speech from the first moments of life, with some sensitivities—particularly those to the broader structure of language—seen irrespective of the *specific* prenatal listening experience, whereas other sensitivities show clear induction from *specific* prenatal and/or immediate postnatal listening.

At birth, human neonates show a listening preference for speech over non-speech. When allowed by high amplitude sucking to listen to speech (isolated nonsense words) rather than non-speech (complex, five formant, sine wave analogs to those words; Vouloumanos & Werker, 2007a), newborns show a listening preference for speech. To address the possibility that this preference was induced from prenatal listening experience, Vouloumanos and Werker also tested neonates on their preference for filtered speech, mimicking that heard in utero, over the same sine-wave analogs. In this comparison, even though the filtered speech was more like the speech heard in utero, no preference over non-speech was found (Vouloumanos & Werker, 2007b). Thus the preference for speech seems to emerge without specific listening experience to induce it. Nonetheless, experience does play a role. The neonatal preference for speech is quite broad, and includes not only human speech but rhesus monkey calls, and it only narrows to be specific to human speech by 3 months of age (Vouloumanos, Hauser, Werker, & Martin, 2010). By 3 months, the preference for human speech is also seen in comparison to many other natural signals (Shultz & Vouloumanos, 2010). While it is possible that the increase in the specificity of the preference seen between birth and 3 months is driven entirely by maturation or entirely driven by listening experience, given the organization seen in the neonate, we suggest the increase in specificity is likely an experience expectant process in which an initial broad substrate “narrows” rapidly when optimal stimuli (in this case, human speech) are encountered.

While the neonatal preference for human speech is broad enough to include other animal calls, neonates none-the-less show a behavioral listening preference for the native language at birth. Sucking paradigms reveal that English neonates prefer to listen to English over Spanish (Moon, Cooper, & Fifer, 1993) and English over Tagalog (Byers-Heinlein, Burns, & Werker, 2010), and French neonates prefer French over German (Mehler et al., 1988). Moreover, “bilingual newborns,” those exposed to two languages from different rhythmical classes in utero, show a preference for both of their native languages (Byers-Heinlein et al., 2010). Nevertheless, like monolingual newborns (Nazzi, Bertoncini, & Mehler, 1998), they can discriminate between those two languages (Byers-Heinlein et al., 2010). Thus, the ability to use rhythmical cues to discriminate languages is not erased by early listening experience with more than one language.

The majority of studies of language discrimination have been with newborns to 4- to 5-month-old infants. These studies indicate that while 4-month-olds continue to discriminate languages from different rhythmical classes (see Nazzi & Ramus, 2003 for a review), it is only by 5 months that monolingual infants can discriminate two languages from within the same rhythmical class (Nazzi, Jusczyk, & Johnson, 2000), and even then they only do so if one of the languages is familiar. Bilingual infants are able to discriminate their two native languages at 4 months even when they are from the same rhythmical class (Bosch & Sebastián-Gallés, 1997). There are no published studies of rhythmical class discrimination in infants older than 5 months, so it is unknown whether listening experience is required to maintain this robust initial sensitivity, but the finding of a different outcome for classification/discrimination versus preference does, we believe, help nuance the understanding that not all experiential influences are the same.

Despite the initial broad listening preference for speech and animal calls, neuroimaging studies reveal that the classic language areas in the brain are activated to speech from the first moments of life, with a different pattern for the native language heard in the womb and the non-native language. Studies using both NIRS (optical imaging using near infrared spectroscopy) and fMRI have revealed that the classic LH temporal and frontal brain areas are more involved in processing Forward than Backward speech for both native (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Peña et al., 2003) and non-native (unfamiliar) languages and that these differ from those for a surrogate, whistled language (May, Gervain, Carreiras, & Werker, in preparation), Nevertheless, NIRS studies also reveal that the native language involves slightly different patterns of activation from that for the non-native language (May, Byers-Heinlein, Gervain, & Werker, 2011; Minagawa-Kawai et al., 2011). Thus, there is both broad preparedness and an influence of experience.

Consonant Perception

The work on the processing of speech versus non-speech reveals an interaction between initial listening biases and specific experience, and some increasing specificity with age, but it is not generally seen as classic evidence for perceptual narrowing. Perhaps the first demonstrations with human infants that the effect of experience on perceptual development can involve a decline in performance came from the work of Werker and Tees on consonant discrimination (Werker, Gilbert, Humphrey, & Tees, 1981; Werker & Tees, 1984). The languages of the world have different repertoires of individual speech sounds that are used to form words and contrast meaning. For example, English distinguishes /r/ from /l/, whereas Japanese has only an intermediate sound. For years it had been known that adults have difficulty discriminating some speech sound differences that are not used in their native language (Lisker and Abramson, 1964; Miyawaki et al., 1975), so it had been assumed that perceptual development involves learning the sound distinctions of the native language (for a review of these views, see Strange & Jenkins, 1978). However, following pioneering work by Eimas and colleagues (Eimas, Siqueland, Jusczyk, & Vigorito, 1971) evidence began to accumulate that young infants can discriminate speech sounds even without specific listening experience, and indeed, can discriminate some non-native speech sound differences they had never heard before (see Aslin, Pisoni, Hennessy, & Perey, 1981; Eilers, Gavin, & Wilson, 1979; and Trehub, 1976 for English-learning infants with non-English sounds, and Streeter, 1976, with Kikuyu-learning infants). To test the emerging, counterintuitive hypothesis that infants might be born with a broad-based sensitivity to differences among the world's speech sounds, and that the effect of experience might be to "maintain" sensitivities that are already present, Werker and colleagues directly compared adults and infants on their ability to discriminate two similar speech sounds that are used to contrast meaning in Hindi but not in English. In support of the hypothesis, they found that while English-speaking adults had difficulty discriminating these Hindi (non-English) distinctions, both adult Hindi-speakers and English-learning infants aged 6–8 months of age succeeded (Werker et al., 1981). Even more surprising at the time, in later work they found that the decline in discrimination of these non-native speech sounds occurs between 6 and 10 months of age (Werker & Tees, 1984).

While there are important exceptions to this general pattern of results which will be reviewed in the Section further along in this paper entitled "Exceptions to perceptual narrowing for language," the pattern of experience primarily serving to maintain discrimination, has now been shown to hold across the vast majority of studies testing non-native consonant perception (for a review, see Werker & Curtin, 2005). Moreover, this pattern is seen whether discrimination is measured by habituation/recovery, familiarization/novelty preference, alternating/non-alternating preference, conditioned head turn, or event-related potentials (ERPs) (Anderson, Morgan, & White, 2003; Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Elsabbagh et al., 2013; Peña, Werker, & Dehaene-Lambertz, 2012; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005; Weikum, Oberlander, Hensch, & Werker, 2012; Werker & Lalonde, 1988, to list but a few).

Vowel Discrimination

Perceptual narrowing has also been reported for vowels (Cheour et al., 1998). Studies of vowel discrimination (as opposed to the structure of vowel categories, Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992; Moon, Lagerkrantz, & Kuhl, 2013) agree that 4-month-old infants can discriminate both native and nonnative vowel distinctions while 10-month-olds fail to show evidence of discriminating the same non-native distinctions. For example, Polka and Werker (1994) tested English-learning infants on their ability to discriminate between the two pairs of high front rounded versus high back rounded vowels that are contrasted in German but not in English (dUt vs. dYt, and dut vs. dyt). At 4 months of age, the English infants discriminated both non-native vowel distinctions well, and they no longer showed evidence of doing so by 10 months, in accord with the original findings reported with consonants. However, there is some suggestion that the decline might begin earlier for vowels than for consonants. At 6–8 months of age, the English infants also discriminated each of the German vowel distinctions significantly better than chance, but, their performance was not as robust as it is for non-native consonants at that age, and was poorer than their discrimination performance for the German vowels at 4 months of age (Polka & Werker, 1994). Other studies have shown that discrimination of vowel categories can change by 8 months of age, slightly earlier than the 10 months seen for consonants (see Sebastián-Gallés, 2010, for a review). Thus discrimination between two non-native vowel categories might become attuned to the properties of the native language at a slightly earlier age than do consonants. These differences in timing could be seen to challenge a single sensitive period for the timing of perceptual narrowing that acts across all kinds of phonetic distinctions. On the other hand, if the narrowing occurs within a fairly constrained window, but is simply a little earlier for vowels and other continuant-like sounds than it is for consonants, it could be argued that there is a single maturationally constrained sensitive period for all phonetic distinctions, but that there is variation within that window for when narrowing occurs, depending on the sonorancy[1] of the phones in question or other factors affecting their salience.

In the vowel perception literature, there have also been studies on infants' perception of the internal structure of vowel categories. Unlike the studies of between category vowel discrimination, these studies reveal experiential influences much earlier in infancy. Infants as young as 6 months show better discrimination of a peripheral versus central member of a native vowel category than they do when tested in the opposite direction—central versus peripheral (Kuhl et al., 1992), but equivalent discrimination in both directions when tested on non-native vowels. A similar finding was recently reported even in newborns (Moon et al., 2013).

Lexical Tone

There are similar changes between 6 and 10 months for discrimination of lexical tone. Young infants hearing tone languages (e.g., Mandarin, Cantonese, Thai) as well as infants growing up exposed to languages that do not use tone differences for lexical contrast (e.g., English) can discriminate lexical tone distinctions, whereas by 9–10 months of age, only infants growing up hearing tone languages continue to show evidence of being able to do so (Mattock & Burnham, 2006; Mattock, Molnar, Polka, & Burnham, 2008; Yeung, Chen, & Werker, 2013). When tested on preference, rather than on between-category discrimination, there appears to be some specificity in the tones infants are learning as a function of the inventory used in their particular language by 4 months of age (Yeung et al., 2013). Specifically, Mandarin and Cantonese, while both tone languages, have slightly different inventories. By 4 months of age, both Cantonese- and Mandarin-learning infants show a preference for the tones used in their native language. Moreover, by 4 months, native tones seem to serve as more stable anchors for discrimination (Yeung et al., 2013).

Audio-Visual Matching of Oral and Visual Speech

When we speak, our mouth movements convey redundant information with the acoustics of the sounds we produce. Very young infants are able to match heard and seen speech. As first demonstrated by Kuhl and Meltzoff (1982, 1984), when presented with two side by side images of the same woman's face either articulating "ee" or "ouu," infants of 4 months (Kuhl & Meltzoff, 1982; Patterson & Werker, 1999; Yeung & Werker, 2013), and 2 months (Patterson & Werker, 2003) look longer to the side that is matching. This ability to match heard and seen sounds is also apparent for heard and seen consonants (MacKain, Studdert-Kennedy, Spieker, & Stern, 1983; Pons, Lewkowicz, Soto-Faraco, & Sebastián-Gallés, 2009). As reviewed by Lewkowicz (this volume), by the end of the first year of life, infants no longer match heard and seen speech if the sounds are not used in their native language (Pons et al., 2009). In their work, infants growing up in Barcelona were tested at 6 and 10 months on their ability to match heard and seen instances of "ba" and "va". This pairing is noteworthy because the distinction is not used in Spanish; instead an intermediate phone is used. At 6 months the Spanish-learning infants matched the heard syllables with the appropriate matching display, but at 10-months they no longer did so. Similar changes between 6 and 10 months have been reported for human infants' matching of rhesus monkey vocalizations to the correct visual display (Lewkowicz & Ghazanfar, 2006).

Young infants are also able to discriminate languages from different rhythmical classes just by watching the movements in silent, talking faces. In this work, English-learning infants aged 4, 6, and 8 months were habituated to three bilingual French-English female speakers first producing sentences in one of their two native languages. On each trial, the infants saw one of the three females producing a unique sentence from the book "The Little Prince,", but the sound was turned off so they had no accompanying audio. Every set of three trials contained each of the three female speakers. Following habituation, infants in the "control" condition were presented with six trials of the same three female speakers in the same order, still producing unique sentences and still in the same language while infants in the experimental condition were presented with six trials of the same three female speakers, but now saw them reciting unique sentences in the other language. Infants at 4 and 6 months in the experimental condition showed an increase in looking, thereby indicating they discriminated the change. At 8 months, however, infants did not recover unless they were growing up bilingual in French and English (Weikum et al., 2007). These results suggest that young infants are sensitive to the cues in silent talking faces that distinguish one language from another, but only retain that sensitivity if they grow up in a language-learning environment where they are exposed to those cues on a continuing basis.

[1] A sound produced with the vocal cords so positioned that spontaneous voicing is possible; a vowel, a glide (y, w), or a liquid (r, l), or nasal (m, n) consonant. Modified from http://oxforddictionaries.com/definition/english/sonorant.

Sign

Finally, a similar pattern of perceptual attunement has been shown for the perception of manual signs. The findings for sign refer to how various degrees of hand opening are categorized. Signing adults discriminate degree of hand opening discontinuously at linguistically relevant points while non-signing adults discriminate these variations more continuously, with the boundary—to the extent it exists—at the mid point in the continuum (Baker, Idsardi, Golinkoff, & Petitto, 2005; Best, Mathur, Miranda, & Lillo-Martin, 2010). Similar results of categorical perception only by signing adults have been reported for two other sign-language distinctions (Emmorey, McCullough, & Brentari, 2003). When tested with the same stimuli Baker and colleagues had used with signing adults, young hearing infants (4–6 months) who have not been exposed to sign discriminated best at the same boundary as do the signing adults, but after 1 year of age performed like non-signing adults and discriminated instead at the mid point in the continuum (Baker, Golinkoff, & Petitto, 2006). However, hearing infants growing up with exposure to a signed language—irrespective of whether it is their only language or occurs along with a spoken language—continue to discriminate variations in hand opening in a linguistic manner even after 1 year of age (Palmer, Fais, Golinkoff, & Werker, 2012).

Altering the Timing of Narrowing

The pattern of narrowing for non-native speech sound discrimination between 6 and 10 months is so robust for stop consonant contrasts, that it occurs at the same gestational age, even for infants who were born several weeks premature, and hence had several weeks extra of postnatal listening experience (Peña et al., 2012). Specifically, when tested in an ERP procedure on the Hindi (non-French) retroflex-dental distinction (Da-da), French infants born up to 3 months premature continued to discriminate this non-native phonetic contrasts at 10 months post-birth, the age at which it is no longer demonstrated by full-term infants. Evidence of discrimination declined about 12 weeks later, when the premature infants reached the gestational age at which full-term infants typically show the decline. These findings support the notion of a critical or sensitive period for attunement, and suggest that listening experience interacts with a maturationally based time-table, such that the native language can only have an impact when the developing brain is open for language input.

These findings are all the more striking because the sounds to which the fetus is exposed preserve rhythmical aspects of speech but largely muddle speech contrasts. Indeed, when tested in utero the typically developing fetus is not able to discriminate the similar sounding consonants da versus ta at 36 weeks gestation (Weikum et al., 2012). Surprisingly, preterm infants born at 29–32 weeks can discriminate the consonants ba versus ga (Mahmoudzadeh et al., 2013). These are different consonants contrasts, one differing in voice onset time (da vs. ta) and the other in place of articulation (ba vs. ga). Nonetheless, the conjoint findings raise the possibility that the fact of birth accelerates the onset of initial consonant discrimination, and hence increases exposure to consonant contrasts. Nonetheless, the results on perceptual narrowing for Hindi distinction presented in the previous paragraph suggest that the timing of openness to perceptual narrowing or attunement remains constrained by gestational age rather than time from birth (Peña et al., 2012), providing even stronger evidence that it is maturational factors, rather than the accrual of a criterial amount of specific experience, that determines the temporal window for perceptual attunement.

While the evidence presented so far in this section indicates maturational constraints on the timing of attunement, such timing can be altered under at least some environmental conditions. For example, exposure to pharmacological agents in utero (SRIs), to untreated maternal depression (Weikum et al., 2012) and to an anomalous diet (Innis, Gilley, & Werker, 2001), all alter the timing of perceptual attunement. English-learning infants who are exposed to SRIs in utero show evidence of an onset of consonant discrimination at an earlier age than do non-exposed infants, and of a decline in the retroflex-dental (Hindi) non-native consonant discrimination at an earlier age (Weikum et al., 2012). In contrast, English-learning infants exposed to maternal depression that is not treated with SRIs (Weikum et al., 2012), or to a vegetarian-only diet that is missing essential fatty acids (Innis et al., 2001), continue to discriminate the Hindi (non-English) retroflex-dental distinction beyond the age at which a decline would be expected. The diet and depression effects presumably induce differences in hormonal and/or neurotransmitter activity in the infants, that in turn alter the timing of brain development. Indeed, diet has been shown to alter the neural representation of voicing differences with breast fed infants showing more lateralization and specificity of areas related to language production versus recognition at 3 and 6 months than soy fed infants (Pivik, Andres, & Badger, 2012). Combined with the evidence on prematurity, these effects on timing are consistent with a biological substrate that is maturationally constrained unless perturbed by neurochemical changes, some of which can be induced by environmental factors.

Another environmental factor that may alter the timing of change is bilingualism. The data are now unequivocal in showing that by the end of the first year of life, infants growing up bilingual are able to discriminate the phonetic distinctions used in both of their languages, but the data are mixed on whether there is a delay in their being able to do so and whether they maintain an ability to discriminate contrasts used in neither language past the typical age of narrowing in monolingual infants. Much of this evidence comes from Spanish-Catalan bilingual infants' discrimination of vowel distinctions that are used in Catalan but not in Spanish. One of the earliest reports (Bosch & Sebastián-Gallés, 2003) indicated that while Spanish-Catalan bilinguals discriminate the Catalan /e/-/E/ vowel at 4 and at 12 months of age, at 8 months of age they fail. This pattern was subsequently reported for a few other Catalan-only vowel distinctions. However, in a more recent study, Sebastián-Gallés and colleagues (Albareda-Castellot, Pons, & Sebastián-Gallés, 2011) showed that when a more sensitive procedure is used, the Spanish-Catalan infants provide evidence of maintaining sensitivity to the distinction across the entire age range (see Sebastián-Gallés, 2010, for a review). Similarly, in an initial report Burns and colleagues found mixed evidence for bilingual French–English infants' maintaining discrimination of both the English d–t^h and the French d–t distinction (Burns, Werker, & McVie, 2003), but in a subsequent report with a larger sample reported success (Burns, Yoshida, Hill, & Werker, 2007), while at the same time showing evidence of a change between 6 and 10 months in discrimination of non-native contrasts by monolingual infants, and maintenance of discriminative sensitivity to the distinctions of both of their native languages by bilingual infants. Indeed, more recent data indicate that the timing of perceptual attunement is similar for bilingual French–English infants as it is for monolingual infants, and show further that the bilingual French–English infants even maintain the ability to discriminate the English d from the French d (Sundara, Polka, & Molnar, 2008). Still, the above data on the timing of phonetic reorganization in bilingual infants leave a lingering possibility that the timing of change occurs later for bilingual infants, leaving open the question of whether the amount of input is important. Bilingual infants hear as much speech as do monolingual infants, but the speech is divided between two languages (Byers-Heinlein, 2013; De Houwer, 2007). Moreover, recent data indicate that when ERP rather than behavioral measures are used, there is also evidence that bilingual phonetic discrimination does develop later, and that bilingual infants may have less mature networks for processing language than same-aged monolingual infants (Garcia-Sierra et al., 2011).

A recent report using NIRS confirmed an age difference in the timing of reorganization of non-native perception in bilingual infants. It also indicates that bilingual infants maintain the ability to discriminate distinctions that are not used in either of their native languages even at 10–12 months (Petitto et al., 2012). Specifically, Petitto and colleagues reported that the maintenance of sensitivity to non-native distinctions (English infants tested on the Hindi d/D distinction) involved different neural areas, left inferior frontal rather than the more classic left superior temporal areas typically involved in phonetic discrimination. It is interesting that Petitto and colleagues interpret these data as revealing a remarkable advantage in the bilingual brain, whereas previous studies that showed continuing discrimination of non-native sounds by bilinguals beyond the age when attunement usually occurs (e.g., Burns et al., 2003; but see Burns et al., 2007) were criticized as suggesting bilinguals are delayed. The critics then published counter-evidence showing relatively similar timing for both groups (Sundara et al., 2008). Whether maintenance of sensitivity to non-native sounds ends up being a bilingual advantage or a bilingual delay will be of interest to see.

Similar findings of maintenance even for non-native information in bilingual infants have been reported in visual language discrimination. As reviewed above, at 4 and 6 but not at 8 months, monolingual English infants can discriminate visual English from visual French, whereas French–English bilingual infants maintain discriminative sensitivity at 8 months (Weikum et al., 2007). More recently it was shown that bilingual Spanish-Catalan infants aged 8 months can also discriminate visual French from visual English, whereas monolingual Spanish or Catalan infants cannot (Sebastián-Gallés, Albareda, Weikum, & Werker, 2012). Like the Petitto study above, this study indicates that bilingual infants may retain sensitivity even to non-native information. While it is still too early to know whether this maintenance truly involves a different—perhaps higher-level attentional system—or whether it is simply delay, the results are intriguing. We know from other research that, like bilingual adults (e.g., Bialystok, Craik, & Luk, 2012), bilingual infants are better at Executive Function type tasks: they can better learn one rule system and then switch to another than can monolingual infants (Kovács & Mehler, 2009a,b). One possibility raised by this work, vis-à-vis the question of perceptual narrowing, is that the attunement to speech sound categories using basic level perceptual and phonological systems occurs in tandem in monolingual and bilingual infants, but that the fact of growing up bilingual also sharpens the attentional system in bilingual infants, thus allowing bilingual infants to have better access to information that has become subthreshold for monolingual infants.

Exceptions to Perceptual Narrowing for Language

While the pattern of "perceptual narrowing" holds for most speech sound distinctions that have been studied, there are important exceptions even in monolingual infants. Some acoustically difficult and rare contrasts seem to require listening experience before they become discriminable. This facilitative role was first illustrated for /th/-/d/ in initial position (Sundara, Polka, & Genesse, 2005), which becomes discriminable only in early childhood. As another example, while the nasal distinction between /m/ and /n/ is common across the world's languages and easily discriminated by young infants, and while /n/ versus /ŋ/ is also common and discriminable in final position (as in "pan" vs. "pang"), /n/ versus /ŋ/ in initial position is very similar acoustically, used in only a few languages of the world, and more easily confused in noise in those languages than are the other nasals (Narayan, 2008). Recently, it has been shown that young infants aged 4, 6–8, and 10 months of age show no evidence of being able to discriminate this distinction if it is not used in their native language, and only begin to do so at around 10 months if it is used in their language (Narayan, Werker, & Beddor, 2010). Similar results have been reported for a vowel length distinction used in Japanese wherein infants younger than 10 months fail to discriminate categorically (Sato, Sogabe, & Mazuka, 2010), whereas by 10 months of age they do (Mugitani, Pons, Fais, Werker, & Amano, 2009; Sato et al., 2010). Similarly, while young infants show a change between 6 and 10 months of age for categorical discrimination of the Flat versus Open hand sign (Baker et al., 2005; Palmer et al., 2012), they fail to show evidence of discriminating some other hand shapes used in sign at both 6 and 10 months (Wilbourn & Casasola, 2007). In all of these examples, experience played a role in inducing or enhancing sensitivity to a language distinction.

Conversely, some acoustically quite similar consonant distinctions seem to remain discriminable even without relevant language experience. This pattern of findings was first illustrated convincingly by Best and colleagues using an apical versus lateral click contrast from Zulu. English infants maintain sensitivity to this distinction at the end of the first year of life, and even across childhood and into adulthood (Best, McRoberts, & Sithole 1988). Similar findings have now been reported for other click contrasts (for a review, see Best, McRoberts, & Goodell, 2001). On the one hand, these examples can be seen to belie the need for exposure in order to maintain a language distinction. Yet, on the other hand, click contrasts may not even be recognized by non-click speakers as linguistic items, and seem to be processed outside of the standard language areas in the brain (see Best & Avery, 1995). Hence, they may remain discriminable as non-linguistic, acoustic objects, much as the burst and formant transition of even the Hindi retroflex-dental d's are distinguished by English speaking adults, when removed from a full syllable (Tees & Werker, 1984).

While both of these cases seem to deviate from the "perceptual narrowing" pattern, they can each be explained in a way that fits within the broader "attunement" framework wherein experience acts both to maintain and to enhance initial sensitivities. For example, the fact that young infants can discriminate some nasal distinctions (e.g., /m/m vs. /n/) and more specifically, can discriminate /n/ versus /ŋ/ in final position, can be interpreted as indicating that infants begin life with the nasal consonant space available, but need experience with the most acoustically similar instances within that space for discrimination to rise above measurable threshold levels (this interpretation, along with an "induction" interpretation, is discussed in Narayan et al., 2010). In the case of the click consonants, as noted above, Best and her colleagues have suggested that perceptual reorganization acts only on those units that fall within the phonological space of the languages heard. Because the clicks fall so far outside of the phonological space of English, they are not subject to the perceptual reorganization that influences perception of sounds that are English-like. Hence, the same non-linguistic, auditory sensitivities that enabled discrimination in the young infant continue to influence discrimination in the older infant and child.

In summary, it appears that while "narrowing" is a common pattern seen for phonetic perception, there are many other patterns as well. In most cases, the ability to discriminate non-native phonetic distinctions does seem to be much more language-universal in the young infant than in the older infant. However, while the lack of experience seems to lead to attenuation in the discriminability of many non-native distinctions, the presence of experience seems to improve as well as to maintain initial sensitivities. In addition, there are cases in which experience seems to induce discrimination of sensitivities that were not present, or at least not above threshold, prior to the onset of experience. There are also cases in which non-native phones continued to be discriminated even without listening experience. Given all these patterns, we suggest "attunement" might be a better term than "narrowing."

The literature reviewed also suggested that in most cases, the timing of attunement seems to be tightly constrained by maturation, although quite distinct environmental conditions, including both drug exposure and exposure to two rather than just a single language, can lead to variation in the timing of change, and some more sonorant or perceptually salient signals may attune earlier than the less salient ones. And finally, we noted the importance of keeping theoretically distinct experiential influences that change preference and/or the internal structure of phonetic categories, from experiential influences that change between category discrimination.

Can Non-Native Phonetic Perception be Reacquired?

As noted above, across a range of studies it has been shown that infants begin to attune to the phonetic differences used in the native language by 9–10 months of age. Is this initial tuning tantamount to full loss of other distinctions, or is there still residual plasticity? To address this question, training studies have been done with both adults and infants. The review of the adult training studies is beyond the scope of this article, but suffice it to say that with systematic training, particularly with feedback, significant improvement on discrimination of non-native contrasts can be induced (Bradlow, Pisoni, Akahane-Yamada, & Tokhura, 1997; Lively, Pisoni, Yamada, Tohkura, & Yamada, 1994; Jamieson & Morosan, 1986; Pruitt, Jenkins, & Strange, 2006). Notably, however, there are enormous differences across populations and across the phonetic distinctions that have been tested. Those consonant contrasts, such as /r/-/l/ and the Hindi /d/-/D/ that show the most robust evidence of perceptual attunement in infancy are the same ones that show the most resistance to training in adulthood (Ingvalson, Holt, & McClelland, 2012; Golestani & Zatorre, 2009). Moreover, when improvements are seen, even for many of the more sonorant phonetic distinctions, training seldom leads to improvements to the level of native speakers (Strange & Dittman, 1984), and only infrequently results in sensitivities that are generalizable to new syllables or new speakers, and that are maintained across time. Furthermore, even when training of discrimination seems to be successful, adults can still be shown to have difficulty using the trained, non-native phonetic differences to segment or recognize words in continuous speech (e.g. Pallier, Bosch, & Sebastián-Gallés, 1997).

Several researchers have also investigated infant recovery in the period between 8 and 10 months when decline in sensitivity is underway, but not yet complete. Here the results are very telling. At 6–8 months of age when the speech perception system is believed to be quite open to experience, a simple 2- to 4-min statistical learning manipulation can collapse (Maye, Werker, & Gerken, 2002) or enhance (Maye, Weiss, & Aslin, 2008) phonetic category discrimination. In this task, infants are presented with syllables that have been modified to vary in equal steps along an eight-step continuum from one sound, for example, /ta/ to another, /da/. In a familiarization phase, all the infants hear all tokens, but in the bimodal condition, infants hear proportionately more of tokens 2 and 7, whereas in the unimodal condition, they hear more of tokens 4 and 5. Following familiarization, they are tested on the end points. At 6–8 months, bimodal familiarization leads to better discrimination of the end points than shown on a pretest before training, and unimodal familiarization leads to worse performance. At 10 months, this 2–4 min of familiarization is ineffective. However, by simply doubling that amount, relearning is possible at 10 months, even for the non-native Hindi retroflex-dental /Da/-/da/ distinction (Yoshida, Pons, Maye, & Werker, 2010). By 18 months, this bimodal manipulation seems to be much less effective. Similarly, while it can improve discrimination in adults, performance is not elevated to become significantly better than chance (Maye & Gerken, 2000). These patterns suggest that plasticity diminishes with age (or native experience) but that it is never entirely eliminated.

The ease with which sensitivity is re-instated at 9–10 months may vary with the extent to which the training task clearly signals communicative intent. One example comes from a study on training English-learning infants to distinguish a Fricative distinction used in Chinese but not English. Infants who interacted with a live adult reading to them in a contingent manner improved in making this discrimination, whereas those who watched a video of the adult or simply listened to the tape, showed no improvement (Kuhl, Tsao, & Liu, 2003). Follow-up studies suggest that the effectiveness of training with the live adult may be driven by greater engagement of attention (Conboy & Kuhl, 2007).

Similarly, sensitivity to non-native contrasts is enhanced at 8–9 months when the contrasts are associated consistently with objects they might name. For example, sensitivity to the non-native Hindi Retroflex-dental distinction can be enhanced in English infants if each syllable type is paired with a distinct object. Following 2-min of familiarization with consistent pairings, English infants aged 9 months show better discrimination of the /Da/-/da/ distinction than they otherwise do at this age, and than they do when a syllable and word are paired together, but in an inconsistent fashion (Yeung & Werker, 2009). This finding has recently been replicated with the same linguistic tone distinction that Mattock and colleagues reported to “narrow” between 6 and 9 months of age, but in this case a referential context is required. Here Yeung, Chen, and Werker (in press) found that simply pairing syllables differing in a non-native tone contrast did not reinstate discrimination. However, if the task was made slightly more intentional by first presenting the infants with known word-object pairings, then infants did succeed by showing an improvement in sensitivity to the non-native tone distinction.

These studies reveal that minimal exposure is required to reinstate sensitivity during the period of decline, but re-instatement is more likely if the training task mimics the conditions under which infants learn language from their parents (live, contingent, referential naming) and/or if attention is drawn to the differences by emphasizing them in the distribution of examples. After infancy, such minimal exposure is insufficient but improvements can be induced by longer training or a reversal of the environment, as happens with international adoption (see International Adoption section).

International Adoption

A limitation of training studies is that in most cases the subjects are still speaking, or have access to, their other language(s). Hence, the possibility exists that it is interference from the first language, rather than limits imposed by sensitive period processes, that makes reacquisition of non-native distinctions difficult. Research with international adoptees who may no longer be exposed to their native language, helps address this question. In studies of simple phonetic discrimination, results indicate that if there is even occasional exposure to the first language, adults who were adopted as children are better able than English monolingual adults at discriminating speech sound distinctions used in the first language but not English (Oh, Jun, Knightly, & Au, 2003). If, however, there is no further exposure to the first language following adoption, discrimination of phonetic contrasts used in that language but not the language used after adoption seems to be entirely lost. Specifically, adults who had been adopted from Korea as children, into French families and who had no further access to Korean after adoption, were no better able than French adults at discriminating the voicing distinctions used in Korean (Ventureya, Pallier, & Yoo, 2004). On the other hand, when retraining procedures are used, evidence for some lasting imprint of the phonetic distinctions from the otherwise attrited language is still evident. For example, in a recent study of 12 adults, 11 of whom had been adopted from Korea into American-English homes before 1 year of age—before they had likely learned any spoken Korean—were nonetheless better able, following 2 weeks of Korean study at the university level, to discriminate the lenis versus aspirated Korean consonant distinctions than English L1 speakers with the same amount of Korean training (Oh, Au, & Jun, 2010). A similar set of findings comes from Korean adoptees living in Sweden who had been adopted between the ages of 1–10 years, who also showed better discrimination of the Korean voicing distinctions following university classes in Korean than did native Swedish speakers (Hyltenstam, Bylund, Abrahamsson, & Park, 2009). Thus, to the extent that retraining is seen as reactivation of old memory traces (e.g., Bjork & Bjork, 2006, one can say that exposure during the first few years of life can have a lasting effect on sensitivity to phonetic contrasts. Nevertheless, when adoption is before age 8, it is possible for the child to learn the novel phonetic contrasts used in the new language and this process appears to be far easier than learning in adulthood.

INDIVIDUATION: DISCRIMINATING BETWEEN FACES AND BETWEEN VOICES

Processing of Faces versus Non-faces

Newborns have a looking preference for stimuli with a face-like structure, but it can be largely explained by preferences for visual properties like top-heaviness (more elements in the top half), congruency (having the more numerous elements in the widest part of the face), contrast (black features on white), and optimal range of spatial frequencies (Cassia, Turati, & Simion, 2004; Cassia, Valenza, Simion, & Leo, 2008; Farroni et al., 2005; Kleiner, 1987). Nevertheless, these looking preferences guarantee that infants will attend to the faces of parents that are frequently within their range of attention. Only at 3 months, do infants looking preferences for face-like structure begin to trump these more general visual proclivities (Kleiner, 1993; Macchi Cassia, Kuefner, Westerlund, & Nelson, 2006; Mondloch et al., 1999). Over the next 6 months, infants' face processing attunes to the types of faces that are seen (e.g., upright, adult, human, own race) and begins to show the first hallmarks of adult expertise.

Adults' expertise in processing upright own-race human faces is marked by a number of signature phenomena: compared to inverted, other-species, or other-race faces, adults discriminate them more accurately, even when there is a change of viewpoint, remember them better, process them more holistically, and excel in discriminating small differences in the spacing among their internal features (reviewed in Maurer, Le Grand, & Mondloch, 2002; Mondloch et al., 2010; Mondloch, Maurer, & Ahola, 2006). They also appear to represent their identity relative to a prototype in a multidimensional face space centred on a norm (Rhodes & Jeffery, 2006). Inverted and other race faces tend to be processed, like objects, at the categorical level (e.g., Asian face) rather than the individual level (e.g., Wu's face) and tend to be discriminated by featural processing (Tanaka, 2001).

At 3 months, rudimentary forms of adult expertise begin to emerge. At 3 months, but not 1 month, infants show evidence of forming a prototype of four faces with which they were familiarized (de Haan, Johnson, Maurer, & Perrett, 2001), begin to scan faces extensively, and begin to fixate the internal features, especially the eyes (Hainline, 1978; Haith, Bergman, & Moore, 1977; Maurer & Salapatek, 1976), the processing of which is likely critical for differentiating faces and building an efficient face space. At the same time (3 months), infants' looking preferences for face-like stimuli first show evidence of being tuned by experience (Kleiner, 1993; Macchi Cassia et al., 2006; Mondloch et al., 1999; Mondloch, Lewis, Levin, & Maurer, 2013); and a looking preference for own race faces emerges (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005; Kelly et al., 2007a), virtually the only type of face infants experience (Rennels & Davis, 2008). [In unusually multicultural environments, infants show no looking preference at this age for faces of their own versus the other experienced race (Bar-Haim et al., 2006).] Nevertheless, as elaborated below, 3-month-old infants discriminate as readily between two other-race faces as between two own-race faces (Kelly et al., 2007b; Kelly et al., 2009) and even when tested with own race faces, they do not appear to integrate information about internal and external features (Cashon & Cohen, 2004), respond similarly to upright and inverted faces on tests of feature integration and of discrimination (Cashon & Cohen, 2004; Turati, Sangrigoli, Ruel, & de Schonen, 2004), and do not yet show evidence of sensitivity to even large differences in the spacing of the internal features (Bhatt, Bertin, Hayden, & Reed, 2005). As with speech, looking preferences for intact over scrambled faces and for own race over other race faces emerge after only a few months of experience but the infant at this age continues to be able to discriminate between non-native, that is, other race faces. Moreover, the system is still open to experience from non-native categories: when faces are presented one at a time, 3-month-olds look as long at other-race as own-race faces.

After 3 months, more complex face processing becomes evident, which is, of course, applied to the types of faces in the infant's environment. By 4–6 months, the infant shows sensitivity for the first time to the spacing of internal features (in own race faces, the only type tested; Hayden, Bhatt, Reed, Corbly, & Joseph, 2007) and evidence of holistic integrative processing of the internal and external features of both own and other race faces (Ferguson, Kulkofsky, Cashon, & Casasola, 2009). Overall, by 4–6 months, the face processing system appears to be qualitatively similar to that of adults. This analysis suggests that the evidence for perceptual narrowing after this age is unlikely to be explained by a qualitative shift in face processing that causes new skills to emerge only for the types of faces to which babies are exposed. What appears more plausible is that these signatures become increasingly refined to be more sensitive to differences among faces of familiar categories so that a face space is built that differentiates maximally among such faces and that deals poorly, if at all, with faces from unfamiliar categories. Thus, Caucasian 8- to 9-month-old infants, unlike Caucasian 4- to 5-month-old infants, show evidence of holistic integration of the internal and external features of upright own race faces but not upright African American faces or inverted faces of either race (Ferguson et al., 2009). Moreover, they evidence of processing Asian faces at the categorical race level without the individuation they manifest for Caucasian faces (Anzures, Quinn, Pascalis, Slater, & Lee, 2010; Hayden, Bhatt, Zieber, & Kangas, 2009). Perhaps both of these changes are evident by 8–9 months because infants have had more time fixating the differentiating features of own race faces (for Caucasian babies fixating Caucasian faces, the eyes; for Chinese babies fixating Asian faces, the nose) (Liu et al., 2011; Wheeler et al., 2011). Consistent with this interpretation, at 9, but not 5 months, race (Caucasian vs. African American) modulates the amplitude of the P400, an ERP signature of perceptual processing (Vogel, Monesson, & Scott et al., 2012). Thus, as with speech, over the first year of life, looking preferences turn into attentional biases to process different aspects of native and non-native faces. Perhaps as a result, the signature pattern of perceptual narrowing becomes evident between 4 and 9 months of age.

Faces of Other Species

The first study to suggest that perceptual narrowing may be a domain-general process compared infants' discrimination of monkey versus human faces. The pattern matched that reported two decades earlier for consonants: at 6 months, infants showed evidence of both discriminations, but 9-month-olds tested with the same method, continued to show the discrimination for human faces but failed to do so for monkey faces (Pascalis, de Haan, & Nelson, 2002). The pattern was replicated for the faces of Barbery macaques (Fair, Flom, Jones, & Martin, 2012; Pascalis et al., 2005) and of sheep (Simpson, Varga, Frick, & Fragaszy, 2011). However, even 12-month-olds show evidence of discriminating Barbery macaque faces if given longer familiarization time (40 s) than is typical (20 s) (Fair et al., 2012), a result suggesting that other-species processing has been attenuated but not lost. Combined, the results suggest that between 6 and 9 months of age, infants' face processing system changes so that it is more difficult to distinguish among animal faces, while the ability to discriminate human faces is maintained or enhanced. (In the only study to include both human and animal faces, the size of the novelty preference for human faces remained constant between 6 and 9 months—a pattern consistent with maintenance.) The parallel timing to perceptual narrowing for consonants has led many researchers to posit a domain-general process of loss/maintenance or attunement (Pascalis et al., 2002; Scott & Monesson, 2009).

Faces of Other Races

Newborns have looking preferences that attract them to faces, but initially the preference is not affected by the race of face. By 3 months, they prefer to look at an own race face when it is paired with an other race face but, in most tests (see equivocations below for two exceptions), they discriminate between two individual adult faces from their own or from another race. For example, following familiarization with one face, 3-month Caucasian infants looked longer at a novel face when both faces were African, Chinese Han, middle eastern, or Caucasian (Kelly et al., 2007b see also Ferguson et al., 2009) and the findings were similar for the discrimination of Caucasian and African faces by Chinese Han babies tested in the same way (Kelly et al., 2009). By 9 months of age, the results are quite different. Infants pass this discrimination task with two faces of their own race/ethnic group but show no evidence of discriminating between two faces of another race/ethnic group: thus, Caucasian 9-month-old infants familiarized with a Caucasian face for 20 s, look longer at a Caucasian novel face but show no evidence of discrimination when tested in the same way with African, middle Eastern, or Chinese Han faces (Kelly et al., 2007b). Conversely, Chinese 9-month-old babies tested in the same way show a novelty preference after familiarization with Chinese faces but not for African or Caucasian faces (middle Eastern faces were not tested) (Kelly et al., 2009). What is not clear is whether 9-month-old infants would process other-race faces more deeply and still show evidence of discriminating them if given more time to learn the target face and to discriminate between the test faces, as was shown for monkey faces at 12 months of age (Fair et al., 2012). Nevertheless, it is clear that by 9 months it is easier for them to discriminate own-race than other-race faces.

Older studies, however, suggest that the other-race effect might emerge at a far younger age. Two studies found evidence for it as early as 3 months, the youngest age tested, and hence no evidence of perceptual narrowing: after habituation to a Caucasian face, the Caucasian infants showed a novelty preference for a new Caucasian face but failed to do so when the same procedure was used for Asian faces (Hayden, Bhatt, Joseph et al., 2007; Sangrigoli & de Schonen, 2004). (Note that these studies did not include an Asian group to mitigate concerns that the Caucasian faces might have been more physically distinct than the Asian faces.) The different patterns of results may be attributable to the difficulty of the discriminations tested. The two studies finding an other-race effect at 3 months used black-and-white faces without external hair cues (Sangrigoli & de Schonen, 2004) and in one case, particularly subtle differences created by morphing (Hayden, Bhatt, Joseph et al., 2007), while the three studies finding that 3-month-old infants can discriminate as well between other-race faces, as between own-race faces, used coloured faces with hair cues (Ferguson et al., 2011; Kelly et al., 2007b; Kelly et al., 2009) (although in two of these the babies had to recognize the familiarized face in a new point of view). It may be that by 3–4 months of age, infants processing of familiar face categories, but not of unfamiliar categories, has advanced to foster attention to, and processing of, internal face cues that allow faces to be recognized even when infants cannot make use of information from colour/luminance of the skin and hair and/or from the shape of the hair and external contour. Support for this possibility comes from evidence that, when tested with own race faces (the only type used, with one exception noted below), at 3 months infants appear to be just beginning to form prototypes of the faces to which they are exposed (de Haan et al., 2001), to scan the internal features (Hainline, 1978; Haith et al., 1977; Maurer & Salapatek, 1976) and to integrate information about the eyes and mouth (Turati, Di Giorgio, Bardi, & Simion, 2010). Nonetheless, they still apparently continue to recognize familiarized faces based on featural processing of the individual internal or external features rather than the relative locations of the internal features (their spacing (Bhatt et al., 2005). or their integration with external features (Cashon & Cohen, 2004). There may be sufficient overlap of the shape, luminance, or texture of the external contour for infants to use those cues to recognize other-race faces even when they are switched from frontal to 3/4 view [as they have been able to do since the newborn period (Turati, Bulf, & Simion, 2008)], while just beginning to use internal cues for own race faces. Of course, the contrasting results come from studies that used different methods. However, that seems unlikely to be the explanation of the discrepant results since all used paired tests following a period of familiarization. Moreover, the specific parameters of the studies finding evidence for an own race advantage (habituation to criterion and 10–20 s as opposed to 5-s test trials) make it unlikely that these studies underestimated infants' ability to discriminate Asian faces at 3 months of age.

The data from infants 5–6 months old are also mixed. On the one hand, Caucasian 5- to 6-month-olds have been reported to show a preference for a novel face following 20 or 30 s of familiarization with a middle Eastern face (Kelly et al., 2007b) or an African American face (Heron-Delaney et al., 2011; Vogel et al., 2012), even when the faces vary in point of view between familiarization and test (Heron-Delaney et al., 2011; Kelly et al., 2007b) or are equated in luminance (Vogel et al., 2012). On the other hand, in other conditions from the same studies, 6-month-old Caucasian infants failed to show evidence of discriminating between Asian or African faces (Kelly et al., 2007b) see also Anzures et al., 2010 for similar findings for African faces with a different method) and, when tested with similar methods, Chinese 6-month-olds failed to show evidence of discriminating African or Caucasian faces (Kelly et al., 2009). In both cases, infants passed the same tests for own race faces. (Note that the data for the Caucasian infants reveals mean novelty preferences of 55% and 57% for novel Asian and African faces, respectively, percentages that are in the range of those that are significant in other studies.) The apparent paradox—that at 6 months infants show a novelty preference after 20 s of familiarization to monkey (Pascalis et al., 2002) or sheep faces (Simpson et al., 2011) while sometimes failing the same tests for other race faces (Kelly et al., 2009, 2007b)—is likely explained by differences in the difficulty of the tests: the monkey and sheep tests used frontal views with prominent hair and contour cues while the race studies used pairings that were matched in cropped hairlines and introduced a change in viewpoint between familiarization and test. This analysis leads to the prediction that if infants were tested on their ability to discriminate human and animal faces based on the internal features alone and with a change in point of view, infants at 6 months would be likely to show evidence of discrimination for the human faces (as has already been shown) but not the animal faces (not yet tested). Conversely, the results at 6 months might be uniformly positive for other race faces if natural external and luminance cues were included and if there was no change in point of view.

Because of the mixed findings, it is unclear whether the changes between 3 and 9 months for other-race faces represent a decline in a capability originally present, given the evidence for an other-race effect as early as 3 months of age. What might be happening instead is the emergence and refinement of complex face processing skills that are applied to whatever faces are in the infant's environment and a consequent difficulty in generalizing those skills to unexposed categories. Those categories might continue, therefore, to be processed by the systems used for non-face objects, much like the continued processing of clicks long after perceptual narrowing for speech sounds may result from their not being treated as part of language.

A related possibility is that the apparent decline in discriminating other-race faces may be that, like adults, by 9 months infants have begun to process other-race faces at the categorical level—that's a "Chinese" face —while they continue to process the own-race faces at the individual level—that's a woman with big eyes and red lips. The same could be the case for animal faces. Thus, when 9-month-olds view an array of faces in which one face is different, they look longer at an array with one Asian face among seven (identical) Caucasian faces than an array with a single Caucasian face among seven Asian faces (Hayden et al., 2009). That pattern is consistent with processing the Asian faces at the categorical (Asian) level but the Caucasian faces at the individual level, at least when given 10–20 s of exposure. If this explanation is correct, the mechanism for perceptual narrowing for other species and other race faces is not maintenance/loss, so much as a change in attention and the level of processing.

Timing and Critical Periods for Face Processing

Unlike language, there have been no studies on the effects of drug exposure or prematurity on the timing of perceptual narrowing for faces. One human study did show that the preference to look at own race faces at 3 months of age depends on biased experience because Israeli and Ethiopian babies growing up in their typical environments at 3 months had a looking preference for Caucasian and Ethiopian faces, respectively, but that bias failed to emerge in Ethiopian babies growing up in a refugee camp where they received a lot of exposure to Caucasian faces (Bar-Haim et al., 2006). Unfortunately, no data were reported on the refugee babies' response to faces from a race to which they were not exposed (analogous to the bilingual babies' response to a third language) nor on whether the timing or extent of subsequent attenuation of discrimination for other race faces was affected.

Indirect evidence that exposure can modulate perceptual narrowing comes from a study of 3-year-olds: those with a younger sibling born when they were 15–41 months old were just as accurate in discriminating upright adult and infant faces, unlike those without a younger sib, who were much less accurate in discriminating infant faces, although their accuracy was still above chance (Cassia, Kuefner, Picozzi, & Vescovo, 2009). Combined with evidence in this issue (Maccia Cassia, Bulf, Quadrelli, & Proietti, in press) that 3-month-old infants, but not 9-month-old infants, can discriminate between infant faces, the findings imply that exposure to a single infant face of a younger sib is sufficient to reverse the narrowing that occurs during the first year of life. Interestingly, the accuracy of the 3-year-olds with a younger sib for upright adult faces (72%) was lower than that of the 3-year-olds without a younger sib (77%), although this difference was not tested for statistical significance. Thus, we do not know if the attunement of face processing to multiple categories (here infant and adult) leads to poorer discrimination for each category nor whether the infants with a younger sib might also be better for other categories with which they have had little exposure (e.g., other race faces).

The importance of exposure in determining the timing and extent of perceptual narrowing for faces is illustrated dramatically in a study of monkeys who were raised in a visually stimulating environment but without exposure to faces, either human or monkey (Sugita, 2008). When tested with either monkey or human faces at the end of deprivation, which had lasted 6–24 months, the monkeys looked longer at faces, either monkey or human, than objects and showed evidence of discrimination between faces of either species. After 1 month of biased exposure—to only monkey faces or only human faces—the looking preference and discrimination ability were demonstrated only for the now familiar category. These data provide strong evidence that there is a biological substrate drawing attention to facial structure and that perceptual narrowing/attunement results from biased exposure to one category of faces, rather than from any intrinsic critical period, although Sugita did not test the effects of extending the face deprivation all the way to adulthood. Presumably the biased exposure attunes neural connections to differentiate individuals in the experienced category, and in the process connections supporting discriminations for other categories are modified or eliminated.

In conclusion, newborns begin with looking preferences that assure exposure to faces, and by 3 months, show looking preferences for members of familiar over unfamiliar categories (e.g., own race). At that point, however, faces of all types seemed to be processed featurally, based especially on differences in the external features. Over the next 6 months, rather than a perceptual loss for unexposed categories, there may be the first building of a rudimentary face space that represents the faces to which the baby is exposed and that deals poorly with faces that differ greatly from them (i.e., those from unexposed categories). Initially that face space will be centred on a female norm which bares a large resemblance to mom but as the baby gains experience with other individuals, it will gradually differentiate to resemble a more average female, with some male smudges as well [see (Rennels & Davis, 2008 and Sugden, Mohamed-Ali, & Moulson, in press) for evidence of the predominance of females in infants' face experience from 2 to 5 months of age]. As would be expected from this account, the baby at 3–4 months is better at differentiating among female than among male faces and has a looking preference for female faces as long as the faces are upright, of a familiar race and the primary caretaker is not the father (Quinn et al., 2010, 2008; Quinn, Yahr, Kuhn, Slater, & Pascalils, 2002; Ramsey, Langlois, & Marti, 2005; Ramsey-Rennels & Langlois, 2006). In other words, for faces, rather than perceptual loss, there appears to be perceptual enhancement or even induction. In fact, the parallel data for male, animal, and other race faces are enlightening: evidence of a looking preference for female faces and better discrimination among them is not interpreted as evidence for perceptual narrowing for male faces, but rather the induction of face processing skills for the types of faces experienced most often. At the same time, the infant begins to treat faces from unfamiliar categories that do not fit into the differentiating face space as aliens, attending to the features that define the category they belong to (e.g., male, other race; other species) rather than to the features that distinguish individual members of the category. Moreover, at least in non-human primates, if the formation of that face space is delayed by lack of exposure to any face, so is the timing of perceptual narrowing.

Voices

As adults, we individuate others not only based on their faces but also on their voices. When tested with voices speaking the native language, the fetal heart rate is higher for the mother's voice than a stranger's voice (Kisilevsky et al., 2003; see DeCasper & Fifer, 1980, for similar evidence in newborns) and by birth, infants will suck harder to hear a novel male voice after habituation to a different male voice (DeCasper &

Prescott, 1984). There have been no studies of newborn or fetal ability to discriminate between voices speaking a foreign language. However, as late as 6 months of age, when tested with a conditioned head-turning procedure, infants are almost as good at discriminating a change from one to a different rhesus monkey voice as they are at discriminating a similar change in two female voices speaking the native language (Friendly, Rendall, & Trainor, in press). That finding suggests that initially infants have a broad ability to discriminate among voices. By 7 months (youngest age tested), infants' looking following habituation increases if they hear a change in the voice speaking adult-directed sentences in their own native language (Dutch) but not if the change is in voices speaking a foreign language (Japanese or Italian) or if the native speech track is reversed to eliminate the native phonology and rhythm (Johnson, Westrek, Nazzi, & Cutler, 2011). Between 6 and 12 months, infants' discrimination of human voices speaking the native language improves, while their discrimination of rhesus monkey voices declines (Friendly et al., in press). During this period, infants shift their fixation patterns from predominantly fixating the eyes, as they did at 4 months, to predominantly fixating the mouth, presumably in order to gain visual information about the speech they hear (Lewkowicz and Hansen-Tift, 2012). At 12 months, this preference is gone for voices speaking the native language but persists for a foreign language, perhaps because the infant no longer recognizes its vocalizations as speech sounds. Combined the data suggest perceptual narrowing for voice recognition to own-species and own-language, although the evidence for an initial broad ability is scanty. Infants younger than 6 months have not been tested on the ability to discriminate two voices speaking a foreign language or two non-human voices.

It is of interest to consider how perception of voices speaking the native language interacts with face processing. In a series of studies, Kinzler and colleagues have shown that as early as 5 months of age, when shown two Caucasian faces, one paired with a sound track in English and the other, with a sound track in French, infants in the U.S. later prefer to look at the face that was speaking English while infants in France later prefer to look at the face that was speaking French. By 10 months, infants prefer to take a toy from the woman whose face was first presented along with their native language (Kinzler, Dupoux, & Spelke, 2007; Kinzler & Spelke, 2011). Still, infants do know that faces of unfamiliar races typically belong to people speaking an unfamiliar language, as shown in two recent studies in which infants were shown side by side faces, and looked longer at the face of their own ethnicity when hearing their own language, and at the face of an unfamiliar race when hearing an unfamiliar language (May & Werker, 2013; Uttley et al., 2013).

In an intriguing study, it has also been shown that infants aged 5 months show a preference for looking at human faces over duck or monkey faces when they hear human voices, and also at monkey faces over human or duck faces when they hear monkey calls (Vouloumanos, Druhen, Hauser, & Huizink, 2009). They do not show a similar preference for duck faces when they hear duck calls. It is suggested that knowledge of the structural properties of human faces and voices not only supports the matching for humans, but also the matching for monkey faces through a constrained generalization mechanism. Whether these sensitivities are present at birth has not been addressed. However, it is known that the ability to match monkey faces with monkey calls declines in later infancy (Lewkowicz & Ghazanfar, 2006).

Training

Perceptual narrowing for faces is easily prevented or reversed during the first year of life by training with individual items from the non-native category. Thus, frequent exposure to individually named monkey faces between 6 and 9 months is sufficient to preserve the discrimination between two Barbary monkey faces at 9 months, when infants are tested with the same method that demonstrated perceptual loss without such exposure (Pascalis et al., 2005). Mere exposure to the monkey faces or labeling each of them as "monkey" is insufficient, likely because, unlike individual names, neither calls attention to the individual face but instead encourages attention to the category "monkey" (Scott & Monesson, 2009). This is a similar effect to the pairing of speech contrasts with distinct objects that reactivates sensitivity to non-native phonetic contrasts at 9 months (Yeung & Werker, 2009). Similarly, infants are easily trained to discriminate among other race faces in situations where they initially fail to provide evidence of the discrimination. At 3 months, merely habituating Caucasian infants to three Asian faces, rather than a single exemplar, is sufficient to induce a novelty preference (Sangrigoli & de Schonen, 2004) When infants are exposed to a storybook with six faces of another race (i.e., Chinese faces for Caucasian infants), each with an individual name, between 6 and 9 months of age, at 9 months, unlike a control group exposed to same-race faces (i.e., Caucasian faces for Caucasian infants), they show evidence of discriminating between novel faces from the trained category (i.e., Chinese), even when presented in a novel point of view (Heron-Delaney et al., 2011). As with monkey faces, then, fairly small amounts of exposure can prevent perceptual narrowing during the first year of life.

As with speech (see above), exposure can also reverse perceptual narrowing, at least when it begins during infancy. Thus, as little as 3 weeks of exposure (shortest tested) to a video of Asian female faces beginning around 9 months of age is sufficient to induce evidence of discrimination of both Asian female and male faces in infants who, as expected, failed to show such discrimination on a pre-test (Anzures et al., 2012). In this case, the video involved the presentation of four women, presented two women at a time, to encourage comparison of the differences between them. During each 1-min presentation, the two women took turns talking and singing in an infant-directed manner. What is unknown is how long the preserved or regained discriminations persist without further exposure to the non-native category, nor how easily such training would work after the first year of life. Also, unknown is what are the critical features that made the video effective for reversing the other-race effect while a video for training a non-native Mandarin discrimination was ineffective (see above). It might be that contingent responding is more important for speech discrimination than for face discrimination, that video is more effective earlier in infancy (cf. 9 months for the other-race video vs. 12 months for the Mandarin video), or that some other difference (multiple faces vs. one talker) is important.

After Infancy: International Adoption

For faces, two studies of Asian children adopted into Caucasian European families indicate that there is some plasticity for reversing the other-race effect after infancy, but the results differ on whether a complete reversal is possible. Thus, in a study of Asian adults adopted into French Caucasian families between 3 and 9 year of age, accuracy was better for discriminating Caucasian (i.e., other race) faces than for discriminating Asian (i.e., own race) faces (Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005). In contrast, when tested as children, 6- to 14-year-old Asian children, who had been adopted into Belgian Caucasian families between 2 and 26 months of age, were equally good at recognizing Asian and Caucasian faces, unlike their Belgian peers who were superior for own-race Caucasian faces (de Heering, de Liedekerke, Deboni, & Rossion, 2010). In both cases the other-race effect was changed by the altered experience, but in the study of children it was eliminated while in the study of adults it was reversed. In neither study, were the results nuanced by the age of adoption or the number of years of exposure to the other-race category. The contrasting results raise the intriguing possibility that the system remains plastic after infancy such that the other-race effect can be eliminated over a short-time by a change of the environment but that a reversal takes many more years of experience, or many more stages of tuning, to be effected and hence is not evident until adulthood. Alternatively, a difference in the methods for evaluating the other race effect might be responsible. Crucial to both findings may be the likelihood that the children rarely saw examples from the native category (Asian faces) after the adoption, much like the importance of ceasing to hear the native language on adoptee's acquiring novel speech contrasts and shedding of those unique to the first language (see above).

Adulthood

By adulthood, we have become experts at processing the identity of faces and use specialized mechanisms to do so involving configural processing. That expertise is tuned to familiar face categories, such that we are less accurate not only for inverted, other-species and other-race faces but also for other-age faces. As well, we process faces from those non-native categories less configurally. Experience in adulthood either by training in the lab or natural exposure induced by a change in the environment (becoming a nursery school teacher; going abroad to study) can reduce the difference between native and non-native categories but seems insufficient to eliminate the difference or reverse it. Thus, the amount of time an adult has been exposed to other-race faces correlates inversely with the size of the other-race effect (reviewed in Meissner & Brigham, 2001) but even years of exposure is insufficient to reverse the effect, perhaps because there is likely to have been continued exposure to own-race faces. After training with feedback in the lab, adults improve in discriminating among inverted faces and among other-race faces, but the training generalizes poorly to new examples and still leaves the trainees far better at differentiating upright and own-race faces (de Heering & Mauer, 2013; Hussain, Sekuler, & Bennett, 2009; McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011) perhaps because the training is limited to a few days. When the training is protracted and socially salient because it involves pursuing a profession in which discrimination of individuals is needed, such as becoming a nursery school teacher or a maternity ward nurse, there is more evidence of plasticity even in adults. Thus, unlike typical adults, who are better at discriminating and remembering adult's faces than children's faces, nursery school and trainee teachers remember children's faces as well as they remember adults' faces (Harrison & Hole, 2009).

They also show evidence of processing children's faces more holistically than do typical adults, with the relative strength of holistic processing for children's versus adult's faces correlated with the number of years of experience with children's faces (de Heering & Rossion, 2008; Kuefner, Cassia, Vescovo, & Picozzi, 2008).

A study of Italian maternity ward nurses found that they are better than typical adults in recognizing a newborn face to which they were just exposed, but only if the face is upright (Picozzi, de Hevia, Girelli, & Macchi Cassia, 2010). As a result, their own age bias (better recognition of adult than newborn faces) is smaller than that of controls and, unlike controls, they show an inversion cost for both adult and newborn faces. However, a comparison of Israeli neonatal nurses to a control group of other nurses and librarians failed to find a advantage in long-term memory for the neonatal nurses, who like the controls, were much better at remembering adult than newborn faces (Yovel et al., 2012). There is no ready explanation for the discrepancy—except that the Italian study measured discrimination and short-term retention, while the Israeli study measured memory after a learning phase. In addition, even in the studies with positive results, we cannot rule out the possibility that those choosing such professions have had heightened interest in, and exposure to, the faces of infants and children during development. Nevertheless, like the studies on retraining of non-native phonetic distinctions in adulthood, the data suggest some residual plasticity in adulthood but far less than that present at the end of infancy or even during childhood. That limit is likely to result from a combination of maturational factors that keep the adult brain stable in its tuning to its long-term environment and of the difficulty of altering a brain network that has learned from experience to be specialized for a native category. Before the stabilization of such a complex network, change will be easier to effect.

COMPARISONS AND CONCLUSIONS

In summary, in this review we have considered the construct of "Perceptual Narrowing" with a detailed review and comparison of both speech processing and face processing. At the outset, we noted that while the phrase is useful as a short hand description of a pattern of data, the various groups who use the term may be operating under different hypotheses about what it in fact means. Throughout this review, we attempted to highlight key research results that are relevant to our conceptualization of the term, and of its limitations. We continue to maintain that if the phrase "Perceptual Narrowing" is used, it is essential to note that there is not only a decline in perception of non-experience stimuli, but also improvement in perception experienced stimuli, as suggested in the original Gottlieb/Aslin term "attunement". As well, it is essential for understanding what is meant by "Perceptual Narrowing" to specify what perception looks like at the outset of experience (assuming that can be determined), what the influences are that lead to change, whether there are maturational constraints on the timing of change or whether it is driven entirely by the amount of experience, and just how permanent any loss of sensitivity is. And finally, it is useful to consider the limits to comparability across different types of perceptual tasks, that is, is phonetic discrimination really comparable to face discrimination?

Our review indicated that for both language and faces, the newborn has relevant attentional biases: toward listening to speech and looking at faces. However, in neither case is the preference highly specific: for speech it extends to rhesus monkey calls and for faces it can be largely explained by general visual biases. Nevertheless, both biases guarantee that newborns will attend to the faces and sounds of their caretakers and, by 3 months of age, the preference has become specific to human faces and voices. One important difference is that the newborn has already had 3 months of exposure to human language in the womb, whereas visual experience begins at birth. The language heard in the womb is effectively filtered to eliminate speech sound contrasts (i.e., consonant or vowel distinctions) but nevertheless—at least toward the end of pregnancy—contains sufficient patterned information for the fetus to learn to recognize the mother's voice, the native language, and a story read repeatedly during pregnancy. A focus on this experience could lead one to suggest that many of the biases shown at birth reflect that prenatal listening history, and indeed some—such as the preference for the maternal voice and maternal language—do. Yet there are other aspects of neonatal speech processing that cannot be easily explained in that way. For example, infants discriminate both native and non-native consonant and vowel contrasts at birth, even though the non-native sounds have not before been heard. Similarly, while bilingual exposed neonates show a preference for both of the languages they heard in utero, they are none-the-less still able to use rhythmical differences to discriminate them, suggesting that experience cannot overwrite that bias.

On being born, the infant not only receives the first patterned visual information, but receives much of it coincident with auditory information from moving lips.

Such temporal synchrony may aid the initial coordination of auditory and visual information (Lewkowicz, Leo, & Simion, 2010). Importantly, however, even when the auditory and visual choices are both in synchrony, infants look preferentially to the moving face that matches the heard speech (Kuhl & Meltzoff, 1982, 1984; Patterson & Werker, 1999; Patterson & Werker, 2003; Walton & Bower, 1993), thus indicating that some representation of the redundant phonetic information is also available.

Studies have documented that at 3–6 months of age, the infant can discriminate both native and non-native speech contrasts, both own- and other-species faces and voices, and a variety of other non-native distinctions (lexical tone, sign categories, other-race faces). While many of the consonant and vowel speech contrasts, auditory–visual speech matching, and rhythmical language discrimination have been tested in newborns and in some cases even in premature infants and fetuses, most of the face discriminations have not been tested in infants younger than 3–6 months. Thus, some may represent the emergence of new skills, possibly based on maturation, but likely also triggered by experience with faces and voices. Thereafter, there are examples of the phenomenon of perceptual narrowing that appear to fit the maintenance/loss model in the sense that younger infants show evidence of discrimination between items of non-native categories while older infants fail the same tests. Examples reviewed here include animal faces (monkeys and sheep), other-race faces, consonants, vowels, lexical tone, visual language, and the matching of speech to articulating faces. However, the ease with which the lost discriminations can be re-established during the period when they normally decline (by increasing the exposure time during the test or a brief period of training) suggest that these examples of perceptual narrowing are better thought of as attenuation and/or reorganization rather than loss. The evidence that items from native face categories are processed differently at 9 months than they were at 3 months (e.g., attention to the internal features of faces) suggests that it is not mere maintenance that is occurring but rather an induction of new skills and reorganization of existing skills, in part reflected in a shift of attention in the features to which the infant attends and the infant's skill in doing so (e.g., the individual versus the categorical level of faces). The emerging evidence that while passive, statistical learning can more easily change speech sound categories at 6 than at 10-months, and that more communicative tasks are more effective by 9–10 months in boosting discrimination of non-native sounds (i.e., both social engagment and the co-occurrence of distinct speech sounds to distinct objects) raises the possibility that there may be some representational redescription in the case of speech sounds as well. None-the-less, there are differences: in later childhood and adulthood, other race face discrimination can still be reacquired with training and sufficient exposure, whereas some phonetic distinctions continue to be difficult, even with substantial training.

There are differences in the timing of perceptual narrowing within both the domains of language and faces. For example, signs of narrowing are present earlier for other-race faces and vowels than for other-species faces and consonants. Some of these differences may reflect merely differences in methodology (e.g., whether or not external features are present). However, the vowel versus consonant timing may also reflect the salience of the distinction, its prevalence in the infants' environment, and/or the distribution of examples the infant hears. (No comparable studies have been done for faces.) Other differences in timing may occur when the infant appears to treat the non-native category as outside the domain of language or faces, as appears to be the case for clicks and may be the case for other-species faces at 6 months of age.

It is of interest to consider the extent to which these differences in timing of perceptual narrowing represent differences in the simple accrual of experience versus more maturationally determined constraints. As noted above, some aspects of speech and faces may be more frequent and/or more salient than others, hence supporting the more rapid accrual of experience. Yet, it is also known that within both the visual and the auditory systems, not all sensitive/critical periods open and close at the same time. It is thus quite conceivable that within the domains of face and of speech processing there are multiple, cascading windows during which experience plays the most robust role. Indeed, in the case of speech it is known that infants attune to the rhythmical properties of the native language before the segmental ones, and within the segmental domain, to vowels ahead of consonants. And, it has been suggested that the earlier tuning to the rhythmical properties may position the infant to better pull out the segments. Future work on "perceptual narrowing" could thus benefit from a more detailed consideration of what differences in timing mean.

As summarized so far, across language and faces there are similarities in the attenuation of discrimination for non-native categories; the development of enhanced skills for native categories, driven at least in part by experience; and variations in timing that may reflect differences in the amount or clarity of input or shifts in infants' attention. Where the data diverge is on the malleability of timing and the related issue of whether there is a critical or sensitive period during which perceptual narrowing occurs. The data on language support a biologically based timetable that is not accelerated in preterm infants despite up to 3 months of additional experience hearing consonant contrasts, and that can be accelerated by exposure to SSRIs and retarded by maternal depression or exposure to a diet lacking essential fatty acids. Those patterns are consistent with a critical period model in which neurochemical changes trigger the onset and end of a critical period during which experience tunes the brain to match the environment (Hensch, 2005; Morishita & Hensch, 2008). The data on faces support a learning model in which the induction of complex processing for one category prevents later learning of a second category: face-deprived monkeys are able to discriminate between monkey or human faces, even as late as 2 years of age and it is only after 1 month of exposure that the monkeys showed perceptual narrowing to the exposed category. These data easily fit a learning model of perceptual narrowing in which the tuning of a neural network for one category makes it difficult to alter connections to encompass a second category. They imply that even if there is a critical period for perceptual narrowing for faces (in monkeys), it is not triggered by maturation or even general visual experience, but rather its timing is delayed until there is exposure to relevant stimuli, much like the delay in the critical period for basic vision in animals by dark-rearing (Cynader, 1983; Mower, Berry, Burchfiel, & Duffy, 1981; Timney, 1987; Timney, Mitchell, & Giffin, 1978). The implication is that perceptual narrowing for different categories is not governed by a single critical period but rather its timing depends on when relevant input is received.

Although in the last paragraph we presented data favoring a biologically based timetable for language and an experientially based timetable for faces, we need to point out that comparable experiments have not been done in the two domains. There have been no studies of humans raised in an acoustically rich environment without exposure to language or studies of perceptual narrowing for faces in preterm babies, or those exposed to SSRIs or other conditions likely to alter the timing of critical periods. Moreover, there is evidence that the details of the environment (salience, frequency, distribution) affect the timing of narrowing for language.

In conclusion, perceptual narrowing is a useful label for describing a phenomenon observed across a number of domains during the first year of life, but it is not the only developmental pattern observed nor does it describe a single process or explain the causative mechanism.

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