Infant Behavior and Development 77 (2024) 101995

Contents lists available at ScienceDirect

Infant Behavior and Development

journal homepage: www.elsevier.com/locate/inbede

Registered Report Stage II

Successful sensitization of 2.5-year-olds to other-race faces through bimodal training

Özlem Sensoy [a,*], Anna Krasotkina [b], Antonia Götz [c], Barbara Höhle [d], Gudrun Schwarzer [a]

[a] Department of Developmental Psychology, Justus-Liebig-University Giessen, Giessen, Germany
[b] Department of Psychology, Neuroscience & Behavior, McMaster University, Hamilton, ON, Canada
[c] MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Australia
[d] Department of Linguistics, University of Potsdam, Potsdam, Germany

ARTICLE INFO

Keywords:
Face perception
Perceptual narrowing
Infancy
Statistical learning

ABSTRACT

The present study investigated the potential for sensitizing 2.5-year-old Caucasian infants to other-race faces (Asian faces). In the domain of face perception, infants become less sensitive to facial distinctions of other-race faces through perceptual narrowing at the end of the first year of life. Nevertheless, infants around 12 months can regain their sensitivity to other-race faces. For instance, exposing them to a specific statistical distribution and employing the mechanisms of statistical learning is one way to enhance their discriminatory abilities towards other-race faces. Following this idea, we investigated if even older infants around 2.5 years can be sensitized to other-race faces. We trained the infants with a bimodal distribution of a morphed continuum of Asian female faces with faces closer to the endpoints presented most frequently. We assessed infants' discrimination of Asian faces by measuring their looking times after the training phase. The 2.5-year-olds showed a difference in looking times after the training, indicating that the exposure to a bimodal frequency distribution led to a successful discrimination between Asian faces. These findings demonstrate that 2.5-year-olds can be sensitized to other-race faces by exposing them to a bimodal distribution of such faces, underlining the plasticity of face perception in childhood.

1. Introduction

During the first year of life, infants undergo a rapid development in perceptual abilities. They exhibit heightened discriminatory responses to frequently encountered stimuli while showing diminished responses to rarely encountered stimuli, a phenomenon known as perceptual narrowing. This specialization is observed in various domains, including face perception (Kelly et al., 2007; Kelly et al., 2009; Kelly et al., 2007). With regards to face perception, infants show reduced sensitivity to distinguishing features in faces of other races by the end of the first year of life (Clerc et al., 2022; Kelly et al., 2009; Krasotkina et al., 2018, 2021; Pascalis et al., 2002), the so called Other-Race Effect (ORE). Despite the long-lasting effects of perceptual narrowing and the ORE (Maurer & Werker, 2014), infants' discriminatory abilities remain adaptable, allowing them to re-learn to differentiate other-race faces (Anzures et al., 2012; Clerc

* Correspondence to: Department of Developmental Psychology, Justus-Liebig-University Giessen, Otto-Behaghel-Str. 10 F, 35394 Giessen, Germany.
E-mail address: oezlem.sensoy@uni-marburg.de (Ö. Sensoy).

https://doi.org/10.1016/j.infbeh.2024.101995
Received 28 November 2023; Received in revised form 15 September 2024; Accepted 18 September 2024
Available online 24 September 2024

et al., 2022; Heron-Delaney et al., 2011; Krasotkina et al., 2021; Markant et al., 2016; Minar & Lewkowicz, 2018; Quinn et al., 2020). A recent study has shown that exposing infants to a specific distribution of exemplars of two faces whose facial features provide a continuum between the two faces enhances 12-month-olds' ability to discriminate such faces (Krasotkina et al., 2021). This suggests that a re-sensitization is possible in conditions that address infants' statistical learning capacities. However, it remains uncertain whether similar sensitization is possible in older infants when perceptual narrowing has established the ORE. To address this question, we conducted a study investigating the impact of statistical learning in 2.5-year-olds by employing a bimodal training approach similar to Krasotkina et al. (2021).

As mentioned, perceptual narrowing is a developmental process occurring within the first year of life, influencing infants' discriminatory abilities across different domains such as face perception. During the first six months of life, infants exhibit comparable discriminatory abilities for both same- and other-race faces (Kelly et al., 2007; Kelly et al., 2009; Krasotkina et al., 2020). Towards the end of the first year of life, infants' abilities to discriminate faces become specialized for those of their own race, coinciding with a decrease in their ability to differentiate faces from other races (Slater et al., 2010; Sugden & Marquis, 2017; Valentine et al., 2016). Even though perceptual narrowing has been demonstrated to be a consistent effect (Kelly et al., 2009; Kelly et al., 2007; Maurer & Werker, 2014), prior studies have also shown that perceptual narrowing and more specifically the ORE can be overcome to some extent. For instance, after being trained with Asian faces in a book, 9-month-old Caucasian infants were still able to successfully discriminate (novel) Asian faces (Heron-Delaney et al., 2011). Similarly, Anzures et al. (2012) found that when they presented 8- to 10-month-old Caucasian infants with videos of Asian women singing and talking in infant-directed speech, infants did not show a reduction of discriminatory abilities towards Asian faces. Other ways of re-sensitizing infants to other-race faces within the first year of life are by adding emotional expressiveness to faces (Quinn et al., 2020), inducing a selective attention bias that enhances infants' individuation of other-race faces (Markant et al., 2016) or pairing other-race faces with auditory information (Clerc et al., 2022; Minar & Lewkowicz, 2018).

One mechanism that may underlie the (re-)sensitization to other-race faces is statistical learning. Statistical learning is a rapid, implicit mechanism enabling us to extract patterns, regularities and consistencies within our environment (Aslin & Newport, 2012).

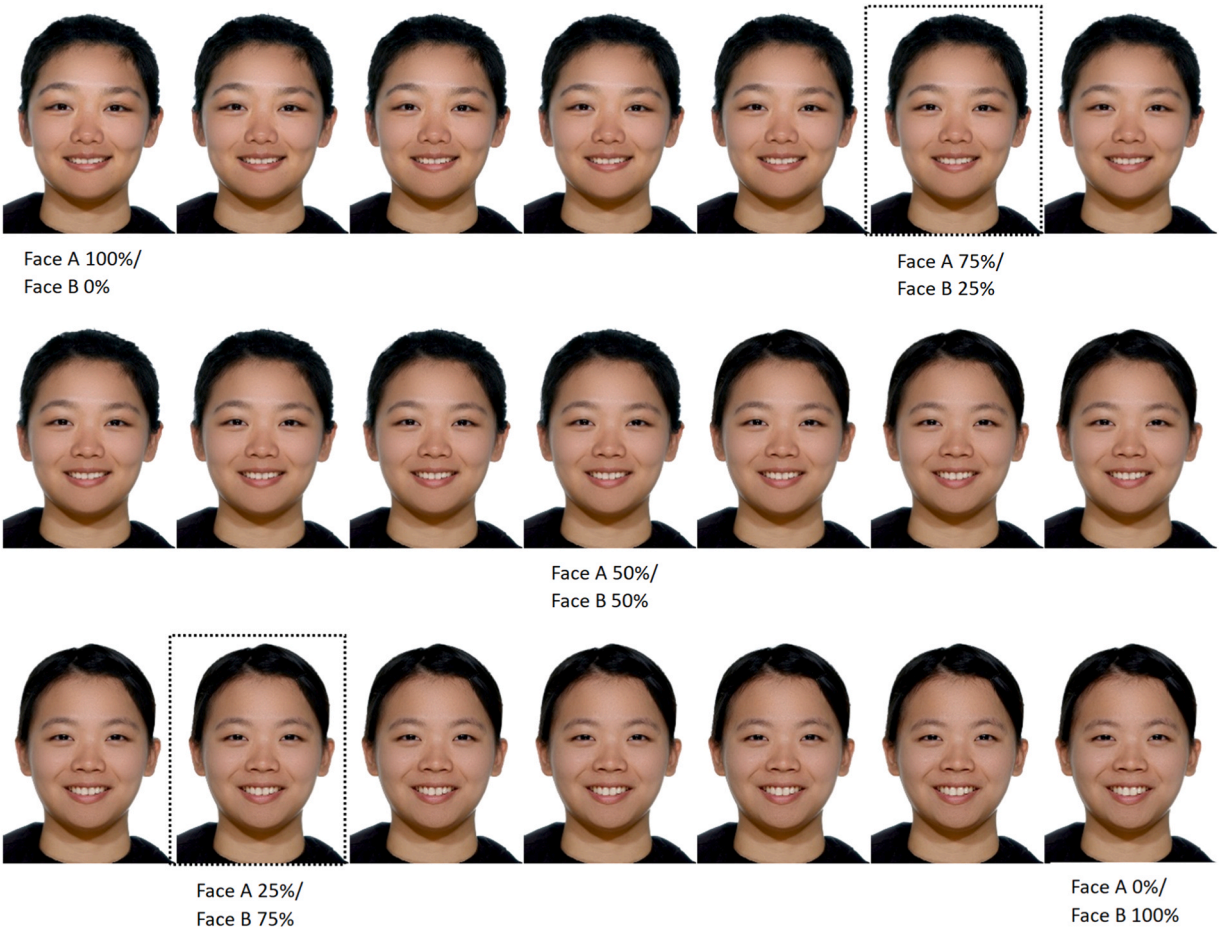

Fig. 1. The morphed continuum from the endpoint Face A to endpoint Face B in 5 % steps with the most frequently presented morphed faces bordered by dotted lines, adapted from Krasotkina et al. (2021).

Evidence for statistical learning can be found from birth on (Bulf et al., 2011), highlighting the importance of statistical learning as a domain-general capacity in diverse aspects of human behavior throughout the lifespan (Campbell et al., 2012; Fiser & Aslin, 2002; Saffran & Kirkham, 2018; Schapiro et al., 2014; Schapiro & Turk-Browne, 2015; Smith et al., 2018).

In the context of perceptual narrowing, statistical learning plays an important role in enabling infants to track the frequency of encountering single events or the co-occurrence of patterns of events or their features (such as facial features). Hereby, the distributional pattern of stimuli significantly influences this learning process (Altvater-Mackensen et al., 2017; Krasotkina et al., 2021; Maye et al., 2002; Yoshida et al., 2010). A bimodal distribution that entails exemplars of stimuli falling into two distinct clusters at the opposite ends of a dimension, has been shown to successfully support the establishment of categories on this dimension across various domains (Krasotkina et al., 2021; Maye et al., 2002; Yoshida et al., 2010) and even reverse the effects of perceptual narrowing (face perception: Krasotkina et al., 2021; speech perception: e.g., Yoshida et al., 2010). Hereby, bimodal distributions are usually tested against unimodal distributions, which did not enhance discriminatory abilities as has been shown in various studies (Krasotkina et al., 2021; Maye et al., 2002; Yoshida et al., 2010).

For the specific case of sensitizing infants to other-race faces, Krasotkina et al. (2021) demonstrated that Caucasian 12-month-olds exposed to a bimodal distribution exhibited enhanced discriminatory abilities toward Asian faces compared to infants exposed to a unimodal distribution. In their study, infants were trained with a continuum of morphed Asian female faces, with morphs close to the endpoints being most frequently presented in the bimodal distribution and the middle morph being most frequently presented in the unimodal distribution (see Fig. 1 for an illustration). Subsequently, in the test-phase infants were presented with pairs of Asian faces that were either identical (match trials) or different (mismatch trials). Infants trained with the bimodal distribution displayed longer looking times in match compared to mismatch trials, indicating their ability to discriminate between other-race faces. In contrast, infants trained with faces consisting of a unimodal distribution did not exhibit any significant difference in looking times between match and mismatch trials. These findings showed that a training with a bimodal distribution of a continuum of other-race faces can improve infants' discriminatory abilities towards such faces, even after undergoing perceptual narrowing. While Krasotkina et al. (2021) demonstrated that a training with a bimodal compared to unimodal distribution can successfully sensitize Caucasian infants to other-race faces again, they did not test the sensitivity towards other-race faces prior to the bimodal training. Assessing infants' discrimination of other-race faces prior to training would allow to infer that the bimodal training led to an improvement in discriminating other-race faces.

In general, previous research has provided evidence of the modifiability of perceptual narrowing in infants. However, less is known about the modifiability of perceptual narrowing in infants beyond the first year of life, particularly in the context of face perception and the other-race effect (ORE). The few existing studies involving 3- to 5-year-olds underscore the stability of the ORE (Anzures et al., 2013; Sangrigoli & Schonen, 2004; Suhrke et al., 2014; Suhrke et al., 2015). One study by Sangrigoli et al. (2005) indicates that the ORE can be reversed in 3- to 9-year-olds. They demonstrated that Korean adults who were adopted between 3 and 9 years of age, hence, after the occurrence of perceptual narrowing, were better in discriminating Caucasian faces compared to Asian Faces. In contrast, 6- to 14-year-old Asian children wo were adopted between the age of 2 and 26 months showed similar discriminatory abilities towards Asian and Caucasian faces (Heering et al., 2010).

Further, McKone et al. (2019) found that natural social contact to other-race faces between the ages of 5 to 12 years, can reduce the ORE compared to such exposure in adulthood. Although these studies suggest modifiability of perceptual narrowing and the ORE in childhood, controlled experimental studies in this area remain scarce. Moreover, statistical learning has mostly been studied in the domain of speech and language processing despite its domain generality. Recent findings on infants' and toddlers' ability to uncover co-occurrence patterns while passively listening to speech stimuli suggest a decrease in this type of statistical learning in infants aged from 1- to 3-year-olds (Paul et al., 2021). Thus, the question arises whether an attenuation of the ORE via statistical learning is still possible in older infants. To approach this question, we tested 2.5-year-olds.

1.1. The current study

The primary objective of this study was to explore the feasibility of modifying the ORE beyond infancy. Previous research has demonstrated that infants can overcome the effects of perceptual narrowing (such as the ORE) through statistical learning (Krasotkina et al., 2021; Maye et al., 2002; Yoshida et al., 2010). Notably, Caucasian 12-month-olds exhibited improved discriminatory abilities towards other-race faces after exposure to a bimodal distribution of Asian faces compared to a unimodal distribution with no pre-exposure tests conducted (Krasotkina et al., 2021). While some studies suggest that the modification of the ORE in older infants is possible (Heering et al., 2010; McKone et al., 2019; Sangrigoli et al., 2005), empirical evidence in this area remains limited. Our study aims to investigate the modification of the ORE in older infants, specifically 2.5-year-olds. Particularly, we tested whether 2.5-year--olds can be sensitized to other-race faces by being exposed to a bimodal distribution of Asian face morphs. For this, we adapted the approach by Krasotkina et al. (2021) with some changes. First, we extended the number of exposure trials for our age group as, at least for the modifiability of perceptual narrowing in speech perception, older infants need increased exposure compared to younger infants to be re-sensitized to non-native speech (Maye et al., 2002; Yoshida et al., 2010). Second, we added a control condition to our experiment to test infants' discrimination of Asian faces before the exposure to the bimodal distribution of Asian faces as we were specifically interested in investigating whether a bimodal distribution would sensitize 2.5-year-olds to Asian faces. The control condition allowed us to infer that indeed the bimodal distribution led to a sensitization to Asian faces. We included the control condition instead of a unimodal training condition, because there is no study indicating that a unimodal statistical training can induce a sensitization for the differences between faces.

Building on the results of Krasotkina et al. (2021), we hypothesized that 2.5-year-olds would exhibit enhanced discrimination of

other-race faces after being familiarized with a bimodal distribution of a morphed continuum of Asian females faces. Particularly, we assumed that 2.5-year-olds would demonstrate a successful discrimination between the other-race faces after the training. Hereby, we expect 2.5-year-olds to show longer looking times for the match compared to the mismatch trials similar to Krasotkina et al. (2021) and Maye et al. (2002) who also found a looking preference for match trials after training to a bimodal distribution compared to a unimodal distribution in which infants did not show a looking preference.

2. Experiment 1: other-race discrimination

2.1. Method

2.1.1. Ethics and data availability statement

This study was conducted in accordance with the German Research Foundation's Research Ethics Guidelines. The local ethics committee of the Justus-Liebig University Giessen approved this study. Caregivers provided written consent prior to their participation in the study. Data available on request from the authors.

2.1.2. Participants

The final sample consisted of 21 infants aged 2.5-years-old (M = 31.38 months, SD = 1.24 months, 8 female). A total of 13 infants were excluded from the final sample, 11 infants were excluded due to fussiness (covered their eyes with the hands, did not want to sit on parent's lap, crying) and 2 infants were excluded due to a failure to calibrate. Sample size was based on the study by Krasotkina et al. (2021), who reported a large effect size ($\eta_p^2 = 0.63$). Hence, we also assumed to find a medium to large effect. A power analysis using G*Power (Faul et al., 2009) showed that a sample size of 16 participants is sufficient to detect an effect size of f = 0.40 with a power of 0.95 and of $\alpha = 0.05$. Infants were recruited from the department's database of infants and were located in Giessen and surrounding areas. Families were first contacted via a letter with information about the study and then via phone or e-mail to ask them whether they were interested in participating in the study at hand. To ensure that infants were as less experienced with other-race faces (in this case Asian faces) as possible, we asked parents whether their child was familiar with Asian people from its daily life (such as Asian family members or friends or infants at the day care). Only if infants had no such experience, they were included in our study. Testings took place in the laboratory of the Department of Developmental Psychology at the Justus-Liebig University. After participation, each infant received a certificate of participation and a gift.

2.1.3. Stimuli & apparatus

Our study used the same stimuli as Krasotkina et al. (2021) as they already demonstrated a successful re-sensitization to other race faces (Asian faces) with these stimuli for 12-month-olds. Morphed faces were created from color photographs of two Asian women (Face A and Face B) by using FantaMorph (Version 5.4.8). The presented morphed continuum comprised 21 faces that gradually changed from Face A (Face A 100 %/ Face B 0 %) to Face B (Face A 0 %/ Face B 100 %) in 5 % steps as can be seen in Fig. 1. Each face had a size of 14.5 cm × 21 cm and was presented centrally on a screen. In the training phase, participants saw all 21 faces (including the endpoints). For the test phase, only the endpoints were presented to participants.

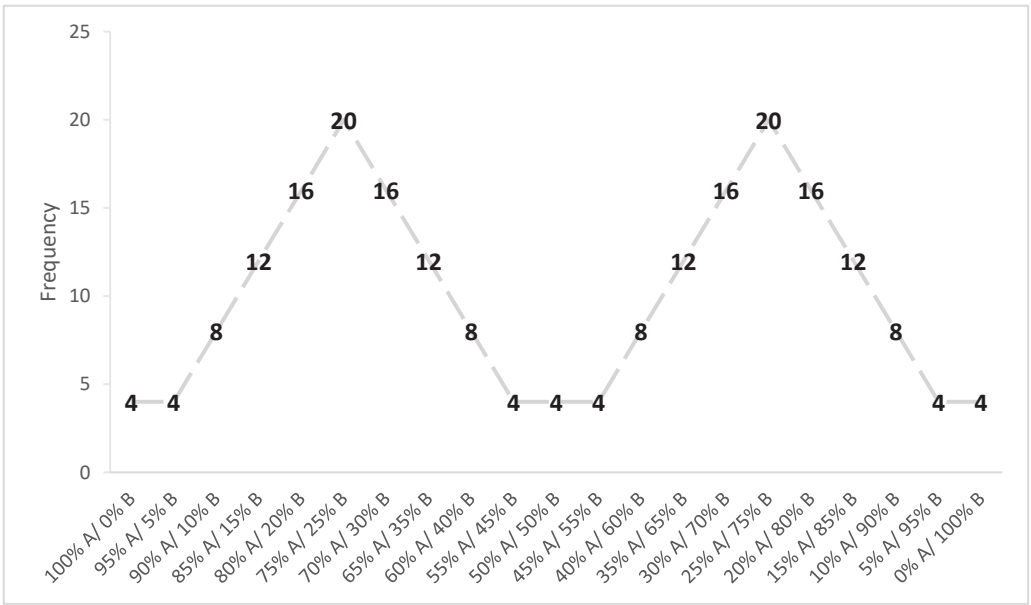

Fig. 2. Frequency distribution schema for the bimodal condition.

We presented our stimuli on a white background centrally on a computer display with a resolution of 1920 × 1080 pixels, and an integrated Tobii tx300 eye tracker with a 300 Hz sampling rate. The viewing distance for the participants was approximately 60 cm. E-Prime 3.0 (Psychology Software Tools, Pittsburgh, PA) was used to run the experiment and to present the stimuli.

2.1.4. Experimental design

The experimental design was adapted from Krasotkina et al. (2021) but slightly modified for the 2.5-year-olds. Our experiment comprised a training and a test phase. Additionally, we included the same test as after the training as a control condition prior to the training phase to control for infants' discrimination of the presented Asian faces (endpoint faces, see Fig. 1) before undergoing our training. In the test phase, the endpoints of the morphed continuum were presented. The training phase consisted of a total of 212 trials with a small break (video of a landscape) after 106 trials. We used the same frequency distribution schema for the bimodal condition as Krasotkina et al. (2021) and adapted it to the amount of training trials in our experiment. Participants saw the 25 % Face A/ 75 % Face B and the 75 % Face A/ 25 % Face B morphs most frequently, 20 times each, and the endpoints were presented for 4 times each (see Fig. 2 for detailed frequency distribution).

In the test phase, we used the endpoint faces both as prime and test faces in match and mismatch trials. In a test trial, one face was always presented at a time. The first face was the prime face. The second face was the target face and differed in match and mismatch trials.

In the match trials, prime and test faces were identical (either Face A in both cases or Face B). In the mismatch trials, prime and test faces were different (Face A as prime and Face B as test or vice versa). For example, in a match trial Face A was both the prime and target face and in a mismatch trial, Face A was the prime and Face B the target face. Similarly, in a match trial Face B was both the prime and target face and in a mismatch trial, Face B was the prime and Face A the target face. Hence, the second face was always compared with the first face (e.g. is the second face identical to the first face? Is the second face different to the first face?). We presented 4 trials in the test-phase. Faces were always presented in the center of the screen. In the training phase, we presented 212 faces with a specific frequency distribution (see also Fig. 2). Faces were shown in random order and the same face never appeared in consecutive trials.

2.1.5. Procedure

All infants were tested in individual sessions that took around 30 min. Infants sat on their parent's lab in a booth for the duration of the experiment. The experiment consisted of a short introduction followed by a calibration. Afterwards the experiment started with our control condition followed by the training phase and ended with the test phase. Parents and infants received a description of the experimental procedure but were blind to the hypotheses. Additionally, parents were asked to not comment on the experiment or point at the screen. Parents also wore dark sunglasses to ensure that the eyetracker was tracking the child's eye movements.

The experiment began with the calibration. We used a 5-point-calibration procedure with an animated red lobster that appeared at each of the 4 corners as well as the middle of the screen. We repeated the calibration until it was successful for all 5 points, however, we excluded participants after 5 failed calibration attempts ($n = 2$). Afterwards, the control condition followed. The control condition that preceded the training phase (as mentioned above) was identical to the test phase. For the match trials, the same face (either only Face A or only Face B) was presented as prime and target, whereas for the mismatch trial, the two faces were presented as either prime or target (e.g. Face A as prime and Face B as target or vice versa). The prime face was presented briefly (750 ms) and followed by a blank screen for 350 ms. Then, the presentation of the target face followed. The target face was presented until the infant looked away for 2 s or looked for a maximum of 20 s. We had 4 trials in total in the control condition, 2 match and 2 mismatch trials.

After the control condition, the experiment started with the training phase. An attention getter (a star) accompanied by a sound was presented for 350 ms before each and in between the presentation of the familiarization faces. The familiarization faces themselves were presented for 750 ms. After 106 faces, we had a short break and infants saw a silent video of a landscape (60 s). Afterwards, the remaining 106 faces were presented, however the accompanying sounds for the attention getter were changed to keep infants engaged.

The training phase was followed by the test phase. In the test phase, a novel visual attention getter accompanied by a sound was presented at the beginning of the trial. As soon as the child fixated the attention-getter, the prime face (100 % Face A or 100 % Face B) appeared for 750 ms. Afterwards, a blank screen followed for 350 ms before one of the test faces (according to match or mismatch trials) was presented. Each test face was presented for as long as a child continued to look at it. The target face was presented until the infant looked away for 2 s or looked for a maximum of 20 s. After 4 trials (2 match and 2 mismatch trials) the test phase ended.

2.1.6. Data reduction

The gaze data was analyzed by using Tobii Pro Studio. According to Krasotkina et al. (2021), we defined a single fixation as a looking period of at least 100 ms within a maximum radius of 30 pixels. One single Area of Interest (AOI) encompassed the entire head with both internal and external face features. For each trial, we calculated the sum of fixation durations for the AOI. Moreover, all infants in the final sample looked at least at 85 % of the faces presented in the training phase and also made at least one fixation towards the prime and test face in the test phase.

2.2. Results

Prior to our main analysis, we checked with our control condition whether infants were able to differentiate between the two endpoint faces before undergoing our training phase. The paired *t*-test (two-tailed) showed no significant difference between match and mismatch trials, $t(20) = -.69$, $p = .501$. The 2.5-year-olds looked equally long in the match ($M = 6.76$ s, $SD = 2.41$ s) and

mismatch trials ($M = 6.20$ s, $SD = 3.22$ s), indicating that they were not able to discriminate between the endpoint faces before our training.

In our main analysis, we analyzed the differences between looking times of the 2.5-year-olds in the match and mismatch trials after the training phase by performing a paired *t*-test (two-tailed). The paired *t*-test revealed a significant difference in looking times between match and mismatch trials, $t(20) = -2.92$, $p = .008$, Cohen's $d = -0.60$. Hereby, the 2.5-year-olds looked longer in the match trials ($M = 5.06$ s, $SD = 3.32$ s) compared to the mismatch trials ($M = 3.30$ s, $SD = 1.98$ s) as can be seen in Fig. 3.

2.3. Discussion

Our results revealed that after undergoing a training with a bimodal distribution of morphed Asian faces, 2.5-year-olds looked longer towards the match over mismatch faces which indicates that they were able to discriminate among Asian faces. They did not show this discrimination in the control condition which we assessed before the training. Here, they looked equally long to match and mismatch faces. This suggests that the exposure to a bimodal distribution of Asian faces enhanced the 2.5-year-olds' sensitivity to other-race faces and their ability to successfully discriminate between these faces. We assume that exposure to the bimodal continuum of morphed Asian faces, and the resulting experience with them, caused the change in 2.5-year-olds' looking behavior—shifting from no differentiation between match and mismatch trials in the control condition to longer looking times at the match trials after exposure.

To test this assumption that prior experience with a specific face category would induce discrimination in terms of longer looking times to match over mismatch faces, we tested 2.5-year-olds' looking behavior for match and mismatch own-race faces in an additional experiment. When face experience is the crucial factor then 2.5-year-olds would look longer at match over mismatch own-race faces without prior training, as infants at this age have already gained a lot of experience with own race faces from their everyday life making a training unnecessary. Hence, we tested a second group of 2.5-year old infants with own-race faces (Caucasian).

3. Experiment 2: own-race discrimination

3.1. Method

3.1.1. Participants

The final sample consisted of 14 infants aged 2.5-years-old ($M = 31.71$ months, $SD = 1.33$ months, 4 female, 10 male). Recruitment was the same as in the main experiment.

3.1.2. Stimuli and procedure

To test infants' own-race discrimination, we used color photographs of two own-race faces (Caucasian faces) as can be seen in Fig. 4. The procedure was identical to the control condition in the main experiment. The experiment consisted of a calibration and a test phase. After calibration, the test phase started and a total of 4 trials was presented to the infants. Again, identical to the control condition in the main experiment, we had 2 match and 2 mismatch trials. In the match trials, we presented the same Caucasian face both as prime and target (either only Face C or only Face D) and in the mismatch trials, the prime and target face were different (either Face C as the prime and Face D as target or Face D as the prime and Face C as target face). Each trial started with the presentation of an attention getter. When infants fixated the attention getter, the prime face was presented for 750 ms. After that, a blank screen followed

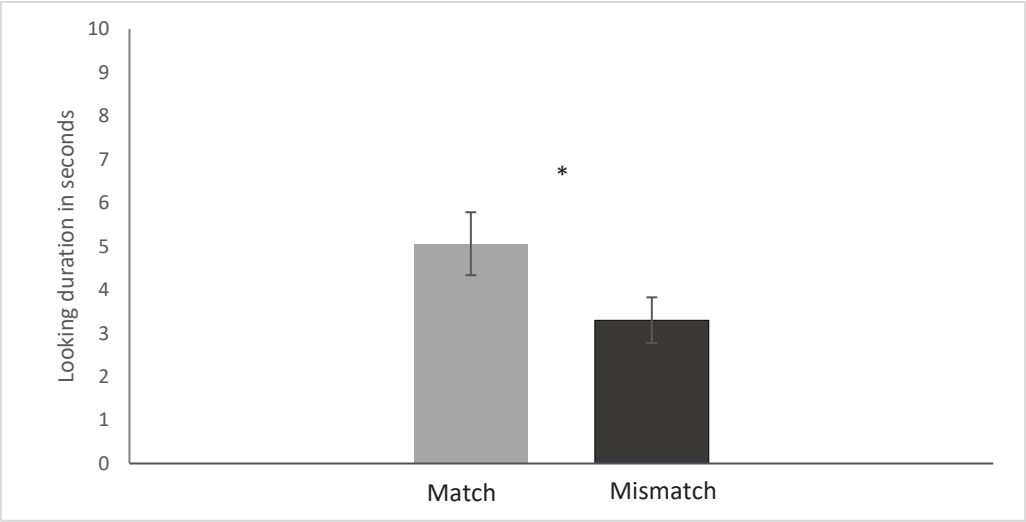

Fig. 3. Looking durations for after the training phase for mismatch and match trials. Error bars are SEM. Note. * $p < .05$.

Fig. 4. Caucasian faces used in the additional experiment as stimuli. Face C on the left and Face D on the right.

for 350 ms and then the target face was presented. The presentation of the target face was infant-controlled as in the main experiment. The target face was presented until the infant looked away for 2 s or looked for a maximum of 20 s. After the presentation of the 4 trials, the experiment ended. Hereby, infants did not undergo the bimodal training.

3.2. Results and discussion

We ran a paired *t*-test (two-tailed) on the differences between looking times in the match and mismatch trials. The paired *t*-test revealed a significant difference in looking times between match and mismatch trials, $t(13) = -2.19$, $p = .048$, Cohen's $d = -0.46$. Hereby, the 2.5-year-olds looked longer in the match trials ($M = 9.06$ s, $SD = 3.07$ s) compared to the mismatch trials ($M = 6.44$ s, $SD = 3.47$ s).

The results of our additional experiment revealed that 2.5-year-olds showed a similar looking preference for own-race faces as they did for other-race faces after undergoing a bimodal training. Specifically, Caucasian 2.5-year-olds showed a looking preference for match over mismatch trials for own-race faces as they did for the other-race faces. This suggests that prior experience with a specific face category (due to a bimodal training regarding Asian faces or everyday life regarding own-race faces) would induce longer looking times to match over mismatch faces. A more in-depth discussion of our findings follows in the general discussion.

4. General discussion

The goal of the present study was to investigate the modifiability of the ORE after the onset of perceptual narrowing. For this, we tested whether 2.5-year-olds can be trained to discriminate other-race faces. Specifically, we examined whether presenting Asian female faces in a bimodal statistical distribution influenced the ability of 2.5-year-olds to discriminate Asian faces. Our results revealed that a training with a bimodal distribution of morphed Asian faces led to a successful discrimination of Asian faces in 2.5-year-olds. Similar to Maye et al. (2002) and Krasotkina et al. (2021), we found a looking preference for match over mismatch trials. Additionally, we found the same looking pattern and preference for match over mismatch trials with own-race faces. Given that 2.5-year-olds are very sensitive to own-race faces, this finding supports our idea that a bimodal distribution sensitizes 2.5-year-olds to other-race faces, leading to a successful discrimination of those faces. This suggests that the ORE can be modified in older infants.

Our findings align with previous research demonstrating infants' ability to overcome the effects of perceptual narrowing by exposure to specific statistical stimulus distributions (Krasotkina et al., 2021; Maye et al., 2002; Yoshida et al., 2010). We were able to replicate and extend the findings of Krasotkina et al. (2021), who also found a looking preference for match over mismatch trials in their study, indicating the successful re-sensitization to other-race faces. Moreover, our study addresses the gap in experimental research concerning the reversibility of the ORE in childhood, an area lacking in prior studies (Heering et al., 2010; McKone et al., 2019; Sangrigoli et al., 2005). Thus, our research bridges these two areas of research and expands upon them, revealing that exposure to a bimodal distribution of other-race faces effectively even sensitizes 2.5-year-olds to other-race faces.

Further, the inclusion of a control condition in our experimental design allows us to infer that the exposure to this distribution enhanced infants' discriminatory abilities, as they were unable to differentiate between other-race faces prior to the training. Together with our own-race experiment that revealed that Caucasian 2.5-year-olds show a comparable looking behavior (as in a looking preference for match over mismatch trials) for own-race faces as they do for other-race faces, this finding supports our idea that a bimodal training is suitable for sensitizing 2.5-year-olds to other-race faces. Thus, the results of our own-race experiment support our idea that the experience that the infants gained through the exposure with the bimodal distribution of Asian faces has led to their change in their looking behavior towards longer looking to the match over mismatch trials. This differentiation in turn would speak for an induced sensitization of other-race (Asian) faces after a bimodal training with such faces.

Moreover, our study adds to the growing body of research indicating that statistical learning is an effective mechanism for (re-) sensitizing infants to information distinguishing between different variations of stimuli. Notably, exposure to a bimodal distribution of stimuli has been shown to influence discrimination of object shapes (Junge et al., 2018), sounds (Maye et al., 2002) and both native

and non-native face identities in infants (Altvater-Mackensen et al., 2017; Krasotkina et al., 2021). Our results extend these findings and demonstrate that this mechanism is effective in toddlers as well. Specifically, our study revealed that 2.5-year-olds can be re-sensitized to other-race faces through exposure to a bimodal distribution, even after the onset of perceptual narrowing, which typically occurs between 6 and 9 months of age (Kelly et al., 2007; Kelly et al., 2009; Krasotkina et al., 2018; Spangler et al., 2013). Our findings also indicate that statistical learning mechanisms are still available in infants to enhance their sensitivity to features that distinguish between different stimuli.

4.1. Limitations

While our study provides important indications about the potential reversibility of the ORE in in older infants, it also raises questions concerning the generalizability of our results. In this regard, it is difficult to know whether the findings reflect restoring sensitivity to two particular stimuli that were initially difficult to differentiate, or restoring sensitivity to an entire class of stimuli. Another important question is about the longevity of the effects of our training. Specifically, longitudinal studies are needed to examine if infants' re-sensitization to other-race faces is only improved for a short period of time (i.e., only visible when tested directly after the training) or whether this improvement lasts for days, weeks, or even longer after the training is completed. Additionally, it is crucial to explore the influence of specific training modifications, such as increased trial numbers or the inclusion of diverse other-race faces, on infants' discriminatory abilities of such faces.

Similar to Krasotkina et al. (2021), we presented the same faces in the test phase along with a morphed continuum of these faces in the training phase. To overcome this limitation in future studies, adding novel other-race faces to the test phase could shed light on how the distinctive features learned through the bimodal distribution impact the discrimination of novel other-races faces, possibly also involving different ethnic backgrounds (e.g., not only Asian faces, but also African-American faces). The modifiability or reversibility of perceptual narrowing in in older infants (i.e., after the onset of perceptual narrowing) is generally not well understood. Consequently, further research exploring diverse domains such as speech perception or the audio-visual integration of face and speech information is needed to enhance our comprehension of the modifiability or reversibility of perceptual narrowing in childhood.

4.2. Conclusion

In conclusion, our study highlights the potential of the modifiability of the ORE in older infants. By exposing 2.5-year-olds to a bimodal distribution of morphed Asian faces, we successfully modified the ORE, demonstrating that infants can be re-sensitized to other-race faces even after the onset of perceptual narrowing. Moreover, our findings align with previous work highlighting the role of statistical learning in (re-)shaping perceptual abilities in infants. Specifically, our results underscore the effectiveness of bimodal distributions in enhancing discriminatory abilities across various domains. Importantly, our study contributes to a deeper understanding of the developmental dynamics of perceptual narrowing, suggesting that exposure to diverse stimuli exemplars can counteract the effects of perceptual narrowing. This finding also emphasizes the importance of a varied exposure to different faces in infancy which may help reducing racial biases in our society in the long term.

Ethics and data availability statement

This study was conducted in accordance with the German Research Foundation's Research Ethics Guidelines. The local ethics committee of the Justus-Liebig University Giessen approved this study. Caregivers provided written consent prior to their participation in the study. Data available on request from the authors.

Funding

The research presented here was funded by the DFG (German Research Foundation) as part of the Research Unit Crossing the Borders (FOR 2253).

CRediT authorship contribution statement

Gudrun Schwarzer: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Özlem Sensoy:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Data curation. **Anna Krasotkina:** Writing – review & editing, Software, Methodology. **Antonia Götz:** Writing – review & editing, Methodology, Conceptualization. **Barbara Höhle:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Data availability

Data will be made available on request.

References

Altvater-Mackensen, N., Jessen, S., & Grossmann, T. (2017). Brain responses reveal that infants' face discrimination is guided by statistical learning from distributional information. *Developmental Science, 20*(2). https://doi.org/10.1111/desc.12393

Anzures, G., Quinn, P. C., Pascalis, O., Slater, A. M., Tanaka, J. W., & Lee, K. (2013). Developmental origins of the other-race effect. *Current Directions in Psychological Science, 22*(3), 173–178. https://doi.org/10.1177/0963721412474459

Anzures, G., Wheeler, A., Quinn, P. C., Pascalis, O., Slater, A. M., Heron-Delaney, M., Tanaka, J. W., & Lee, K. (2012). Brief daily exposures to Asian females reverses perceptual narrowing for Asian faces in Caucasian infants. *Journal of Experimental Child Psychology, 112*(4), 484–495. https://doi.org/10.1016/j.jecp.2012.04.005

Aslin, R. N., & Newport, E. L. (2012). Statistical learning: From acquiring specific items to forming general rules. *Current Directions in Psychological Science, 21*(3), 170–176. https://doi.org/10.1177/0963721412436806

Bulf, H., Johnson, S. P., & Valenza, E. (2011). Visual statistical learning in the newborn infant. *Cognition, 121*(1), 127–132. https://doi.org/10.1016/j.cognition.2011.06.010

Campbell, K. L., Zimerman, S., Healey, M. K., Lee, M. M. S., & Hasher, L. (2012). Age differences in visual statistical learning. *Psychology and Aging, 27*(3), 650–656. https://doi.org/10.1037/a0026780

Clerc, O., Fort, M., Schwarzer, G., Krasotkina, A., Vilain, A., Méary, D., Lœvenbruck, H., & Pascalis, O. (2022). Can language modulate perceptual narrowing for faces? Other-race face recognition in infants is modulated by language experience. *International Journal of Behavioral Development, 46*(2), 83–90. https://doi.org/10.1177/01650254211053054

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Fiser, J., & Aslin, R. N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences of the United States of America, 99*(24), 15822–15826. https://doi.org/10.1073/pnas.232472899

Heering, A. de, Liedekerke, C. de, Deboni, M., & Rossion, B. (2010). The role of experience during childhood in shaping the other-race effect. *Developmental Science, 13*(1), 181–187. https://doi.org/10.1111/j.1467-7687.2009.00876.x

Heron-Delaney, M., Anzures, G., Herbert, J. S., Quinn, P. C., Slater, A. M., Tanaka, J. W., Lee, K., & Pascalis, O. (2011). Perceptual training prevents the emergence of the other race effect during infancy. *PLOS ONE, 6*(5), Article e19858. https://doi.org/10.1371/journal.pone.0019858

Junge, C., van Rooijen, R., & Raijmakers, M. (2018). Distributional Information Shapes Infants' Categorization of Objects. *Infancy, 23*(6), 917–926. https://doi.org/10.1111/infa.12258

Kelly, D. J., Liu, S., Ge, L., Quinn, P. C., Slater, A. M., Lee, K., Liu, Q., & Pascalis, O. (2007). Cross-race preferences for same-race faces extend beyond the african versus caucasian contrast in 3-month-old infants. *Infancy, 11*(1), 87–95. https://doi.org/10.1207/s15327078in1101_4

Kelly, D. J., Liu, S., Lee, K., Quinn, P. C., Pascalis, O., Slater, A. M., & Ge, L. (2009). Development of the other-race effect during infancy: Evidence toward universality? *Journal of Experimental Child Psychology, 104*(1), 105–114. https://doi.org/10.1016/j.jecp.2009.01.006

Kelly, D. J., Quinn, P. C., Slater, A. M., Lee, K., Ge, L., & Pascalis, O. (2007). The other-race effect develops during infancy: Evidence of perceptual narrowing. *Psychological Science, 18*(12), 1084–1089. https://doi.org/10.1111/j.1467-9280.2007.02029.x

Krasotkina, A., Götz, A., Höhle, B., & Schwarzer, G. (2018). Perceptual narrowing in speech and face recognition: Evidence for intra-individual cross-domain relations. *Frontiers in Psychology, 9*, 1711. https://doi.org/10.3389/fpsyg.2018.01711

Krasotkina, A., Götz, A., Höhle, B., & Schwarzer, G. (2020). Infants' gaze patterns for same-race and other-race faces, and the other-race effect. *Brain Sciences, 10*(6). https://doi.org/10.3390/brainsci10060331

Krasotkina, A., Götz, A., Höhle, B., & Schwarzer, G. (2021). Bimodal familiarization re-sensitizes 12-month-old infants to other-race faces. *Infant Behavior & Development, 62*, Article 101502. https://doi.org/10.1016/j.infbeh.2020.101502

Markant, J., Oakes, L. M., & Amso, D. (2016). Visual selective attention biases contribute to the other-race effect among 9-month-old infants. *Developmental Psychobiology, 58*(3), 355–365. https://doi.org/10.1002/dev.21375

Maurer, D., & Werker, J. F. (2014). Perceptual narrowing during infancy: A comparison of language and faces. *Developmental Psychobiology, 56*(2), 154–178. https://doi.org/10.1002/dev.21177

Maye, J., Werker, J. F., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition, 82*(3), B101–B111. https://doi.org/10.1016/S0010-0277(01)00157-3

McKone, E., Wan, L., Pidcock, M., Crookes, K., Reynolds, K., Dawel, A., Kidd, E., & Fiorentini, C. (2019). A critical period for faces: Other-race face recognition is improved by childhood but not adult social contact. *Scientific Reports, 9*(1), Article 12820. https://doi.org/10.1038/s41598-019-49202-0

Minar, N. J., & Lewkowicz, D. J. (2018). Overcoming the other-race effect in infancy with multisensory redundancy: 10-12-month-olds discriminate dynamic other-race faces producing speech. *Developmental Science, 21*(4), Article e12604. https://doi.org/10.1111/desc.12604

Pascalis, O., Haan, M. de, & Nelson, C. A. (2002). Is face processing species-specific during the first year of life. *Science, 296*(5571), 1321–1323. https://doi.org/10.1126/science.1070223

Paul, M., Männel, C., van der Kant, A., Mueller, J. L., Höhle, B., Wartenburger, I., & Friederici, A. D. (2021). Gradual development of non-adjacent dependency learning during early childhood. *Developmental Cognitive Neuroscience, 50*, Article 100975. https://doi.org/10.1016/j.dcn.2021.100975

Quinn, P. C., Lee, K., Pascalis, O., & Xiao, N. G. (2020). Emotional expressions reinstate recognition of other-race faces in infants following perceptual narrowing. *Developmental Psychology, 56*(1), 15–27. https://doi.org/10.1037/dev0000858

Saffran, J. R., & Kirkham, N. Z. (2018). Infant statistical learning. *Annual Review of Psychology, 69*, 181–203. https://doi.org/10.1146/annurev-psych-122216-011805

Sangrigoli, S., Pallier, C., Argenti, A.-M., Ventureyra, V. A. G., & Schonen, S. de [S.] (2005). Reversibility of the other-race effect in face recognition during childhood. *Psychological Science, 16*(6), 440–444. https://doi.org/10.1111/j.0956-7976.2005.01554.x

Sangrigoli, S., & Schonen, S. de [Scania] (2004). Effect of visual experience on face processing: A developmental study of inversion and non-native effects. *Developmental Science, 7*(1), 74–87. https://doi.org/10.1111/j.1467-7687.2004.00324.x

Schapiro, A. C., Gregory, E., Landau, B., McCloskey, M., & Turk-Browne, N. B. (2014). The necessity of the medial temporal lobe for statistical learning. *Journal of Cognitive Neuroscience, 26*(8), 1736–1747. https://doi.org/10.1162/jocn_a_00578

Schapiro, A. C., & Turk-Browne, N. (2015). Statistical Learning. *In Brain Mapping* (pp. 501–506). Elsevier,. https://doi.org/10.1016/B978-0-12-397025-1.00276-1

Slater, A., Quinn, P. C., Kelly, D. J., Lee, K., Longmore, C. A., McDonald, P. R., & Pascalis, O. (2010). The shaping of the face space in early infancy: Becoming a native face processor. *Child Development Perspectives, 4*(3), 205–211. https://doi.org/10.1111/j.1750-8606.2010.00147.x

Smith, L. B., Jayaraman, S., Clerkin, E., & Yu, C. (2018). The developing infant creates a curriculum for statistical learning. *Trends in Cognitive Sciences, 22*(4), 325–336. https://doi.org/10.1016/j.tics.2018.02.004

Spangler, S. M., Schwarzer, G., Freitag, C., Vierhaus, M., Teubert, M., Fassbender, I., Lohaus, A., Kolling, T., Graf, F., Goertz, C., Knopf, M., Lamm, B., & Keller, H. (2013). The other-race effect in a longitudinal sample of 3-, 6- and 9-month-old infants: Evidence of a training effect. *Infancy, 18*(4), 516–533. https://doi.org/10.1111/j.1532-7078.2012.00137.x

Sugden, N. A., & Marquis, A. R. (2017). Meta-analytic review of the development of face discrimination in infancy: Face race, face gender, infant age, and methodology moderate face discrimination. *Psychological Bulletin, 143*(11), 1201–1244. https://doi.org/10.1037/bul0000116

Suhrke, J., Freitag, C., Lamm, B., Teiser, J., Fassbender, I., Poloczek, S., Teubert, M., Voehringer, I. A., Keller, H., Knopf, M., Lohaus, A., & Schwarzer, G. (2014). The other-race effect in 3-year-old German and Cameroonian children. *Frontiers in Psychology, 5*, 198. https://doi.org/10.3389/fpsyg.2014.00198

Suhrke, J., Freitag, C., Lamm, B., Teiser, J., Poloczek, S., Fassbender, I., Teubert, M., Voehringer, I., Keller, H., Knopf, M., Lohaus, A., & Schwarzer, G. (2015). Experience with headwear influences the other-race effect in 4-year-old children. *Journal of Experimental Child Psychology, 137*, 156–163. https://doi.org/10.1016/j.jecp.2015.03.011

Valentine, T., Lewis, M. B., & Hills, P. J. (2016). Face-space: A unifying concept in face recognition research. *Quarterly Journal of Experimental Psychology (2006), 69* (10), 1996–2019. https://doi.org/10.1080/17470218.2014.990392

Yoshida, K. A., Pons, F., Maye, J., & Werker, J. F. (2010). Distributional phonetic learning at 10 months of age. *Infancy: The Official Journal of the International Society on Infant Studies, 15*(4), 420–433. https://doi.org/10.1111/j.1532-7078.2009.00024.x