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Development of Face Processing:

Are there Critical or Sensitive Periods?

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Abstract

The existence of critical or sensitive periods has been argued for cognitive functions such as language, which allows for communication with conspecifics. Faces also play a crucial role in establishing social communication. Here we discuss if either critical or sensitive period concepts apply to face processing. We first describe how experience shapes the face processing system during development. Our reading of the literature is that while there is not support for the existence of a critical period, there is some evidence of a sensitive period, with the face processing system showing early sensitivity to the effects of experience in the first year, remaining flexible until 10-12 years of age, and becoming less sensitive to the effects of experience thereafter. We also discuss possible links between the sensitive periods for faces and language. We conclude with the idea that sensitive periods may reflect balancing of the need to adapt rapidly to the communication culture within's one native social group, while retaining some degree of openness to the possibility of perturbations to one's local environment that can occur across the lifespan.

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Interactionist accounts of perceptual development describe the combination of genetic endowment and postnatal experience needed to account for how given a given ability reaches a mature phenotype. Important for such accounts is the specification of the timing of experience, and the associated concepts of critical and sensitive periods. A critical period is a time window during development when a particular experience must be undergone for complete development to occur [1]. The softer, sensitive period concept refers to a time window when one is maximally sensitive to the effects of experience [2].

Support for the existence of critical or sensitive periods has been documented for cognitive functions essential for social communication [3]. Notably, language is among the systems that allow individuals to adapt to a social group that has developed a culture of communication, and in particular, to become specialized for interacting with social stimuli at hand in the closer environment [4]. A handful of studies have investigated language development in children and adolescents that were deprived of first language input from birth because they grew up in isolation or with uncorrected hearing impairment or both [5, see also 6 for a commentary]. Results demonstrated that these developmental populations exhibited great difficulties in learning language afterwards, notably showing severe and unchanging syntactic impairment (i.e., compromised ability to comprehend and produce a combination of words organized into a meaningful sentence). While the acquisition of vocabulary seems to remain possible throughout the lifespan, the existence of critical or sensitive periods for language learning is also supported by studies examining such linguistic processes as phonetic learning, language discrimination,

and audiovisual speech perception [7]. Results show that predominant exposure to one's native language during the first year of life greatly lessens the initial infant universal discriminatory skills to the one predominant in the environment [8]. However, it is important to add that there is no *definitive* answer as to whether language development undergoes critical rather than sensitive periods or both. This is because it is not possible to completely isolate a child only from language input, without suppressing primary sensory inputs (auditory and visual) and social interactions. Nevertheless, one can counter argue that all of the above are necessary ingredients for the full development of language. Overall, then, at a macro level, given a broad construal of the range of deprivational experience that can curtail ability, we will consider that language undergoes sensitive periods during its development [see 7 for further discussion]. However, at a more micro level, we also recognize that language is a complex multimodal cognitive function that can be decomposed into more specific abilities, some of which may have critical and sensitive periods and others not.

Faces also play a crucial role in our social life, in terms of adapting rapidly to one's group social habits and communication traditions. Recognizing that someone is human, from a specific gender or racial group, is indeed central to identifying individuals, as well as for directing appropriate behavior or interpersonal interaction, and can be done based on faces. There is a general consensus that during development, we become 'face experts' and the immature face processing system present at birth is modulated by experience [9,10,11,12,13].

The goal of this paper is to discuss whether there are critical or sensitive periods in the development of face processing. Face processing includes attention (i.e., orienting to a face and gazing at it, inclusive of scanning of its features), categorization (i.e., sorting faces into different

groups), and recognition (i.e., individuating specific faces). To examine the effect of experience on face processing, researchers have made use of naturally occurring asymmetries, where some categories occur with greater frequency than others. We concentrate here on face race because it has been the most widely investigated social category and has the most pronounced asymmetry with many infants around the world experiencing own- and other-race faces in a greater than 9:1 ratio [14,15]. Another approach to investigating experiential influence on face processing has been to study individuals with congenital cataracts who have had surgical correction for those cataracts at different ages [16,17,18]. One further study with laboratory animals used controlled deprivation with faces to understand the influence of experience on face processing [19]. Lastly, influential studies exploring potential links between experiential effects on face and oral language processing are highlighted. Faces and oral language are temporally and spatially bound, given that the speech signal emerges from the talking mouths of faces [20]. As such, they are both essential for human social communication [4]. We therefore explore how face and language processing might influence each other while both systems are undergoing experience-based developmental change [21] and explore how different types of language specific experience (e.g., bilingualism) influence face scanning and recognition. We turn now to a review of the relevant studies.

Impact of experience on face processing

Experience affects face processing soon after birth. In the case of face race, 3-month-old infants having more experience with own-race than other-race faces look more at own-race over other-race faces [22,23]. For recognition, which is measured in infants by familiarizing with one face from a given race and then determining if a novel face from the same race is preferred over the familiar face, 3-month-olds recognize faces from multiple races. However, with increased

exposure to own-race faces and lack of exposure to other-race faces, older infants from 6 to 9 months of age gradually “lose” the ability to recognize other-race faces but maintain the ability to recognize own-race faces [24,25]. This development is thought to reflect the onset of the Other Race Effect (ORE) observed in adults, i.e., the lessened face processing abilities for faces from another racial group. The developmental pattern of greater to lesser sensitivity is also called perceptual narrowing, and is analogous to experience-induced changes in the ability of infants to discriminate native language features better than non-native language ones [4,6,21,26]. Perceptual narrowing additionally occurs with category formation, which is measured in infants by familiarizing with multiple faces from a given race category and then determining if a novel face from a novel race category is preferred over a novel face from the familiar category. Between 6 and 9 months, infants transition from representing categories for different classes of other-race faces based on facial physiognomy to representing own-race faces in one category and all other-race faces as a single broad “other” category [27]. If experience is shaping the face processing system in the early months, the existence of sensitive or critical periods remains a reasonable possibility to consider for rapid tuning to the proximal environment [28]. Moreover, given different timings for developmental change in preference and recognition, there is the possibility of multiple periods of differential sensitivity to experience for different face processing capacities, just as there may be multiple periods of differential sensitivity to experience for different language processing capacities [7].

Are there critical periods in face processing?

The most direct way to address this question would be to access a population who has not seen faces for a long period since birth. Maurer and collaborators have tested patients who were deprived of early visual experience because they were born with dense cataracts in both eyes,

preventing experience with patterned input, such as faces [16]. Surgery took place a few months after birth, and full vision was delayed until then. When tested later in childhood or adulthood, patients treated for bilateral congenital cataracts were found to have deficits in visual acuity and motion sensitivity, and process faces differently and less efficiently than controls, even though recognition of objects from other visual classes such as houses was preserved. This research indicates that even a brief, transient phase of visual deprivation early in life, which prevents facial input, leads to long lasting changes in face-processing abilities. In a study with a longer period of deprivation, five patients who were blind because of dense cataracts until 9 to 17 years learned to categorize faces after corrective surgery, suggesting some flexibility may exist for the categorization aspect of faces [17]. Notably, these patients were not tested on face recognition. Moreover, an additional group of cataract patients with a comparable of deprivation lasting up to 14 years did not display an electrophysiological signature of responding to faces (i.e., N170) [18]. However, the period of deprivation was not face specific, so it is then impossible to determine if the deficit observed is linked only to not seeing faces or more generally to an atypical development of the visual system [29], although as noted above, such a critique can be countered with arguments for a contribution from domain-general visual abilities to face processing [30].

Non-human primates, have been used as a model of human face processing [31], and comparative studies can suggest a common evolutionary route for face processing. One study by Sugita [19] may best illustrate the critical role of experience in the development of face processing in macaques. Infant Japanese macaques (*Macaca fuscata*) were separated from their parents at birth and reared by humans for a period of 6 to 24 months. During this time, the monkeys had no interaction with other monkeys, and the human caregivers wore whole face

masks to ensure that the monkeys were not exposed to faces of any kind. Following the face-deprivation period, monkeys were then either introduced to fellow macaques or humans, and face learning was allowed to commence. When tested for face preference during the deprivation period, monkeys showed a preference for both monkey and human faces over objects, but no preference for either category of faces when presented simultaneously. Furthermore, monkeys were able to recognize familiar monkey and human faces, as measured with a standard recognition paradigm, despite no previous exposure with any such faces. However, when the monkeys were tested a month after termination of the deprivation period, their behavioral performance had altered dramatically. Monkeys exposed to human faces retained their preference for human faces over objects, but they also preferred to look at human faces over monkey faces. The monkeys exposed to monkey faces preferred monkey faces over objects, but showed no preference when human faces and objects were presented simultaneously. Furthermore, when tested for recognition, monkeys were only able to display recognition for faces from the category to which they were exposed. Details about later face processing abilities in this population of monkeys are lacking, but the pattern of results from the Sugita study suggests that even after a long period of deprivation, face processing remains intact and retains a normal pattern of sensitivity to experience, providing evidence against the idea of a critical period for face processing.

Are there sensitive periods in face processing?

Using face race as the model because of the available data, one can ask whether being raised in a multiracial population influences the face processing system? In one study, 3-month-old Caucasian infants who had experienced both African and Caucasian faces did not show a visual preference for Caucasian faces [32], indicating that experience with another race of faces is

sufficient to null an own-race preference. In another study, development of the ORE in face recognition was investigated in 4- and 9-month-old Malaysian-Chinese infants who were exposed to both Malay and Chinese faces (primarily female) [33]. They found that 4-month-old infants only recognized female own-race faces, whereas 9-month-old infants recognized both own- and other-race female faces. Being exposed to two categories of faces from an early age had allowed the infants to maintain the ability to process other-race faces after 9 months of age. Moreover, the typical decline in the ability to discriminate other-race faces can be prevented and even undone if individuation-based experience with other-race faces via picture books or videos is provided by 6 or 9 months of age [34, 35].

What is the effect of contact with various kinds of faces in older participants, children, teenagers, or adults? Relevant research has examined until what age the face processing remains plastic enough to “re-learn” to process other-race faces by testing adults who were exposed or not exposed to other-race faces during their primary school years [36]. A key finding was that the ORE was reduced with increasing other-race contact, as long as that contact occurred before approximately 12 years of age. Moreover, participants without experience with other-race faces during childhood who were exposed to other-race faces for a long period (up to 5 years), still had difficulties recognizing other-race individuals as adults [see also 37]. That sensitivity to experience remains high up through age 12 would also encompass a change in the faces experienced from caregivers to peers [38, 39, 40, 41].

We can further ask whether a category of faces learned during childhood can be lost later if exposure is reduced? Two face recognition studies were performed on participants who were adopted at various ages in a different country than their native one and exposed to a different,

predominant category of faces. In particular, Asian children who were adopted by Caucasian families from infancy showed recognition for both Caucasian and Asian faces in comparison with age-matched (Caucasian) controls who recognized Caucasian faces better than Asian faces [42]. In a separate study, whereas Korean adults raised in Korea showed a standard ORE in recognizing Korean but not Caucasian faces, a complete reversal of the ORE was found in Korean adults who were adopted as children and raised with Caucasian families for approximately 23 years [43]. These studies suggest that the face processing system remains flexible into childhood, thereby allowing for learning unfamiliar categories of faces. However, if a specific category of faces completely disappears from the environment, the system may lose processing capabilities for it. Overall, this kind of sensitive period presents similarities with the one observed for language.

Training studies performed with adults are also relevant to the issue of sensitivity to the effects of experience across the lifespan. Studies have found that different training paradigms involving individuation with other-race faces can reduce the other-race effect, although the beneficial effects seem to be temporary, for example, present in immediate discrimination, but not recognition memory tests (44). Moreover, such training in adults has been shown to produce an immediate reduction of implicit racial bias against the trained other race, presumably disrupting the tendency to respond to members of other-race classes at a categorical level (45). However, in adults, such reduction tends to last only for a few days (46). Yet, in preschool children, a recent study has shown that individuation training can produce a reduction in bias for up to two months (47). The set of training results taken together is consistent with the idea of a sensitive period in that there is evidence for a heightened early sensitivity that can yield change of significant duration followed by moderated sensitivity that yields change of lesser duration.

Is there a link between face and spoken language narrowing?

We have argued here and elsewhere that narrowing can be conceived of as a process that allows the infant to become more efficient or specialized for social stimuli present in their environment, whether those stimuli are instantiated in spoken language or faces [4,48]. As a consequence, face and language processing become linked and may influence each other. This suggestion is supported by the observation that in everyday life, learning of face-language associations is reinforced by own-race faces talking in children's native language and other-race faces talking in a non-native language. It is also supported by a study with infants that used a within-subject design to track narrowing in both the language and face domains [21]. The key findings were that narrowing for face race (own vs. other) and narrowing for speech (native vs. non-native) were not correlated at 6 months, negatively correlated at 9 months, and positively correlated at 12 months (see also 49). This evidence suggests that the systems are initially not linked but come to influence each other in different ways at different times. It is possible that they compete with each other for limited attentional capacity at 9 months, but subsequently facilitate each other at 12 months with increased attentional capacity [20] and greater Hebbian association across systems, where stimulation of one system leads to cortical activation in the other system [50].

If face and language systems interact during their sensitive period, does a distinctive experience for one system influence how the other explores and processes its environment? So far, only a few studies have investigated this question unidirectionally, by testing whether exposure to a bilingual environment, instead of a monolingual one, influences how individuals pay attention to and recognize human faces. In particular, evidence from infants growing up in a bilingual environment shows that they look more at the mouth region of talking and non-talking faces than same-age monolingual infants [51,52,53; see also 54 for a more nuanced view]. These outcomes

provide further support for the conclusion that visual exploration of faces is specifically constrained by the particularities of the language environment infants are exposed to. Moreover, one study conducted in adults suggests that bilingualism influences not only face scanning but also face recognition [55]. With the use of a classical ORE paradigm, it was reported that bilingual adults exhibit a weaker ORE than their monolingual peers. This finding suggests that exposure to more than one language leads, at least in adulthood, to a specific perceptual organization that goes beyond language processing and extends to the analysis of face configurations. However, in infancy, while the sensitive periods for face and language processing are still presumably open, one study comparing monolingual and bilingual 11-month-old infants did not show an effect of bilingualism on the ORE, which was found to be present in both groups of infants [56]. Additional research should further explore not only the influence of language experience on face narrowing, but also the influence of face experience on language narrowing. Such inquiries could improve our understanding of the processes that allow sensitive periods for faces and language to begin, continue, and end.

Conclusion and directions for future research

From our review of the literature, there is some evidence of a sensitive period for face processing. However, there is no evidence of a critical period, as the face processing system remains flexible for an extended period of time. From a functional perspective, it may be that face processing developmental systems, like language processing developmental systems, have been designed by natural selection to tailor an individual's cognition to the local social context [4]. For aspects of this context that tend to remain stable within a single lifetime, we may expect systems to rapidly become efficient at processing locally relevant information. For aspects that tend to vary within a single lifetime, we may expect continued plasticity. These observations fit

with findings of early sensitivity (within the first year) to the effects of experience and consequent perceptual reorganization. They also correspond with extended sensitivity beyond the first year, and even some degree of malleability in adulthood.

Overall, for the field to make headway in further specifying a sensitive period for face processing, a more systematic approach is needed to compare sensitivity to experience within the proposed sensitive period (up to 10-12 years of age) with sensitivity to experience after that period. Also, given the possibility of multiple sensitive periods for different aspects of face processing, such an approach would allow for refinement of more precise time-windows and their correspondence with various aspects of face processing (e.g., attention, categorization, recognition). We additionally need to better understand the link between sensitive periods and the development of an effective communicative system that combines multimodal cues from faces and language. Finally, we need to better understand the neurocognitive mechanisms responsible for sensitive periods, and how specific experience with multiple categories of faces or multilingual environments or both influences the development of face processing.

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Research Highlights

Literature suggests the existence of a sensitive period until 10-12 years of age

However, there is no evidence of a critical period for face processing

Some evidence suggests that face and language sensitive periods interact

Studies need to determine if specific face processes have distinct sensitive periods

Future research should investigate links in sensitive periods for faces and language