

Enhanced Prototype Formation for Other-Race Faces in Infancy: Developmental Trajectories and Environmental Adaptations

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Abstract

Face prototype formation plays a pivotal role in translating face experience into robust internal representations. However, the early developmental trajectory and experiential influences on this cognitive capacity remain underexplored. Across five within-subject experiments conducted in Canada and China across different time periods, we investigated how face race and environmental context modulate infant prototype formation. Using a novel prototype formation paradigm, we discovered infants consistently exhibited stronger prototype formation for unfamiliar other-race faces compared to own-race faces, and this bias increased significantly with age. Furthermore, we demonstrated remarkable plasticity. Infant cohorts tested during and after COVID-19 lockdowns show opposite age-related trajectories in face prototyping, reflecting differential environmental exposure to diverse faces. These findings illuminate the experience-dependent nature of early face processing specialization, suggesting infants' prototype formation dynamically adapts to optimize face processing within specific environments. We discuss implications for understanding the developmental origins of face processing biases and potential social consequences.

Keywords: face processing; prototype formation; other-race; infancy, summary statistical learning; COVID-19

Introduction

A fundamental objective of cognitive development is the continuous transformation of external experience into robust internal representations. This is especially evident in the early development of face processing, where experience with particular face categories (e.g., own-race faces) shapes perceptual specialization during infancy. For instance, studies have consistently demonstrated that infants progressively develop specialized face processing abilities throughout the first year of life, ostensibly as a consequence of accumulating visual experience (e.g., Kelly et al., 2005, 2007b; Quinn et al., 2016). Despite this converging evidence highlighting the experiential origins of face processing specialization, the precise mechanisms mediating this developmental trajectory remain incompletely understood (Xiao et al., 2024).

To address this gap in knowledge, the present study investigates the role of face prototype formation in early face processing development during the first year of life. Face prototype formation refers to the implicit statistical learning process by which individuals construct an averaged

representation, or "prototype," that encapsulates the commonalities across a set of encountered faces. This prototype serves as an internal reference, facilitating the efficient recognition and categorization of novel faces by enabling comparisons to this abstracted representation. Specifically, the current study examined whether face prototype formation is modulated by variations in face familiarity (e.g., own-race versus other-race faces), whether its characteristics evolve developmentally across infancy, and whether it exhibits adaptive plasticity in response to significant environmental changes in face exposure. To this end, we conducted five experiments with infant cohorts in both Canada and China. Through these investigations, we aim to elucidate the developmental trajectory of face prototype formation. We also seek to illuminate how this early learning mechanism contributes to the emergence of sophisticated face processing capacities in infancy.

Face prototype formation is recognized as a foundational cognitive process that underpins the efficient mental representation of facial information encountered in the environment. Research suggests that this capacity operates implicitly yet robustly. For example, Cabeza et al. (1999) demonstrated that adult participants, after exposure to multiple face exemplars, exhibited an increased tendency to falsely recognize a never-seen prototype face. Such results indicated the implicit abstraction of a prototypical representation. This process further facilitates the extraction of commonalities across faces within specific categories. Computational models, such as Principal Component Analysis (PCA), have illustrated how individuals can encode and summarize facial features that define group-specific prototypes (Gao & Wilson, 2014). Developmental studies then extended these findings, demonstrating that prototype formation emerges early in ontogeny (e.g., Inn et al., 1993; Gao et al., 2015). Together, evidence from both adult and developmental populations underscored the critical role of prototype formation as a key mechanism in face learning.

Building upon the established understanding of prototype formation in older children, where research has highlighted a pronounced developmental trajectory (e.g., Gao et al., 2015), a critical question arises regarding the ontogeny of this capacity. Is face prototype formation operative earlier in infancy, and if so, what role does it play in the early stages of face processing development? Indeed, while investigations

into prototype formation in infancy remain comparatively sparse, a nascent body of work suggests its presence and potential relevance to early face perception. For instance, Damon et al. (2017) provided preliminary evidence for prototyping abilities in infants. Participants demonstrated stronger visual attention towards face stimuli perceptually proximal to a prototype. Furthermore, de Haan et al. (2001) showed that even 3-month-old infants exhibited recognition of averaged faces derived from previously viewed exemplars. While these initial findings are informative in establishing the existence of prototype formation abilities in early infancy, they do not definitively elucidate the functional significance of this capacity in driving the development of face processing expertise. It remains unclear whether prototype formation in infancy serves as a critical mechanism shaping experience-dependent face processing outcomes, or whether it represents a more peripheral, or even epiphenomenal, aspect of early perceptual learning. Thus, further investigation is warranted to determine the precise contribution of face prototype formation to the developmental trajectory of infant face processing.

To address the aforementioned gap in our understanding, the present study proposes face prototype formation as a key mechanism by which early face experience is translated into the development of specialized face processing capacities. We posit that infants' early experiences with face categories, which are crucial for shaping subsequent face processing abilities (Bar-Haim et al., 2006; Kelly et al., 2007a; Kelly et al., 2007b; Kelly et al., 2005), are effectively processed and organized through prototype formation. If prototype formation indeed serves as a consequential developmental mechanism, particularly in driving experience-dependent outcomes such as perceptual narrowing, it should exhibit several defining characteristics consistent with such a role. Specifically, we hypothesize that face prototype formation should: 1) be modulated by familiarity with different categories of faces, reflecting the influence of experience; 2) undergo age-related changes across infancy, indicative of developmental progression; and 3) demonstrate plasticity in response to variations in environmental conditions, highlighting its adaptive nature.

To examine the influence of face familiarity on prototype formation, we employed a within-subject design. Each infant was presented with both own-race and other-race faces. Face race served as an index of infants' differential real-world experience, allowing us to investigate how varying degrees of exposure to different face categories modulate prototype formation abilities. Furthermore, by recruiting infant cohorts from both Canada and China, we were able to assess the generalizability of the prototype effect across populations where the designation of "other-race" differs. We hypothesized that prototype formation would be modulated by face experience, predicting stronger prototype formation for less familiar, other-race faces compared to more familiar, own-race faces.

To investigate developmental changes in prototype formation, we recruited infants across a broad age range

within the first year of life. This age-diverse sample enabled us to examine potential developmental trajectories in prototype formation as infants approach one year old. Specifically, this approach allows us to explore how perceptual and experiential changes across infancy contribute to prototype formation. We hypothesized that prototype formation for other-race faces would increase with age, reflecting accumulated experience and perceptual refinement.

Finally, to probe the plasticity of prototype formation in response to environmental variation, we recruited infant cohorts during distinct periods: during COVID-19 pandemic lockdowns in 2022 and post-lockdown in 2023. These cohorts experienced markedly different levels of facial diversity in their daily environments due to lockdown restrictions. This naturalistic manipulation of environmental conditions allowed us to investigate the plasticity of infants' statistical learning capacities in response to varying face exposure. We predicted that prototype formation exhibits plasticity, adapting to specific environmental circumstances. Specifically, we expected diminished prototype formation in infants with increased exposure to diverse faces (post-lockdown cohort) and enhanced prototype formation in infants with more homogenous face exposure (lockdown cohort).

General Methods

To examine infants' face prototype formation, we first familiarized them with 12 "family faces" that shared a common appearance, giving the impression that they belonged to the same family. Each family face was created by digitally averaging a prototype face with a distinct individual face. If infants were able to detect the shared features among these family faces, they would form a mental representation of the prototype face, even though it was never shown during the learning phase. To assess whether infants had indeed formed such a prototype, each test trial presented the prototype face side-by-side with a novel face. If infants recognized the prototype face as familiar, they would exhibit a preference for the novel face, thereby demonstrating novelty preference as an index of prototype formation.

During the learning phase, each of the 12 family faces was shown for 3 seconds, yielding a total of 36 seconds (12×3 s). Two test trials followed, each lasting 5 seconds. The positions of the prototype and novel faces (left vs. right) were counterbalanced across the test trials. The total duration of the learning phase (36 seconds) was akin to those used in studies with similar (familiarization) designs (Kelly et al., 2007a). We used a *within-subject design* with two own-race and two other-race blocks presented in an ABBA order. This counterbalancing allows for direct comparisons of face prototype formation under more familiar (own-race) versus less familiar (other-race) conditions. To ensure the generalizability of our findings, we generated 20 distinct sets of own-race faces and 20 sets of other-race faces (800 faces in total). These sets were randomly selected for each participant, and within each set, the family faces, prototype

face, and novel face were all unique. This approach minimized the possibility that any observed effects stemmed from idiosyncratic features of particular face images.

Experiments 1, 1A, and 2 were conducted in the laboratory using the EyeLink 1000Plus eye-tracker to record infants' looking patterns. Experiments 3A and 3B were conducted online, where infants participated in their homes. Their looking patterns were coded from video recordings.

Experiment 1

Participants

Forty-two (17 females) infants participated in Experiment 1. These infants ($M_{age} = 271$ days, 133 to 356 days, White) were recruited from the Hamilton, Ontario area in Canada. According to the 2021 census, seventy-five percent of individuals in this region are White, while 25% identify as non-White. These data were collected between November 2022 and August 2023.

Results

Infants demonstrated a pronounced novelty preference ($M = 0.57$, $SD = 0.13$, one-sample $t(41) = 3.34$, $p = .002$, Cohen's $d = 0.52$) when viewing other-race faces but not in the own-race condition ($M = 0.51$, $SD = 0.15$, one-sample $t(41) = 0.54$, $p = .592$, Cohen's $d = 0.08$). A paired-sample t -test revealed that the difference between the own- and other-race conditions was significant ($p = .044$, $t(41) = 2.08$, Cohen's $d = 0.32$) (see Figure 1A).

We found that infants tended to form prototypes of other-race faces, but not for own-race faces. These findings suggest that differential experience with faces can lead to a greater tendency for prototyping. Infants may have less visual experience with other-race faces and thus see them prototypically. On the other hand, own-race faces may be viewed more individually. Infants may have more experience viewing and interacting with own-race individuals, requiring the need to individuate between faces.

Experiment 1A

Here we attempted to replicate the finding of Experiment 1 with a cohort of Asian infants. For Asian infants, Asian faces would be familiar, and White faces would be unfamiliar. A replication would determine whether it is the familiarity to faces, or a specific face race that led to the enhanced prototype formation.

Participants

Ten (3 female) infants participated in this experiment. These infants ($M_{age} = 323$ days, 180 to 384 days, Asian) were recruited from the Hangzhou, Zhejiang province in China. The population of this region consists of 99.5% East Asian (Chinese) individuals. Five infants were removed from the following analyses due to fussiness during the experiment and 1 infant was removed due to inattentiveness. Further, 2 infants were removed due to issues with calibration (e.g.,

inability to calibrate due to program failure). Finally, 1 infant was removed from the analyses as their novelty preference results were beyond 3 standard deviations from the mean, making this participant an outlier. The data were collected between December 2022 and March 2023.

Materials and Procedure

The materials and experimental procedure of Experiment 1A were identical to that of Experiment 1. While Experiment 1A was conducted in China, the lab environment resembled that of the Canadian lab with identical eye-tracking system and stimuli presentation equipment.

Results

One-sample t -tests revealed that Asian infants demonstrated a significant novelty preference ($p < .001$, $t(9) = 6.56$, Cohen's $d = 2.08$) when viewing other-race faces ($M = 0.59$, $SD = 0.04$). Also, in line with Experiment 1, the same infants did not demonstrate any visual preference in the own-race face condition ($M = 0.49$, $SD = 0.12$, $p = .836$, $t(9) = -0.21$, Cohen's $d = 0.07$). A paired-sample t -test confirmed that infants' novelty preference in the two conditions was significantly different from one another ($p = .038$, $t(9) = 2.43$, Cohen's $d = 0.77$) (see Figure 1B). Chinese Asian infants demonstrated advanced prototyping of other-race faces, not own-race faces, akin to what we found in White infants in Experiment 1. This advanced face prototyping is likely driven by experience with faces.

Paired-sample t -tests on combined data from Experiments 1 and 1A revealed no significant differences ($p = .065$, $t(51) = 1.89$, Cohen's $d = 0.26$) in looking time between own- ($M = 33.39$ s, $SD = 12.87$) and other-race faces ($M = 35.32$ s, $SD = 14.04$).

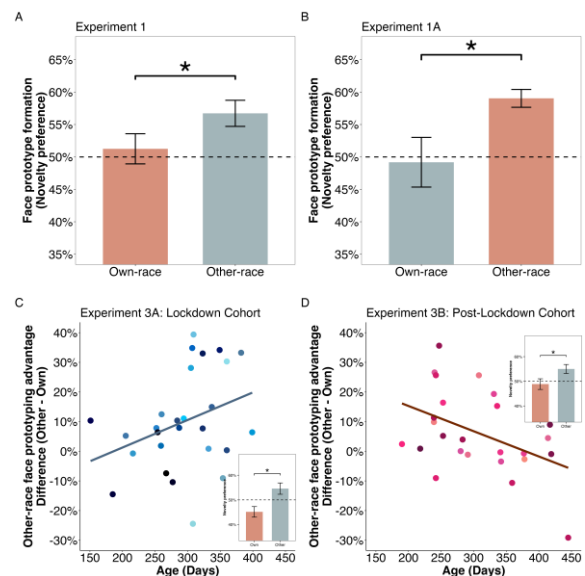


Figure 1. **Panels A & B.** Infants' novelty preference for own- and other-race faces, in Experiments 1 and 1A. **Panels C & D.** Infants' advances of prototyping other-race faces

changed with age in Experiment 3A and 3B. Group-level novelty preferences were shown in the smaller subplots. Error bars represent one standard error to the means.

Experiment 2

Experiment 2 aimed to address if infants' advanced prototype formation for unfamiliar other-race faces reflects a genuine bias in implicit learning or if this result is merely a by-product of their inability to discriminate unfamiliar faces (i.e., perceptual narrowing). Specifically, it is well-known that infants have difficulty recognizing other-race faces in late infancy (Kelly et al., 2007b). This perceptual challenge would possibly lead infants to perceive the family faces as the same person therefore showing a strong novelty preference in the test phase. To verify this possibility, in the learning phase of Experiment 2, we presented the same faces, instead of 12 distinctive family faces, removing the opportunity for infants to form prototypes. Should the inability to distinguish faces cause the advanced novelty preference, we should replicate the findings of Experiment 1s.

Participants

Thirty-five (17 females) infants participated in this experiment. These infants ($Mean_{age} = 295$ days, 187 to 439 days, White) were recruited from the Hamilton, Ontario area in Canada. 1 infant was removed from the following analyses due to inattention towards the stimuli and 2 infants were removed as they were statistical outliers based on standardized Z -scores. The data was collected between February and April 2024.

Materials and Procedure

The materials and procedures were highly similar to those in Experiment 1s except that we showed one family face throughout the 12 learning trials. For each learning trial, we modulated brightness and size of the face images randomly within a range of 85% to 115%. These variations in pictorial properties were implemented to simulate the low-level variations that exist among the family faces in Experiment 1s. As such, participants did not see exactly identical face images across trials. These low-level variations remained identical across experiments. Experiment 2's stimuli lacked natural variations inherent to different family faces, resulting in less visual variance. Differences between faces should be easier to detect compared to family faces. Further, Experiment 2 only used other-race faces, as they were the focus to reveal the mechanism of advanced prototype formation, which was observed only in the other-race conditions in Experiment 1s. Like Experiment 1s, each participant was tested with two blocks using unique set of faces.

Results & Discussion

We used the same one-sample t -test to examine infants' visual preference in the test phase. Their visual preference remained at the chance level ($M = 0.50$, $SD = 0.12$) and did not reach statistical significance ($p = .965$, $t(34) = 0.05$,

Cohen's $d = 0.01$). To further evaluate infants' visual preference, we directly compared the visual preference of this experiment with that in Experiment 1, given that both experiments were conducted in the same lab and participants were recruited from the same region. Using an independent-sample t -test, we found a significant difference in infants' visual preference between the two experiments (independent-sample t -test: $t(75) = 2.33$, $p = .022$. Cohen's $d = 0.53$; Experiment 2: $M = 0.50$, $SD = 0.12$; Experiment 1: $M = 0.57$, $SD = 0.13$, $p = .002$, $t(41) = 3.34$, Cohen's $d = 0.52$). These results suggest that the novelty preference found in Experiment 1s was unlikely to be caused by infants' inability to distinguish other-race faces. Thus, infants' perceptual ability is not the cause of the advanced prototype formation. This result provides further support for the notion that it resulted from the prototype formation process, in which infants engaged strongly for unfamiliar other-race faces than familiar own-race faces.

Experiment 3A & 3B

Experiment 3s aimed to explore the early developmental trajectory of the face prototype formation by focusing on how the impact of face-race change over the first year of life. Moreover, we examined the plasticity of the developmental trajectory by focusing on two cohorts. The first cohort were recruited during the COVID-19 pandemic (the Spring & Summer of 2022, Expt 3A) and the second cohort were recruited one year after the COVID-19 pandemic (the Spring & Summer of 2023, Expt 3B). Infants had drastically different visual experiences caused by policies implemented during the COVID-19 pandemic, such as lockdowns. Even though we recruited from the same multi-cultural society, the lockdown (2022) cohort had more restricted exposure to people beyond their family members (i.e., own-race faces) as compared to the post-lockdown (2023) cohort, who had much broader exposure to other-race faces in their visual environments. Should prototype formation play a pivotal role in driving early development, we expected these cognitive capacities to exhibit strong adaptation to the environment, thereby demonstrating contrasting developmental trajectories between the two cohorts.

Participants

Experiment 3A recruited 28 infants (15 females, ($Mean_{age} = 285$ days, 139 to 399 days, White) from the Southern Ontario area in Canada. The data was collected between January and May 2022. Experiment 3B recruited 25 infants (13 females, $Mean_{age} = 307$ days, 190 to 445 days, White) from the same region. One infant was removed from the following analyses as neither of their caregivers were White. These data were collected between June and August 2023.

Materials and Procedure

The experimental materials and program of Experiment 3s were identical to that of Experiment 1s. Infants and parents participated in this study on their own computers from home. The experiment was developed with PsychoPy and hosted on

Pavolia online test platform. As infants were participating the study, we recorded their looking behaviours with Zoom video conference software. Infants were seated on their parents' lap and positioned to be in the middle of their device's screen. Prior to the study, infants' looking direction was calibrated with a 12-second calibration procedure, in which a colourful target would move from side-to-side on the screen twice. The same online testing procedure was used in recently published studies (e.g., Kim et al., 2024).

Results & Discussion

Infants' looking behaviour was coded by independent coders using Datavyu software (Datavyu Team, 2014). Coders were blind to the face stimuli being presented and could only see the infant on screen. Coders would label infants' looking behaviour as looking to the right or left of the screen, looking at the center of the screen, or not codable (e.g., infant was looking away from the screen).

For the lockdown (2022) cohort, we used a one-sample *t*-test to examine infants' novelty preference in both own- and other-race conditions. The novelty preference for other-race faces reached marginal significance condition ($M = 0.54$, $SD = 0.12$, $p = .056$, $t(27) = 1.99$, Cohen's $d = 0.38$) and was below the chance level ($M = 0.45$, $SD = 0.11$, $p = .032$, $t(27) = 2.26$, Cohen's $d = 0.43$) in the own-race condition. More importantly, the novelty preference in these two conditions were significantly different from one another (paired-sample $t(27) = 3.00$, $p = .006$, Cohen's $d = 0.57$).

For the post-lockdown (2023) cohort, infants' novelty preference in the other-race condition ($M = 0.55$, $SD = 0.09$) was significantly above chance (one-sample $t(24) = 2.75$, $p = .011$, Cohen's $d = 0.55$). However, the novelty preference in the own-race condition ($M = 0.49$, $SD = 0.11$) was not significantly above chance levels (one-sample $t(24) = -0.53$, $p = .604$, Cohen's $d = 0.11$). Additionally, infants' novelty preference in these two conditions were significantly different from one another (paired-sample $t(24) = 2.20$, $p = .037$, Cohen's $d = 0.44$). Experiments 3A & 3B replicated the findings of Experiment 1s, even when tested remotely. These experiments showed the same advanced prototype formation for other-race faces among infants. Interestingly, infants' own-race preference in Experiment 3A was significantly below chance. However, compared to infants' novelty preference for other-race faces, this finding was not replicated amongst the other experiments.

Age-related changes in infants' prototype formation were also analyzed. To do so, we performed a Pearson correlation between infants' age in days and their advantage for forming other-race face prototypes. This advantage was calculated by taking the difference between infants' novelty preference in the other-race condition and the own-race condition (Novelty Preference_{Other-race} – Novelty Preference_{Own-race}). These difference scores represent the advantage of other-race faces in prototype formation. The Pearson correlation revealed that infants' other-race face prototype formation increased with age ($r = .38$, $p = .049$, see Figure 1C).

Infants' other-race prototyping advantage increased with age. This result aligns with the expected developmental trajectory of infants' perception and categorization of other-race faces. As infants age to 1 year old, they experience increasing difficulty when viewing other-race faces. Moreover, infants in this cohort were tested in 2022, amidst ongoing COVID-19 lockdowns. As such, it is possible that infants had very limited exposure to other-race faces, resulting in an inability to accurately discriminate these faces. With the post-lockdown cohort, the same Pearson correlation analysis was conducted to examine the developmental change in the race-dependent prototyping. In contrast to the finding with the lockdown cohort, we found a negative relation ($r = -.44$, $p = .026$), indicating that infants' other-race prototyping advantage decreased significantly with age in the post-lockdown cohort. That is, with increased age infants' prototyping unfamiliar other-race faces become similar to that of own-race faces (see Figure 1D). Moreover, we performed a follow-up mixed two-way Analysis of Variance (ANOVA) to compare the age effect between cohorts. This analysis revealed significant interactions between age and cohort ($F(1, 49) = 9.48$, $p = .003$, $\eta^2 = .16$). The main effects of age ($F(1, 49) = 0.01$, $p = .939$, $\eta^2 < .01$) and cohort ($F(1, 49) = 0.69$, $p = .411$, $\eta^2 = .01$) were not significant.

We interpreted this age-related change in the context of the racially diverse environment where the cohort grew up within. With the returned-to-normal social interactions, infants of this cohort had much more opportunity to see people of other-race faces. Although the quality and quantity of these other-race exposure or interactions are not on par with those with own-race people (e.g., caregivers), they exerted significant impact on calibrating the implicit learning tendency that underlies the prototyping processes.

General Discussion

With five experiments, this study provided compelling evidence that infants possess a robust capacity for face prototype formation. Consistent across experiments, we demonstrated that this capacity was modulated by face experience, with infants exhibiting a stronger tendency to form prototypes for less familiar, other-race faces compared to more familiar, own-race faces. Critically, Experiment 2 established that this enhanced prototype formation for other-race faces is not attributable to a mere artifact of perceptual deficits in discriminating unfamiliar faces but rather reflects a genuine bias in implicit learning. Furthermore, our investigation across age revealed a nuanced developmental trajectory: in the cohort tested during pandemic-related lockdowns (2022), the prototyping advantage for other-race faces increased with age. In contrast, the cohort tested post-lockdown (2023) exhibited developmental plasticity, demonstrating a diminished tendency to prototype other-race over own-race faces with increasing age.

This study provides critical insights into the developmental origins of the adult and child advantage in other-race face categorization (e.g., Ge et al., 2009; Woo et al., 2020). While prior work has often attributed this advantage to impaired

other-race face discrimination, our infant data challenges this view. We propose prototype formation as a foundational mechanism. We suggest that stronger other-race prototype formation isn't just a result of poor discrimination but may cause later individuation difficulties. Experiment 2 supports this. By preventing prototype formation with identical habituation faces, we tested the discrimination deficit hypothesis. If novelty preference in Experiment 1 was simply due to discrimination failure, Experiment 2 should have shown similar preference. However, chance-level looking in Experiment 2 indicated infants could discriminate when prototyping was blocked. This dissociation suggests the categorization advantage isn't primarily due to perceptual deficits. Instead, advanced prototype formation for unfamiliar faces may drive later challenges in other-race face individuation. Thus, this study offers a novel mechanistic account, shifting focus from perceptual deficits to prototype formation as a proactive force in shaping face processing from infancy.

Infants' robust prototype formation abilities, particularly the bias towards other-race faces, prompt a reconceptualization of experience-dependent perceptual development. Traditionally, this development has been largely theorized as a bottom-up process. Prolonged sensory input passively shapes neural networks to efficiently process frequently encountered stimuli. Unfamiliar sensory input, like other-race faces, was thus thought to result in less efficient processing. This "gain or loss" perspective suggests perceptual narrowing reflects a genuine loss of ability to process less frequent stimuli, such as other-race faces. However, our findings, alongside recent evidence (Xiao et al., 2024; Xiao & Emberson, 2023), challenge this view. Instead of a passive shaping of a purely perceptual system, we propose that experience-dependent development is actively guided by biased learning processes, specifically implicit statistical learning mechanisms like prototype formation. Our study suggests that this inherent bias in learning—the stronger tendency to prototype unfamiliar faces—may drive seemingly perceptual outcomes like perceptual narrowing, without necessarily implying a fundamental alteration or loss in the perceptual system itself. Indeed, recent work by Xiao et al. (2024) supports this. These authors demonstrated that infants retain comparable perceptual capacity for own- and other-race faces, while differences emerge at higher-level cognitive stages, such as memory-based top-down modulation, which is enhanced for own-race faces. Further, previous work has suggested that the hippocampus plays a role in pattern separation to minimize interference between similar stimuli (see Yassa & Stark, 2011 for a review). As such, it is possible that this brain region contributes to differential face processing through separating own- and other-race face stimuli into distinct patterns, thereby facilitating accurate face recognition. These prior works suggest that "perceptual narrowing," at least in the context of face processing, may not be a loss of perceptual acuity but rather a manifestation of strategically differentiated cognitive processing strategies shaped by

biased implicit learning. Our study thus adds critical empirical support to this emerging perspective. We highlight the proactive and learning-driven nature of experience-dependent perceptual development in infancy.

The demonstrated plasticity of face prototype formation underscores its fundamental and adaptive role in early cognitive development. The contrasting developmental trajectories observed between the lockdown and post-lockdown infant cohorts exemplify this plasticity. The lockdown cohort, experiencing reduced environmental diversity due to COVID-19 lockdowns, exhibited an increasing tendency to prototype other-race faces with age. Conversely, the post-lockdown cohort, with greater exposure to diverse faces post-lockdown, showed a decreasing tendency. This divergence likely reflects the differential facial environments. The lockdown cohort's primary face exposure was likely limited to immediate family (own-race), while the post-lockdown cohort encountered a broader range of faces in a more open social environment. This capacity for prototype formation to dynamically adjust in response to varying environmental input highlights its adaptive nature and its crucial role in calibrating cognitive processes to prevailing environmental demands. This plasticity aligns with other experience-dependent face processing capacities, such as the age-related improvements in masked face recognition observed during the pandemic (Kim et al., 2024), further demonstrating the broader plasticity of infant face processing systems. In essence, the adaptive plasticity of prototype formation suggests its vital role in enabling infants to efficiently process and navigate the specific facial landscape of their environment, optimizing early face processing skills for the prevailing social context.

Infant differential face prototyping may illuminate social bias origins. Even infants have shown in-group/out-group biases (Xiao et al., 2014, 2017, 2018). Prototyping, akin to stereotyping, underlies social biases, like gender stereotypes in children (Berndt & Heller, 1986). Our finding of early perceptual prototyping suggests it could be a precursor to social stereotypes. While we don't directly link prototypes to social stereotypes, biased early perceptual processing, like differential prototyping, may create a foundation for later social biases. Longitudinal studies should explore the developmental path from prototype formation to social stereotypes. Crucially, Experiment 3B indicates a potential mitigation strategy: environmental diversity reduces other-race prototyping. Future work may explore diversity-based interventions to reduce stereotyping across domains.

In sum, this study demonstrates infant face prototype formation as a fundamental, dynamic capacity. This ability is experience-modulated and adaptively plastic, evidenced by cohort differences reflecting environmental diversity. This plasticity suggests avenues for mitigating downstream social biases. These results support a strategic adjustment model: early learning proactively calibrates cognitive strategies to environmental demands, beyond simple perceptual gain or loss.

References

- Bar-Haim, Y., Ziv, T., Lamy, D., & Hodes, R. M. (2006). Nature and Nurture in Own-Race Face Processing. *Psychological Science*, 17(2), 159–163. <https://doi.org/10.1111/j.1467-9280.2006.01679.x>
- Berndt, T. J., & Heller, K. A. (1986). Gender stereotypes and social inferences: A developmental study. *Journal of Personality and Social Psychology*, 50(5), 889–898. <https://doi.org/10.1037/0022-3514.50.5.889>
- Cabeza, R., Bruce, V., Kato, T., & Oda, M. (1999). The prototype effect in face recognition: Extension and limits. *Memory & Cognition*, 27(1), 139–151. <https://doi.org/10.3758/BF03201220>
- Damon, F., Méary, D., Quinn, P. C., Lee, K., Simpson, E. A., Paukner, A., Suomi, S. J., & Pascalis, O. (2017). Preference for facial averageness: Evidence for a common mechanism in human and macaque infants. *Scientific Reports*, 7(1), 46303. <https://doi.org/10.1038/srep46303>
- de Haan, M., Johnson, M. H., Maurer, D., & Perrett, D. I. (2001). Recognition of individual faces and average face prototypes by 1- and 3-month-old infants. *Cognitive Development*, 16(2), 659–678. [https://doi.org/10.1016/S0885-2014\(01\)00051-X](https://doi.org/10.1016/S0885-2014(01)00051-X)
- Gao, X., Maurer, D., & Wilson, H. R. (2015). The PCA learning effect: An emerging correlate of face memory during childhood. *Cognition*, 143, 101–107. <https://doi.org/10.1016/j.cognition.2015.06.011>
- Gao, X., & Wilson, H. R. (2014). Implicit learning of geometric eigenfaces. *Vision Research*, 99, 12–18. <https://doi.org/10.1016/j.visres.2013.07.015>
- Ge, L., Zhang, H., Wang, Z., Quinn, P. C., Pascalis, O., Kelly, D., Slater, A., Tian, J., & Lee, K. (2009). Two faces of the other-race effect: Recognition and categorisation of Caucasian and Chinese faces. *Perception*, 38(8), 1199–1210. <https://doi.org/10.1068/p6136>
- Kelly, D. J., Liu, S., Ge, L., Quinn, P. C., Slater, A. M., Lee, K., Liu, Q., & Pascalis, O. (2007a). Cross-Race Preferences for Same-Race Faces Extend Beyond the African Versus Caucasian Contrast in 3-Month-Old Infants. *Infancy: The Official Journal of the International Society on Infant Studies*, 11(1), 87–95. <https://doi.org/10.1080/15250000709336871>
- Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Ge, L., & Pascalis, O. (2007b). The Other-Race Effect Develops During Infancy. *Psychological Science*, 18(12), 1084–1089. <https://doi.org/10.1111/j.1467-9280.2007.02029.x>
- Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Gibson, A., Smith, M., Ge, L., & Pascalis, O. (2005). Three-month-olds, but not newborns, prefer own-race faces. *Developmental Science*, 8(6), F31–F36. <https://doi.org/10.1111/j.1467-7687.2005.0434a.x>
- Kim, K. K., Fang, W., Liu, A. Y., Panesar, D., & Xiao, N. G. (2024). Altered development of face recognition among infants born amid the COVID-19 pandemic. *Journal of Experimental Child Psychology*, 244, 105942. <https://doi.org/10.1016/j.jecp.2024.105942>
- Quinn, P. C., Lee, K., Pascalis, O., & Tanaka, J. W. (2016). Narrowing in categorical responding to other-race face classes by infants. *Developmental Science*, 19(3), 362–371. <https://doi.org/10.1111/desc.12301>
- Woo, P. J., Quinn, P. C., Méary, D., Lee, K., & Pascalis, O. (2020). A developmental investigation of the other-race categorization advantage in a multiracial population: Contrasting social categorization and perceptual expertise accounts. *Journal of Experimental Child Psychology*, 197, 104870. <https://doi.org/10.1016/j.jecp.2020.104870>
- Xiao, N. G., & Emberson, L. L. (2023). Visual Perception Is Highly Flexible and Context Dependent in Young Infants: A Case of Top-Down-Modulated Motion Perception. *Psychological Science*, 34(8), 875–886. <https://doi.org/10.1177/09567976231177968>
- Xiao, N. G., Ghersin, H., Dombrowski, N. D., Boldin, A. M., & Emberson, L. L. (2024). Infants' top-down perceptual modulation is specific to own-race faces. *Journal of Experimental Child Psychology*, 242, 105889. <https://doi.org/10.1016/j.jecp.2024.105889>
- Xiao, N. G., Quinn, P. C., Liu, S., Ge, L., Pascalis, O., & Lee, K. (2018). Older but not younger infants associate own-race faces with happy music and other-race faces with sad music. *Developmental Science*, 21(2), Article 2. <https://doi.org/10.1111/desc.12537>
- Xiao, N. G., Wu, R., Quinn, P. C., Liu, S., Tummeltshammer, K. S., Kirkham, N. Z., Ge, L., Pascalis, O., & Lee, K. (2017). Infants Rely More on Gaze Cues From Own-Race Than Other-Race Adults for Learning Under Uncertainty. *Child Development*, 89(3), e229–e244. <https://doi.org/10.1111/cdev.12798>
- Xiao, W. S., Fu, G., Quinn, P. C., Qin, J., Tanaka, J. W., Pascalis, O., & Lee, K. (2014). Individuation training with other-race faces reduces preschoolers' implicit racial bias: A link between perceptual and social representation of faces in children. *Developmental Science*, 18(4), 655–663. <https://doi.org/10.1111/desc.12241>
- Yassa, M. A., & Stark, C. E. L. (2011). Pattern separation in the hippocampus. *Trends in Neurosciences*, 34(10), 515–525. <https://doi.org/10.1016/j.tins.2011.06.006>