Neural Correlates of Subordinate-Level Categorization of Own- and Other-Race Faces in Infancy

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ABSTRACT

Perceptual narrowing is a domain-general process in which infants move from a broad sensitivity to a wide range of stimuli to developing expertise within often experienced native stimuli (Maurer & Werker, 2014). One outcome of this is the own-race bias, characterized by an increasing difficulty in discriminating other-race faces with age and experience for those raised in a racially homogenous environment (Anzures, Quinn, Pascalis, Slater, Tanaka, & Lee, 2013). Theorists have proposed that this is due to a categorization-individuation process, wherein infants begin to categorize non-native stimuli but continue to individuate native stimuli (Hugenberg, Young, Bernstein, & Sacco, 2010; Nelson, 2001). Exposure to multiple exemplars during initial learning has been found to facilitate infant categorization of other-species faces while exposure to a single exemplar does not (Dixon, Reynolds, Romano, Roth, Stumpe, Guy, & Mosteller, 2019). The goal of this study was to investigate the effects of initial learning conditions on infants' ability to individuate and categorize own- and other-race faces. Ten-month-old infants were familiarized with a single exemplar or multiple exemplars of own- or other-race faces. Event-related potentials (ERPs) were recorded while infants were presented with the familiar face(s) they were exposed to during familiarization, novel faces from the same race used during familiarization, and novel faces from a race other than the one used in familiarization. Infants familiarized with a single exemplar, regardless of race, showed significant differences in both the Nc component (associated with visual attention) and the LSW (associated with recognition memory) between familiar and novel faces at the subordinate-level category of race. No differences were found across conditions for the P400 component associated with face processing. Infants familiarized with multiple exemplars showed no evidence of discriminating faces at the categorical or individual level. Results suggest that in contrast to other-species faces, infants at this age may process human faces more efficiently when familiarized with a single exemplar. The implications of the current findings are discussed in relation to the impact of initial learning conditions on infants' ability to individuate and categorize own- and other-species faces and social implications of infants' processing of other-race faces.

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1. INTRODUCTION

Perceptual narrowing is a developmental phenomenon that occurs as infants' initial broad sensitivity to a wide range of stimuli narrows down to focus on pertinent information they are regularly exposed to in their native environment. Perceptual narrowing is believed to be a necessary process involved in developing expertise in a given area of functioning. During the early stages of the development of face perception, perceptual narrowing is characterized by an increase in perceptual sensitivity for native faces (e.g., same-species faces) and a reduction in perceptual sensitivity to non-native faces (e.g., other-species faces). For example, 6-month-old infants are able to recognize a previously seen monkey face and discriminate the "familiar" monkey face from a novel monkey face. In contrast, 9-month-old human infants no longer demonstrate the ability to discriminate familiar from novel monkey faces but maintain this ability with human faces (Pascalis, de Haan, & Nelson, 2002).

Studies utilizing picture books for training have shown that perceptual narrowing for other-species faces is malleable between 6 and 9 months of age. For example, Scott and Monesson (2009) provided picture books of monkey faces for parents to show their infants on a regular basis between 6 and 9 months. Three types of training conditions were used: individual training (monkey faces were labeled with individual names), category training (monkey faces were all labeled categorically "monkey"), and exposure training (monkey faces were not labeled). At 9 months of age, the infants were tested in a preferential looking recognition memory task using monkey faces not included in the training books. Only infants who received individual training were able to discriminate novel from familiar monkey faces during testing. These findings indicate that individual training and label learning (but not category training or mere exposure) allowed the infants to maintain the ability to discriminate other-species faces at the individual level at an age when they would no longer be able to do so without training.

Follow-up studies using neural (event-related potentials/ERP) measures have found that infants who receive individual training show evidence of neural specialization at 9 months of age for the class of stimuli they receive training with, and infants who receive category-level training do not. For example, Scott and Monesson (2010) found that infants who received category training of monkey faces (all faces labeled "monkey") did not demonstrate inversion effects, implying they were less sensitive when processing the faces. The face inversion effect is an index of face specialization and refers to the disproportionately greater difficulty in processing inverted (upside-down) faces compared to inverted non-face stimuli (Cashon & Holt, 2015). Similarly, infants trained from 6 to 9 months of age at the individual level with picture books of computer-generated novel objects showed greater Nc ERP amplitude to infrequent compared to frequently presented stimuli, while those trained at the category level did not differentiate by frequency of individual stimulus presentation (Pickron, Iyer, Fava, & Scott, 2018). The Nc, or negative central, is a negatively polarized ERP component that peaks around 350 to 750 milliseconds after stimulus onset over frontal and midline electrodes and is associated with infant attention. Nc provides an index of infant attention with a greater Nc amplitude associated with greater attentional engagement (Guy, Zieber, & Richards, 2016; Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005, 2009; Richards, 2003). Past work utilizing cortical source analysis with infant participants has identified areas of prefrontal cortex, including anterior cingulate cortex, as sources of the Nc (Reynolds & Richards, 2005, Reynolds et al., 2010).

In Scott and Monesson's 2010 study, infants who received individual training with monkey faces (each monkey had an individually labeled name) demonstrated inversion effects on the N290 and P400 ERP components associated with infant face processing, implying a greater sensitivity when processing the faces. The N290 is an infant face processing component marked by negative amplitude peak about 290 milliseconds from stimulus onset. It is larger in amplitude to inverted human but not inverted monkey faces, indicating it is tied to holistic processing and not individual recognition. The N290, as well as the P400, is thought to be a precursor to the adult N170 as it is similarly sensitive to human faces compared to non-face stimuli such as objects (Conte, Richards, Guy, Xie, & Roberts, 2020; de Haan, Johnson, & Halit, 2003; Dixon, Reynolds, Romano, Roth, Stumpe, Guy, & Mosteller, 2019). The P400 is an infant ERP component associated with face processing, as it has a shorter latency to faces over non-faces in young infants and becomes more sensitive to upright human faces with age (Halit, de Haan, & Johnson, 2003). Importantly, the P400 has also been shown to be associated with subordinate-level categorization in infancy (Dixon et al., 2019; Quinn Doran, Reiss, & Hoffman, 2010; Scott, Monesson, & Buchinski, 2008; Xie et al., 2010). Categorization literature focuses on three types: superordinate-level, which are very broad or general categories (e.g., animate, inanimate); basic-level, which are generic categories based on perceptual characteristics nested within superordinate-level categories (e.g., cats, dogs); and subordinate-level, which are more inclusive and specific categories nested within basic-level categories (e.g., coat colors of cats: cow cat, tortoiseshell cat). The P400 is manifested as a positively polarized change in ERP amplitude that occurs approximately 400 milliseconds post stimulus onset at posterior electrodes (de Haan, Johnson, & Halit, 2003; Dixon et al., 2019). Studies utilizing source analysis with infant participants have shown that the posterior cingulate cortex is a potential cortical source of the P400 (Conte, Richards, Guy, Xie, & Roberts, 2020; Guy, Zieber, & Richards, 2016; Xie, McCormick, Westerlund, Bowman, & Nelson, 2018).

Taken together, these findings indicate that perceptual narrowing in face processing may be related to the development of categorization. Infants may begin to categorize non-native faces unless explicitly trained to individuate (Scott, 2011; Scott & Monesson, 2009, 2010). Perceptual narrowing is also related to the own-race bias. Infants raised in a racially homogenous environment demonstrate a decreased ability to discriminate other-race faces with increasing age (Anzures, Quinn, Pascalis, Slater, Tanaka, & Lee, 2013; Kelly et al., 2007; Kelly et al., 2005). Recent theorists have thus proposed that own-species and own-race biases are due to a categorization-individuation process (Hugenberg, Young, Bernstein, & Sacco, 2010; Nelson, 2001; Pascalis, de Haan, & Nelson, 2002; Reynolds & Roth, 2018; Scott & Monesson, 2010).

1.1 Social Implications of Own-Race Bias

In racially homogenous environments, infants are repeatedly exposed to individual own-race members and rarely encounter other-race faces. Because these infants lack exposure to other-race faces, researchers have theorized infants begin to categorize other-race faces as a conceptually homogenous group that encompasses any race that does not belong to the infant's own-race, despite perceptual dissimilarities like color differences (Lee, Quinn, & Heyman, 2017; Lee, Quinn, & Pascalis, 2017; Quinn, 2019; Quinn, Lee, & Pascalis, 2019; Quinn, Lee, Pascalis, & Tanaka, 2016). With repeated positive experiences with own-race members, own-race individuals become conceptualized as trustworthy and friendly (Lee, Quinn, & Heyman, 2017; Lee, Quinn, & Pascalis, 2017; Xiao, Quinn, Lee, & Pascalis, 2018). Since other-race groups are categorized as distinct from the positive associations experienced with own-race members, this can lead to members of other-race groups being interpreted negatively in childhood (Dunham, Chen, & Banaji, 2013; Katz & Kofkin, 1997; Setoh, Lee, Zhang, Qian, Quinn, Heyman, & Lee, 2018). For example, 7-month-old Chinese infants are more likely to rely on gaze cues from own-race faces than other-race faces if the cues are not 100% accurate or 100% inaccurate. This means in situations of uncertainty, infants are more likely to rely on own-race than other-race individuals (Xiao, Wu, Quinn, Liu, Tummeltshammer, Kirkham, …, & Lee, 2018). Furthermore, 9-month-old Chinese infants associate own-race Chinese faces with happy music and other-race Black faces with sad music, but 6-month-olds do not show this association (Xiao, Quinn, Liu, Ge, Pascalis, & Lee, 2018). Other consequences beyond a simple visual preference for own-race faces include more in-depth facial scanning of own-race faces, attributing more positive emotions with own-race faces, trusting own-race faces more, and other positive social biases for own-race faces (Xiao, Quinn, Lee, & Pascalis, 2017).

Studying how early attentional biases associated with face processing can later develop into social biases has implications for infant development as well as our understanding of child and adult social prejudices. Children belonging to a majority racial group show stronger own-race positive biases, and children belonging to minority racial groups are less likely to show a positive bias for their own-race (Dunham, Baron, & Banaji, 2008; Dunham, Chen, & Banaji, 2013; Setoh, Lee, Xhang, Qian, Quinn, Heyman, & Lee, 2018). Additionally, children's' ability to sort faces by race predicts their implicit association test (IAT) results on racial biases (Setoh, et al., 2018). The individuation of own-race faces, and subsequent categorization of other-race faces, can potentially incorporate negative social associations, laying the groundwork for racial biases to form as children grow older and integrate additional social context. Thus, this early categorization of other-race faces as separate from own-race faces in infancy has social consequences in later years. It is important to investigate what mitigating factors are involved with this category formation process (Heron-Delaney, et al., 2011; Lee, Quinn, & Heyman, 2017; Lee, Quinn, & Pascalis, 2017; Loyd & Gaither, 2018; Pauker, Williams, & Steele, 2017; Sullivan, Wilton, & Apfelbaum, 2020; Qian et al., 2017a, 2017b; Quinn, 2019; Xiao et al., 2015; Zucker & Patterson, 2018).

1.2 Category Formation in Infancy

Previous work on infant category formation has shown that experiencing multiple exemplars during initial exposure enhances learning in infancy. For example, infants at 3.5, 4.5, and 6.5 months of age are more likely to show evidence of recognition of an object if it is presented paired with another object during familiarization than if the object is presented by itself during familiarization (Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). Furthermore, 4-month-old infants demonstrate basic-level categorization of cats and dogs when given simultaneous presentations of two exemplars during learning, but they do not demonstrate this level of learning when exposed to single presentations of exemplars (Oakes & Ribar, 2005). In general, exposure to multiple exemplars appears to enhance infant processing and recognition of stimuli over exposure to a single exemplar (e.g., Casasola & Park, 2013; Dixon, Reynolds, Romano, Roth, Stumpe, Guy, & Mosteller, 2019; Oakes, Kovack-Lesh, & Horst, 2009; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982; Vukatana, 2017; Vukatana, Graham, Curtin, & Zepeda, 2015).

Dixon and colleagues (2019) investigated the potential effects of initial learning conditions on subordinate-level categorization of other-species in infancy. While previous studies had examined infants' categorization of animals at 6 months of age (Quinn, Westerlund, & Nelson, 2006), this was the first study to examine older infants' subordinate-level categorization of non-human primate faces after the onset of perceptual narrowing. Using ERP, 9-month-old infants were shown repeated presentations of either a single exemplar or multiple exemplars of a monkey species (either capuchin or macaque) during familiarization. During test trials, infants then viewed the familiar exemplar(s) (familiar trials), novel exemplars from the *same* species as the familiarized category (novel-*same* trials), and novel exemplars from a novel category of *other* species of monkey (novel-*other* trials).

The results revealed several interesting findings. Infants who were familiarized with multiple exemplars showed greater Nc amplitude to novel-other (novel category exemplars) compared to familiar and novel-same trials. Infants also showed a greater P400 amplitude to novel-other trials in comparison to familiar and novel-same trials. Finally, the multiple exemplars familiarization condition in Dixon et al. (2019) also showed significant differences in late slow wave (LSW) amplitude associated with recognition memory at left frontal electrodes between familiar and novel-other trials. The LSW occurs from approximately 750 to 2000 milliseconds after stimulus onset and is most often located at temporal and anterior electrode sites (de Haan, 2007, 2013; Guy, Reynolds, & Zhang, 2013). Because the polarity and directional change of the LSW can vary across electrode sites and tasks, specific predictions regarding the direction of LSW effects can be problematic (see de Haan, 2007 and Guy et al., 2013 for more extensive discussions related to this point). However, the LSW has been consistently shown to demonstrate differential amplitude based on stimulus repetition or novelty/familiarity, thus changes in amplitude of the LSW are assumed to reflect perceptual processing and recognition memory in infancy (de Haan & Nelson, 1999; Guy, Reynolds, Mosteller, & Dixon, 2017; Guy, Reynolds, & Zhang, 2013; Nelson & Collins, 1991, 1992; Reynolds, Guy, & Zhang, 2011; Snyder, Garza, Zolot, & Kresse, 2010; Snyder, Webb, & Nelson, 2002; Webb, Long, & Nelson, 2005; Wiebe, Cheatham, Lukowski, Haight, Muehleck, & Bauer, 2006).

In summary, the findings from the multiple exemplars familiarization condition show infants processed the monkey faces at the subordinate-level based on species, as opposed to based simply on novelty and familiarity. In contrast to the multiple exemplars familiarization condition, infants in the single exemplar familiarization condition showed no difference in Nc, P400, or LSW amplitude between any of the trial types (familiar, novel-same, novel-other). Thus, when familiarized with multiple exemplars of other-species faces, 9-month-old infants demonstrated subordinate-level categorization based on monkey species. In contrast, if infants were only familiarized with a single category exemplar, they showed no evidence of either subordinate-level categorization or individuation (Dixon et al., 2019).

1.3 Current Study

Findings from the extant literature indicate that perceptual narrowing within the first year of life results in the own-race bias for infants who experience a racially homogenous environment (Anzures et al., 2013). The own-race bias leads to reduced ability to discriminate novel from familiar other-race faces with increased age in infancy (Lewkowicz, 2014; Mauer & Werker, 2014; Quinn, Lee, & Pascalis, 2018). Eventually, infants begin to combine other-race faces into a single category and stop differentiating between subordinate-level categories of other-race faces, potentially categorizing them all together as “not own-race” (Kelly, Quinn, Slater, Lee, Ge, & Pascalis, 2007; Kelly, Liu, Lee, Quinn, Pascalis, Slater, & Ge, 2009; Quinn, Lee, Pascalis, & Tanaka, 2016). However, as described above, Dixon et al. (2019) found that 9-month-old infants can form subordinate-level categories of *other-species* faces when shown multiple exemplars during learning, allowing for differentiation between two other-species groups. Conversely, familiarization with a single exemplar of an other-species face does not allow for differentiation between two other-species categories at this age (Dixon et al., 2019).

Presumably, as the own-race bias and the own-species bias are both related to perceptual narrowing and categorization, it is likely that similar cognitive processes are involved in infants' categorization of human faces based on race as those involved in infants' categorization of other-species' faces.

The proposed study investigated whether initial learning conditions affect 10-month-old infants' ability to form subordinate-level categories of own- and other-race faces. Similar to the procedure used by Dixon et al. (2019), this was tested by showing 10-month-old infants either multiple exemplars or a single-exemplar of either own-race or other-race faces during familiarization. Neural correlates of infant attention (Nc), face processing (P400), and recognition memory (LSW) were analyzed in response to the face(s) shown during familiarization (familiar), novel faces from the same race used during familiarization (novel-same), and novel faces from a race not used during familiarization (novel-other).

2. PREDICTIONS

2.1 Own-Race Familiarization Conditions

In the own-race familiarization conditions, because infants have had heavy exposure to and presumably begun to develop expertise at processing faces of their own-race, we expected infants familiarized with a single exemplar would show evidence of individuation (discrimination between the familiar face and novel-same race faces) as well as evidence of subordinate-level categorization based on race (discrimination between novel-same race faces and novel-other race faces). Thus, it was predicted that infants in the own-race, single exemplar familiarization condition would show greater Nc amplitude (i.e., greater attention) to both novel-other and novel-same faces in comparison to the familiar face. However, for the P400 associated with subordinate-level category detection (Dixon et al., 2019; Quinn et al., 2010), it was predicted infants would show greater P400 amplitude to novel-other faces in comparison to novel-same and familiar faces but no differences in P400 amplitude between the familiar face and novel-same faces. Similar to the Nc, for the LSW component associated with recognition memory, it was predicted infants would show differential LSW amplitude to both novel-other faces and novel-same faces compared to the familiar face.

For the own-race, multiple exemplars familiarization condition, we predicted infants would demonstrate greater amplitude Nc and attention to novel-other faces in comparison to familiar and novel-same faces. We predicted no differences in Nc amplitude between familiar faces and novel-same faces. We expected the P400 results to mirror the Nc results. Similarly, for the LSW we expected differential amplitude to the novel-other faces in comparison to the familiar and novel-same faces, but no differences between LSW amplitude to the familiar faces in comparison to the novel-same faces. These sets of findings would indicate subordinate-level categorization based on race but a lack of individuation of the familiar face from novel-same faces due to the very brief exposure to individuals infants in this familiarization condition would receive.

2.2 Other-Race Familiarization Conditions

For the other-race, single exemplar familiarization condition, we predicted no significant differences in Nc, P400, or LSW amplitude across all face categories, which would indicate a failure to both individuate the familiar face and categorize other-race faces at the subordinate-level. We expected a single exemplar of an other-race face would not be enough exposure to overcome the own-race bias in later recognition trials.

For the other-race, multiple exemplars familiarization condition, however, it was predicted that infants would show greater Nc and P400 amplitude to the novel-other faces compared to familiar and novel-same faces, but no differences in Nc and P400 amplitude between the familiar faces and novel-same faces based on previous findings indicating exposure to multiple exemplars during initial learning facilitates subordinate-level categorization of other-species faces (Dixon et al., 2019). Similarly, it was predicted that infants familiarized to multiple exemplars would demonstrate differential LSW amplitude for the novel-other faces in comparison to the familiar and novel-same faces. These findings would indicate subordinate-level categorization of faces based on race, but a lack of individuation of familiar faces compared to novel faces of the same race (novel-same).

3. METHODS

3.1 Participants

All procedures associated with this study followed a protocol approved by the Institutional Review Board of the BLINDED FOR REVIEW and were carried out in accordance with relevant guidelines and regulations. The final dataset included 46 10-month-old infants. Sample size was based on previous studies with similar procedures and designs (Dixon et al., 2019; Guy, Reynolds, Mosteller, & Dixon, 2017; Guy, Reynolds, & Zhang, 2013; Quinn et al., 2010; Pickron et al., 2018; Scott & Monesson, 2010). Participants were randomly assigned to one of the four familiarization conditions: own-race, single exemplar ($N = 10$); own-race, multiple exemplars ($N = 12$); other-race, single exemplar ($N = 13$); and other-race, multiple exemplars ($N = 11$). Two versions of each familiarization condition were created for between-subjects counterbalancing of the exemplar faces used during familiarization. Thus, for the single exemplar conditions, one of two possible faces were used for familiarization and the face that was used was counterbalanced across participants. For the multiple exemplars conditions, the set of 10 faces used for familiarization and the set of 10 faces used as novel faces were counterbalanced across participants.

All infants were recruited for participation in the USA and tested within three weeks of their 10-month birthdate. Mean age of testing was 308.61 days (*SD* = 5.93, *range* = 298 - 320). Eligible infants included those who were born full-term (no less than 37 weeks gestation) without any major complications during pregnancy or birth, and who had no known visual difficulties or other developmental issues. Participants were recruited without regard to race, ethnicity, or gender, but it was expected that the majority of infants would be White due to the demographics of the local population. Participants included 42 Non-Hispanic White infants and 4 Hispanic White infants (23 females, 23 males). An additional 43 infants were tested but excluded due to fussiness ($N = 10$), not enough artifact free ERP trials ($N = 27$), or technical difficulties ($N = 6$). Additionally, 14 infants were excluded from this dataset due to identifying as a race other than Non-Hispanic White or Hispanic White but are included in an ongoing dataset exploring how minority race infants process majority and minority race faces.

3.2 Apparatus

Testing took place in a sound-attenuated darkened room. Participants were positioned in their caregiver's lap approximately 55 centimeters away from a color monitor (27-inch Dell

Gaming Monitor S2716DG). Black cloth curtains were drawn to surround the infant and caregiver to ensure attention was paid to the monitor and distractions were minimized. Infant attention to the screen was logged via a digital video recorder positioned directly above the monitor (AXIS P3364-LV Network Camera). During testing, infant looking to the screen was judged online using a video feed to the experiment control room during the study. The camera footage was recorded and synchronized with EEG data through NetStation 5.4.1.2 software (Electrical Geodesics Incorporated, EGI; Eugene, Oregon). E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA) was used to display the experimental stimuli onscreen and to send experimental events to NetStation, which utilizes a NTP (Network Time Protocol) process to synchronize these stimulus events with the EEG and video data.

3.3 Visual Stimuli

Stimuli for this experiment were sourced from The Chicago Face Database, which is a digital collection of high-resolution full-color photographs of human faces of various races, genders, and ages expressing different emotions (Ma, Correll, & Wittenbrink, 2015). Stimuli for this study were chosen based on extensive norming data included with the database. Additionally, the stimuli in the database were subjected to extensive standardization and luminance testing to ensure visual perceptual qualities were controlled for. Options were constrained to women actors to avoid possible gender interaction effects on categorization of race (Tham, Bremner, & Hay, 2015; Tham, Woo, & Bremner, 2018). Additionally, past studies have shown infants usually demonstrate visual preferences for female over male faces (e.g., Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002; Reynolds & Roth, 2018), thus we elected to use female faces to maximize the number of trials participants would complete during testing. Neutral expressions were chosen to avoid any interaction effects with faces displaying a highly salient emotion (Quinn, Lee, & Pascalis, 2020). First, all pictures of White, Black, and Asian women displaying a neutral expression were selected. Within each race, photos were narrowed down based on age to exclude very young or very old faces to avoid possible age interaction effects on categorization of race (Damon, Quinn, Heron-Delaney, Lee, & Pascalis, 2016). Finally, a total of 60 faces were chosen (20 White, 20 Black, and 20 Asian faces) to be included in the final dataset based on what proportion of independent raters agreed the race of the face matched the self-identified race of the actor. The rating proportion was created by taking the number of participants who indicated the selected race and dividing that by the number of people who rated the face. A score of 1.0 indicates all raters agreed on the race of the actor. The 20 White faces all had a perfect 1.0 proportion; the 20 Black faces all had a perfect 1.0 proportion; the 20 Asian faces had an average rating of 0.95 (*SD* = 0.04, *range* = 0.88 - 1.0). The 1,087 independent raters of the Chicago Face Database had a high range of reliability, from 0.89 to 0.99, depending on the measure (Ma, Correll, & Wittenbrink, 2015).

Once the faces were selected, the images were run through a custom MATLAB script that cropped them to an oval shape (MATLAB R2018a version 9.4.0.813654. Natick, Massachusetts: The MathWorks Inc., 2018). Having the faces displayed as an oval reduced additional peripheral cues such as hairstyle and hair color. The resulting full-color ovals were presented against a white background in the center of the monitor (see Figure 1 for an example of both stimuli and procedure for each familiarization condition). Although many studies on own-race bias have used grayscale images to reduce perceptual differences between faces, it has been found that infants do not discriminate races by color (Bar-Haim, Ziv, Lamy, & Hodes, 2006) and that grayscale versus full-color has no effect on whether the own-race bias manifests in adults (Ito & Urland, 2003). Therefore, to maintain ecological validity, stimuli were presented in full-color.

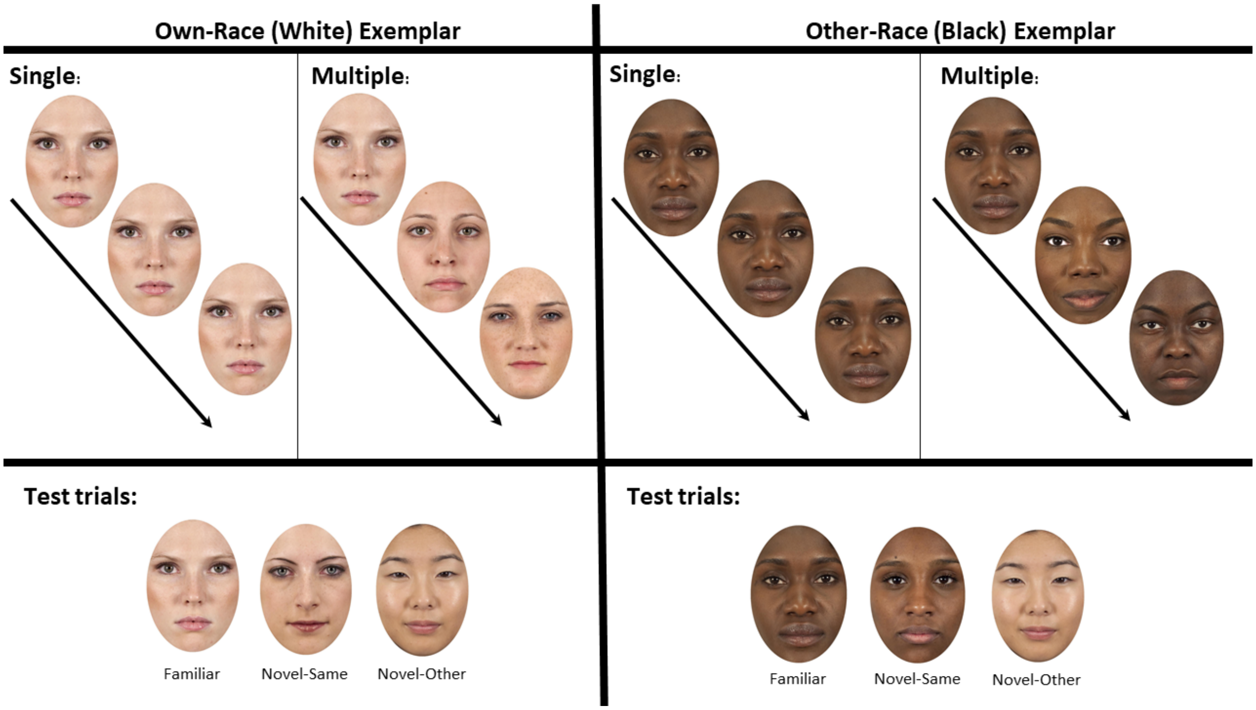

Figure 1. Sample stimuli and procedure for each familiarization condition.

The "own-race" familiarization condition in the experiment showed pictures of White actors as the familiar stimuli, and the "other-race" familiarization condition showed pictures of Black actors as the familiar stimuli. Past studies have shown that loss of sensitivity for White infants to other-race faces associated with perceptual narrowing occurs earlier for Black faces than for Asian faces (Kelly et al., 2007; Kelly et al., 2009). Thus, as a more stringent test of our hypothesis that exposure to multiple exemplars during familiarization would facilitate processing of other-race faces after perceptual narrowing has occurred, we elected to consistently use Black faces as the familiar race for the other-race familiarization condition. Both familiarization conditions, own-race and other-race, viewed Asian faces for the novel-other stimuli for test trials.

A dynamic non-social attention-getter was used between each face presentation during familiarization. A small colorful circle radiated centrally as a wind chime audio track played in the background. This attention-getter was used to ensure infants were centrally fixated during familiarization trials. During testing, Sesame Street audiovisual clips that did not feature human faces were used to redirect infants' attention if they became distracted or bored during the test trials.

3.4 Procedure

After informed consent was obtained, the infant's caregiver filled out a demographic survey. This survey was linked only with the participant's experimental ID number and asked family background and demographic information. Questions included asking the caregivers' occupation, level of education, and household income to determine socioeconomic status. Additional questions ascertained the caregivers' self-reported race, the race of the infant, and race, age, gender, and relationship to the infant of any other people living with or interacting often with the infant. There was also a question about whether the infant attended a daycare or other group setting often. This was to collect data on the likelihood that the infant was often exposed to other-race faces that differed from their caregivers' race(s). However, for this study, the infant participants had experienced either nearly exclusive exposure to own-race individuals or were from an interracial family. Therefore, infants were first excluded based on self-reported race of immediate family, and none of the remaining infants were excluded based on answers to the group setting question.

After informed consent and the background survey, the infant was seated on their caregiver's lap approximately 55 cm away from the monitor. An appropriately sized EGI sensor net was fitted as a second experimenter distracted the infant with toys and infant-directed speech to reduce the chance of fussiness. The experimental procedure was modeled after the Dixon et al. (2019) paradigm. There were two phases of the experiment: familiarization trials and test trials. The first phase consisted of 20 repeated 1000 ms presentations of a single face for the single exemplar familiarization conditions, or 10 faces repeated twice each for a total of 20 presentations for the multiple exemplars familiarization conditions. This resulted in 20 s total familiarization time for all four familiarization conditions, which is based on previous studies showing this is adequate for infants to show a novelty preference at this age (e.g., Courage & Howe, 2001; Richards, 1997; Rose, 1983; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). During familiarization, the attention-getter stimulus played between each face to ensure central fixation of the infant. Once the experimenter judged the infant to be centrally fixated, a button was pressed that centrally displayed a face image for 1000 ms. A 200 ms blank white screen preceded each image to be used as a pre-stimulus ERP baseline. A blank white screen also followed each stimulus presentation and varied randomly in duration from 1000 to 1500 milliseconds.

Immediately after the 20 familiarization trials were complete, the test trials began. There were three stimulus types shown during testing: depending on if it was a single or multiple exemplars familiarization condition, the face or faces used during the familiarization phase (familiar trials), novel faces from the same race as the face or faces shown during familiarization (novel-same trials), and novel Asian faces which were not used during any familiarization condition (novel-other trials). The presentation of the three stimulus types (familiar, novel-same, and novel-other) were presented in pseudo-random order with equal probability of presentation across a block of trials. Images were presented in blocks of 30 stimulus presentations. Stimulus presentation continued as long as the infant did not become tired or fussy. Infants included in the dataset completed an average of 108 test trials of stimulus presentations.

3.5 EEG Recording and Analysis

EEG data was collected using the EGI Geodesic EEG System 400 (GES 400) 128-channel system. This system includes HydroCel Geodesic Sensor nets, NetAmps hardware, and NetStation software recording program. The nets include 124 electrodes mounted in a geodesic configuration of pedestals that are held in place with elastic connections. Electrolytic sponges are located within the pedestals and the entire net is soaked in a saline-based electrolytic solution for five minutes prior to capping the infant. The additional 4 channels included in the 128-channel system are available for EOG (electrooculogram) and/or ECG (electrocardiogram) recording, which were not used in this study. During capping, pedestals corresponding to the vertex, mastoids, and nasion locations were marked and used to position the sensor net on the infant's head in relation to the anatomical landmarks. The elasticity of the net connections maintains the correct position of the pedestals corresponding to the remaining 120 electrodes. The average interelectrode distance of the scalp electrodes is 21 millimeters.

When placed properly, electrode impedance of the net ranged from 10 to 50 kΩ. If impedance exceeded 100 kΩ during net placement, the electrodes were repositioned until an appropriate impedance was obtained. The EGI system uses high-impedance amplifiers connected to a computer A/D card in an iMac computer. The EGI system's NetStation program performed the A/D sampling, stored calibrations for each channel, and stored impedance data. Communication between the two computers was temporally synchronized based on the sending of experimental information (e.g., trial type, trial onsets) from the experimental Dell computer to the NetStation program on the Mac using the E-Prime NTP. Bandpass filters were set from 0.10 to 30.00 Hz with 20k amplification and a sampling rate of 1000 Hz.

Once EEG data was collected, the recordings were inspected for artifacts (e.g., blinks, movement, saccades, drift, distraction) and poor recordings using the NetStation Review system. Artifacts were defined as Δ>250 μV/250 milliseconds within a single ERP segment and NetStation's Artifact Detection tool was used to mark trials bad if artifacts were found. Segments in which more than 10% of the channels were marked bad were excluded from analysis. For those that had less than 10% of the channels marked bad, bad channels were replaced using a spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989; Srinivasan, Tucker, & Murias, 1998). Following EEG editing, only participants who contributed 7 or more ERP trials per trial type for stable ERP averages were included for analysis (Carver & Vaccaro, 2007; de Haan & Nelson, 1997; Hoehl & Wahl, 2012; Reynolds & Richards, 2019). See Table 1 for average number of trials included in the analysis by familiarization condition. The number of trials included in the ERP averages did not differ significantly across familiarization conditions and trial types (*F*(6,84) .746, *p* = .615).

Table 1.
Average number of trials (SD) included in ERP averages by familiarization condition.

Familiarization Condition	Familiar Trials	Novel-Same Trials	Novel-Other Trials
Single Own-Race	16.50 (6.87)	15.10 (7.46)	15.80 (5.57)
Multiple Own-Race	14.75 (5.40)	15.17 (5.78)	15.08 (5.57)
Single Other-Race	16.92 (7.65)	17.31 (7.76)	17.08 (6.79)
Multiple Other-Race	20.18 (8.41)	18.36 (9.32)	20.27 (8.64)

As is standard practice in the field (DeBoer, Scott, & Nelson, 2007), electrode locations used for each ERP component were based on visual inspection of the grand average waveforms and previous studies (i.e., Nc component: Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005, 2009; Richards, 2003; P400 component: de Haan, Pascalis, & Johnson, 2002; Quinn, Doran, Reiss, & Hoffman, 2010; Xie, McCormick, Westerlund, Bowman, & Nelson, 2018; LSW component: de Haan & Nelson, 1999; Guy, Reynolds, & Zhang, 2013; Reynolds & Richards, 2019; Snyder, Webb, & Nelson, 2002; Webb, Long, & Nelson, 2005; Wiebe, Cheatham, Lukowski, Haight, Muehleck, & Bauer, 2006). The EEG was segmented from 200 ms before stimulus onset to 1500 ms after onset. Nc mean amplitude was analyzed from 345 to 600 milliseconds following stimulus onset at frontal-central electrode locations ("Fz", 5, 6, 12, 13, and 112). P400 mean amplitude was analyzed from 350 to 750 milliseconds following stimulus onset and analyzed at midline occipital electrodes ("Oz", 70, 74, 75, 82, and 83). The LSW mean amplitude was analyzed from 800 to 1500 milliseconds following stimulus onset at frontal-central electrode locations ("Fz", 5, 6, 12, 13, and 112). The stimuli and data from this study are publicly available at: insert public link here

4. RESULTS

To compare results across familiarization conditions, a full-factorial ANOVA was conducted. The familiarization conditions were separated based on number of exemplars and race. The design included the between-subjects factor of familiarized exemplars (2: single exemplar, multiple exemplars), the between-subjects factor of familiarized race (2: own-race, other-race), and the within-subjects factor of trial (3: familiar, novel-same, novel-other). Full factorial ANOVAs were run separately on the averages for each ERP component (Nc, P400, and LSW). For component analyses with significant interaction effects in the factorial analysis, follow-up analyses were run within each familiarization condition using ANOVA and paired-samples *t*-tests (two-tailed). IBM SPSS Statistics was used for these analyses (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp.). All significant tests are reported based on an alpha level of $p < .05$.

4.1 ERP Overview

4.1.1 The Nc Component

The Nc component showed trending significance for a two-way interaction of race and trial ($F(2,84) = 2.635$, $p = 0.078$, $\eta p^2 = 0.059$) and a significant three-way interaction of exemplar, race, and trial ($F(2,84) = 6.693$, $p = 0.002$, $\eta p^2 = 0.137$). Follow up analyses for the three-way interaction are reported by familiarization condition below.

4.1.2 The P400 Component

No significant differences were found across familiarization conditions in the full factorial analysis of the P400 component (all *p*s > .05), thus follow-up analyses are not reported. Figures for the ERP waveforms for the P400 component are provided as supplemental materials for the interested reader.

4.1.3 The LSW Component

The LSW showed a significant three-way interaction of exemplar, race, and trial ($F(2,84) = 4.563$, $p = 0.013$, $\eta p^2 = 0.098$). Follow-up analyses by familiarization conditions are reported below.

4.2 Own-Race Familiarization Conditions

4.2.1 Nc: Own-Race Familiarization Conditions

For the single exemplar, own-race familiarization condition, infants showed significantly greater Nc amplitude when viewing novel-other trials ($M = -9.329$, $SE = 2.166$) in comparison to familiar trials ($M = -4.734$, $SE = 2.816$), ($t(9) = 2.496$, $p = .034$). The difference in Nc amplitude for novel-other trials in comparison to novel-same trials approached significance ($M = -4.565$, $SE = 1.675$), ($t(9) = -2.217$, $p = .054$). Familiar trials and novel-same trials were not significantly different in amplitude ($t(9) = -0.058$, $p = .955$). Since results showed familiar and novel-same trials were not significantly different, these trial types were collapsed together to allow for a comparison by race. Results showed significantly greater Nc amplitude (*t*(9) = 3.411, *p* = .008) in response to the novel race category (*M* = -9.329, *SE* = 2.166) compared to the familiar race category (*M* = -4.649, *SE* = 1.802). See left panel of Figure 2.

For the multiple exemplars, own-race familiarization condition, there were no differences between familiar trials (*M* = -4.973, *SE* = 1.995) and novel-same trials (*M* = -8.446, *SE* = 2.018), (*t*(11) = 1.516, *p* = .158) or between familiar trials and novel-other trials (*M* = -4.179, *SE* = 1.075), (*t*(11) = -0.313, *p* = .760). There was trending significance for amplitude differences between novel-same trials and novel-other trials (*t*(11) = 1.857, *p* = .090). Since results showed familiar and novel-same trials were not significantly different, these trial types were collapsed together to allow for a comparison by race. Results showed no differences in Nc amplitude (*t*(11) = -1.187, *p* = .260) in response to the novel race category (*M* = -4.179, *SE* = 1.075) compared to the familiar race category (*M* = -6.710, *SE* = 1.647). See right panel of Figure 2.

We predicted that the Nc amplitude would differ by race for both own-race familiarization conditions. The single exemplar familiarization condition did support our predictions and showed infants differentiating the novel from the familiar race given the greater Nc amplitude when viewing novel-other trials. However, infants did not differentiate familiar from novel-same, meaning they did not individuate the single face they saw during familiarization like we predicted. Additionally, we predicted the same for the multiple exemplars familiarization condition, but the results were insignificant. The lack of Nc amplitude differences suggests infants who were familiarized to multiple own-race faces failed to differentiate by race or individual.

4.2.2 LSW: Own-Race Familiarization Conditions

For the single exemplar, own-race familiarization condition, no differences were found between familiar trials (*M* = 6.684, *SE* = 3.447) and novel-same trials (*M* = 7.776, *SE* = 1.842), (*t*(9) = -0.224, *p* = .827). The difference in LSW amplitude between familiar trials and novel-other trials (*M* = -0.983, *SE* = 2.910) (*t*(9) = 2.015, *p* = .075) approached significance. Similarly, the difference between novel-same trials and novel-other trials approached significance (*t*(9) = -2.068, *p* = .069). Since results showed familiar and novel-same trials were not significantly different, the average amplitude for both familiarized race trial types were collapsed together and compared to novel-other to compare infants' responses to the familiar race category to the novel race category. As can be seen in the left panel of Figure 2, the familiar race category had significantly greater LSW amplitude (*M* = 7.175, *SE* = 1.688) compared to the novel race category (*M* = -0.983, *SE* = 2.910), (*t*(9) = 2.437, *p* = .038).

For the multiple exemplars, own-race familiarization condition, there were no significant LSW amplitude differences. Familiar trials (*M* = 3.055, *SE* = 3.021) were not significantly different than novel-same trials (*M* = .151, *SE* = 2.753) (*t*(11) = 0.741, *p* = .474) or novel-other trials (*M* = 3.062, *SE* = 2.735) (*t*(11) = -0.001, *p* = .999). There were also no differences between novel-same trials and novel-other trials (*t*(11) = 0.680, *p* = .511). Since results showed familiar and novel-same trials were not significantly different, these trial types were collapsed together to allow for a comparison by race. Results showed no differences in LSW amplitude (*t*(11) = -0.337, *p* = .742) in response to the novel race category (*M* = 3.062, *SE* = 2.735) compared to the familiar race category (*M* = 1.603, *SE* = 2.124). See right panel of Figure 2.

We predicted that the LSW amplitude would differ by race for both own-race familiarization conditions. The single exemplar familiarization condition did support our predictions and showed infants differentiating the novel from the familiar race by LSW amplitude. Infants also showed no amplitude differences between familiar and novel-same trials, suggesting they are categorizing by race. However, infants did not differentiate familiar from novel-same, meaning they did not individuate the single face they saw during familiarization like we predicted. Additionally, we predicted the same for the multiple exemplars familiarization condition, but the results were insignificant. The lack of LSW amplitude differences suggests infants who were familiarized to multiple own-race faces failed to differentiate by race or individual.

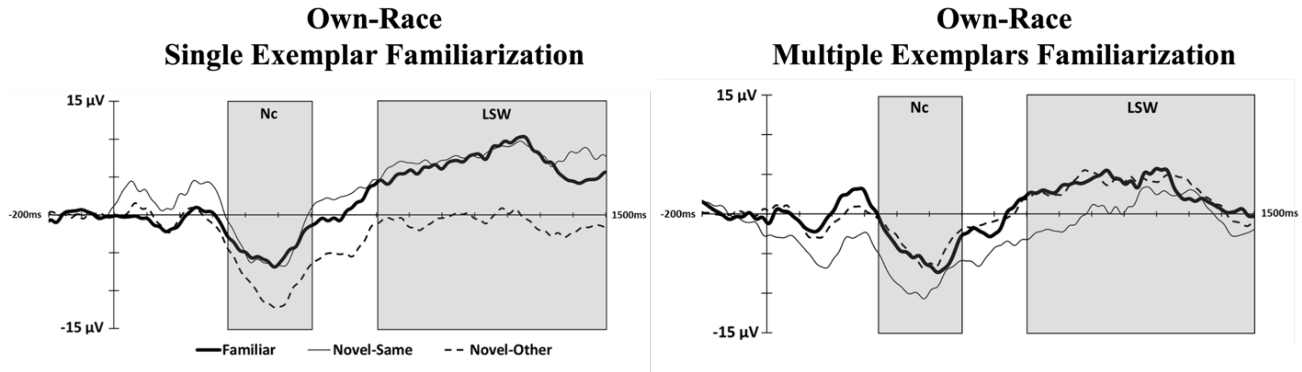

Figure 2. Nc and LSW components by stimulus type at frontal-central electrodes for the own-race familiarization conditions. The single exemplar familiarization condition is shown on the left panel and the multiple exemplars familiarization condition is shown on the right panel. Familiar trials are represented with a thick solid line. Novel-same trials are represented with a thin sold line. Novel-other trials are represented with a dashed line. The y-axis represents amplitude in microvolts and the x-axis represents time in 100ms segments. Stimulus onset is at the x-axis and y-axis intersection. The shaded boxes represent the time windows for the analyses of the Nc component (345-600 ms) and the LSW (800-1500 ms).

4.3 Other-Race Familiarization Conditions

4.3.1 Nc: Other-Race Familiarization Conditions

For the single exemplar, other-race familiarization condition, infants showed significantly greater amplitude Nc to familiar trials (*M* = -10.805, *SE* = 2.424) compared to novel-other trials (*M* = -2.813, *SE* = 2.484), (*t*(12) = -4.395, *p* = .001). Infants also showed significant Nc amplitude differences when viewing novel-other trials compared to novel-same trials (*M* = -10.100, *SE* = 2.276), (*t*(12) = 2.470, *p* = .030). Familiar and novel-same trials were not significantly different in amplitude (*t*(12) = -0.292, *p* = .775). Since results showed familiar and novel-same trials were not significantly different, an average of the amplitude for both trial types was compared to novel-other to compare the familiar race category to the novel race category. Results showed the familiar race category had significantly greater Nc amplitude (*M* = -10.452, *SE* = 2.017) compared to the novel race category (*M* = -2.813, *SE* = 2.484), (*t*(12) = -3.583, *p* = .004). See left panel of Figure 3.

For the multiple exemplars, other-race familiarization condition, there were no significant amplitude differences. Familiar trials (*M* = -4.332, *SE* = 1.653) were not significantly different than novel-same trials (*M* = -5.997, *SE* = 2.160) (*t*(10) = 0.631, *p* = .542) or novel-other trials (*M* = -5.573, *SE* = 1.333) (*t*(10) = 0.574, *p* = .578). There were also no differences between novel-same trials and novel-other trials (*t*(11) = 0.186, *p* = .857). Since results showed familiar and novel-same trials were not significantly different, these trial types were collapsed together to allow for a comparison by race. Results showed no differences in Nc amplitude (*t*(10) = 0.228, *p* = .824) in response to the novel race category (*M* = -5.573, *SE* = 1.333) compared to the familiar race category (*M* = -5.165, *SE* = 1.398). See right panel of Figure 3.

We predicted that the Nc amplitude would not differ by race for the single exemplar, other-race familiarization condition due to the own-race bias, but would differ for the multiple exemplars, other-race familiarization condition because of the facilitating effects of multiple exemplars. Also due to the own-race bias, we predicted the single exemplar, other-race familiarization condition would not show differential Nc amplitude between the familiar and novel-same trials, indicating the infants failed to individuate the familiar face. Interestingly, results show the opposite of our predictions. Infants who were familiarized with a single other-race face showed evidence of differentiating categorically by race but no evidence of individuating. Infants who were familiarized to multiple other-race exemplars had null results, suggesting they did not individuate nor categorize by race.

4.3.2 LSW: Other-Race Familiarization Conditions

For the single exemplar, other-race familiarization condition, there was a significant difference between familiar trials (*M* = 0.241, *SE* = 2.074) and novel-other trials (*M* = 7.437, *SE* = 3.135) (*t*(12) = -2.903, *p* = .013). There was also a significant difference between novel-same trials and novel-other trials (*t*(12) = 2.254, *p* = .044). There was no significant difference between familiar trials and novel-same trials (*M* = 0.191, *SE* = 1.500) (*t*(12) = 0.019, *p* = .985). Since results showed familiar and novel-same trials were not significantly different, an average of the amplitude for both trial types was compared to novel-other to compare the familiar race category to the novel race category. As shown in the left panel of Figure 3, the familiar race category had significantly lower LSW amplitude (*M* = 0.216, *SE* = 1.226) compared to the novel race category (*M* = 7.437, *SE* = 3.135) (*t*(12) = -2.839, *p* = .015).

For the multiple exemplars, other-race familiarization condition, there were no significant LSW amplitude differences. Familiar trials (*M* = 2.492, *SE* = 1.378) were not significantly different than novel-same trials (*M* = 4.856, *SE* = 2.852) (*t*(10) = -0.760, *p* = .465) or novel-other trials (*M* = 2.231, *SE* = 1.882) (*t*(10) = 0.115, *p* = .910). Novel-same trials and novel-other trials were not significantly different from each other (*t*(10) = -0.798, *p* = .443). Since results showed familiar and novel-same trials were not significantly different, these trial types were collapsed together to allow for a comparison by race. Results showed no differences in LSW amplitude (*t*(10) = 0.612, *p* = .554) in response to the novel race category (*M* = 2.231, *SE* = 1.882) compared to the familiar race category (*M* = 3.674, *SE* = 1.569). See right panel of Figure 3.

We predicted that the LSW amplitude would not differ by race for the single exemplar, other-race familiarization condition due to the own-race bias, but would differ for the multiple exemplars, other-race familiarization condition because of the facilitating effects of multiple exemplars. Also due to the own-race bias, we predicted the single exemplar, other-race familiarization condition would not show differential Nc amplitude between the familiar and novel-same trials, indicating the infants failed to individuate the familiar face. Interestingly, results show the opposite of our predictions. Infants who were familiarized with a single other-race face showed evidence of differentiating by race but no evidence of individuating. Infants who were familiarized to multiple other-race exemplars had no LSW amplitude differences, suggesting they did not individuate nor categorize by race.

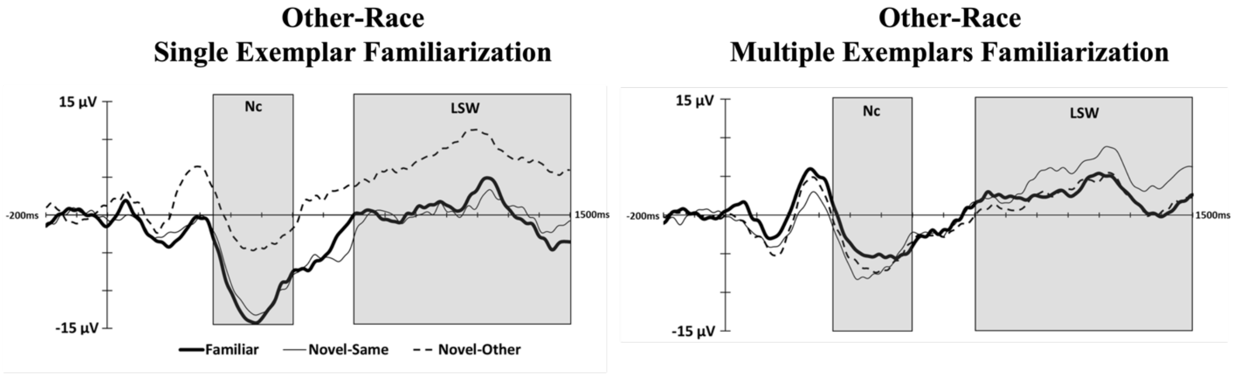

Figure 3. Nc and LSW components by stimulus type at frontal-central electrodes for the other-race familiarization conditions. The single exemplar familiarization condition is shown on the left panel and the multiple exemplars familiarization condition is shown on the right panel. Familiar trials are represented with a thick solid line. Novel-same trials are represented with a thin sold line. Novel-other trials are represented with a dashed line. The y-axis represents amplitude in microvolts and the x-axis represents time in 100ms segments. Stimulus onset is at the x-axis and y-axis intersection. The shaded boxes represent the time windows for the analyses of the Nc component (345-600 ms) and the LSW (800-1500 ms).

5. DISCUSSION

This study is the first of its kind to examine neural correlates of attention, face processing, and recognition memory in 10-month-old White infants while viewing own-and other-race faces under learning conditions designed to induce either individuation or categorization. While young infants are able to individuate human faces of all races, studies have shown that around 9 months of age infants maintain the ability to individuate own-race (or the most experienced race) faces but fail to individuate other-race faces (Balas, 2013; Balas & Quinn, 2015; Quinn, Lee, & Pascalis, 2018; Quinn, Lee, Pascalis, & Tanaka, 2016). This apparent failure to individuate may relate to development of category formation (Grossman, Gliga, & Mareschal, 2009; Hugenberg, Young, Bernstein, & Sacco, 2010; Nelson, 2001; Quinn, Westerlund, & Nelson, 2006). The categorization-individuation model was a major influence on the design and reasoning behind this study (Hugenberg, Young, Bernstein, & Sacco, 2010; Nelson, 2001; Pascalis, de Haan, & Nelson, 2002; Reynolds & Roth, 2018). With age and experience, infants may continue to individuate stimuli commonly encountered in their native environment but shift to processing uncommonly encountered stimuli at a categorical level. Based on this model, we predicted 10-month-old infants would categorize instead of individuate other-race faces and would thus benefit from exposure to multiple exemplars during familiarization. In contrast, we predicted exposure to a single exemplar during familiarization would facilitate individuation of an own-race face but would be insufficient for individuation of a single other-race face due to the own-race bias (Sugden & Marquis, 2017).

The findings were somewhat inconsistent with these predictions. As expected, results indicated 10-month-old White infants were able to discriminate faces at the subordinate-level category of race if familiarized with a single face. Contrary to our predictions, this effect occurred regardless of whether infants were familiarized with an own-race or other-race face. White infants who saw either a single White face or a single Black face during familiarization subsequently showed significant differences in both the Nc component (associated with visual attention) and the LSW (associated with recognition memory) between White and Asian faces or

Black and Asian faces depending on familiarization condition. However, they did not show differences in Nc or LSW amplitude between the familiar face and novel faces from the same race, indicating that infants did not individuate the familiar face. This finding was unexpected for infants familiarized with a single exemplar from their own-race as past studies using behavioral measures indicate that infants of this age should be capable of individuating own-race faces following 20 s of familiarization (e.g., Pascalis et al., 2002).

The lack of direct evidence of individuation of the face in the own-race, single exemplar familiarization condition may be due to characteristics of the familiarization procedure used in the current study. In contrast to the current procedure, which used 20 brief (1000 ms) presentations of a face for familiarization, the majority of previous research on infant recognition of other-race faces has used infant-controlled habituation or accumulated-looking familiarization, in which infants are able to scan faces until they lose interest or until they reach 20 to 30 s of accumulated looking (e.g., Anzures et al., 2012; Kelly, Quinn, Slater, Lee, Ge, & Pascalis, 2007; Krasotkina, Götz, Höhle, Schwarzer, 2018; Pascalis et al., 2002; Quinn, Lee, Pascalis, & Tanaka, 2016). The rapid presentation familiarization procedure used in the current study was designed to be consistent with brief stimulus presentations used in ERP studies and to reduce attrition due to boredom (Fisch, 1999; Luck, 2014; Picton et al., 2000). However, it may be the case that more prolonged looks and scanning of the face during initial learning are necessary for the level of perceptual processing required for individuation at this age. The current findings from the single exemplar familiarization conditions may reflect only partial encoding of the familiar face sufficient for categorization by race but insufficient for individuation within race.

Evidence in support of the possibility that the current findings may reflect partial familiarization is seen in the opposite direction of the Nc component results for the own- and other-race single exemplar familiarization conditions. Behaviorally, infants show a novelty preference if they have fully encoded a familiar stimulus, but they show a familiarity preference if they have only partially processed the familiar stimulus because they are presumably motivated to finish the encoding process (Colombo, Mitchell, & Horowitz, 1988; Fagan, 1974; Fantz, 1964; Freeseman, Colombo, & Coldren, 1993; Hunter & Ames, 1988; Hunter, Ames, & Koopman, 1983; Reynolds, 2015; Reynolds, Courage, & Richards, 2010; Richards, 1997; Rose et al., 1982; Simpson, Jakobsen, Fragaszy, Okada, & Frick, 2014). Infants show greater Nc amplitude for stimuli they demonstrate visual preferences for behaviorally, regardless of novelty or familiarity (Reynolds, Courage, & Richards, 2005). In the current study, infants familiarized with a single own-race (White) face showed greater Nc amplitude to the novel-other race faces consistent with a *novelty* preference for the novel Asian faces (see left panel of Figure 2). In contrast, infants familiarized with a single other-race (Black) face showed greater Nc amplitude to familiar and novel-same race faces compared to novel other-race (Asian) faces (see left panel of Figure 3). This may imply infants in the Other-Race familiarization condition were slower to process the other-race face during familiarization and their Nc results reflect a *familiarity* preference for the partially encoded Black face during test trials, in contrast with the Own-Race familiarization condition showing a *novelty* preference for the Asian faces. Thus, the opposite direction of differences in Nc amplitude based on race may provide evidence of the own-race bias, as infants may have been more efficient at processing an own-race face compared to an other-race face.

An alternative explanation for the lack of individuation in the current study could be that the infants were simply processing the familiar face at the categorical level. This is consistent with a longitudinal study on habituation to faces conducted by Colombo et al. (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004) that found infants failed to demonstrate evidence of individuating human faces at 9 months of age under conditions in which they did so at both younger and older testing ages. Colombo et al. (2004) concluded that at 9 months of age, infants may respond to all faces equivalently at the superordinate-level as opposed to the individual level. Peykarjou, Pauen, and Hoehl (2014) examined 9-month-old infants' categorization of human and ape faces at three different categorical levels – superordinate, basic, and individual. Using a rapid repetition ERP paradigm, they found that infants demonstrated superordinate-level (faces versus houses) and basic-level (human versus ape) categorization but failed to demonstrate individual-level processing of either human or ape faces. These findings could provide support for the possibility that infants simply process faces at the categorical level at this age. These findings could also provide support for the possibility that the brief stimulus presentations typical of ERP studies are sufficient for categorization but insufficient for individuation at this age.

It is noteworthy that, regardless of race, infants who were shown multiple faces during familiarization showed no evidence of either categorization or individuation across all ERP components analyzed in the current study. No significant differences based on race or trial type were found for the multiple exemplars familiarization conditions. This finding was unexpected and inconsistent with our prediction that exposure to multiple exemplars during familiarization would result in subordinate-level categorization for both the own- and other-race familiarization conditions. Importantly, the single exemplar results discussed above indicate 10-month-old White infants *are indeed* capable of subordinate-level categorization based on race under these testing conditions. Given the behavioral literature on own-race bias, it was hypothesized that this study would reveal differential effects of initial learning conditions on categorization and P400 amplitude when 10-month-old infants viewed own- and other-race faces. In face processing literature, the P400 is often associated with familiarity and orientation of human faces (de Haan, Pascalis, & Johnson, 2002; Halit, de Haan, & Johnson, 2003; Scott, Shannon, & Nelson, 2006). The P400 has also been identified as a subordinate-level category marker (Dixon et al., 2019; Quinn et al., 2010; Scott, et al., 2008; Xie et al., 2010). Regardless of race or number of exemplars, there were no differences between test trials in P400 amplitude for any familiarization condition. It may be the case that these null effects reflect all face types being categorized at the basic-level as human faces (Colombo et al., 2004; Peykarjou et al., 2014) instead of being categorized by race. It must be noted that this possibility is speculative as null effects must be interpreted with caution.

However, the combined findings of the current study and the Dixon et al. (2019) study using other-species faces may be consistent overall with the categorization-individuation model in that infants tested with human faces in the current study only differentiated faces at the subordinate-level when familiarized with a single face exemplar (an individuation procedure), and this differential responding based on race was found for ERP components related to attention (Nc) and recognition memory (LSW) but not for the ERP component related to subordinate-level categorization (P400). In contrast, infants tested with monkey faces (Dixon et al., 2019) only differentiated faces at the subordinate-level when familiarized with multiple face exemplars (a categorization procedure), and this differential responding based on monkey-species was found for ERP components related to attention (Nc), recognition memory (LSW), and subordinate-level categorization (P400). Taken together, these findings may indicate 9- to 10-month-old infants remain focused on individuating own-species faces (regardless of race) but shift to categorizing other-species faces by this age and thus benefit differently depending on if the learning condition uses a single exemplar (facilitates individuation) or multiple exemplars (facilitates categorization).

5.1 Limitations

There were some notable limitations tied to recruitment constraints for this study. A global pandemic (COVID-19) was a limiting factor in participant recruitment, resulting in data collection concluding earlier than anticipated (Freedman, Headley, Serwas, Ruhland, Castellanos, Combes, & Krummel, 2020). Although this size of the final *N* for this study is not atypical for infant visual ERP studies, including more participants would have increased statistical power. As described in the Participants section, recruitment issues also limited the racial distribution of our final dataset to only White infants. Including groups of infant participants who do not belong to the local majority White group would have increased the generalizability of our findings and allowed for full counterbalancing of racial groups across familiarization conditions.

On the note of participants, it must be acknowledged that the current study's dataset was therefore based on White infants being familiarized to White or Black faces. While we theorize how this relates to face race processing development, it should be recognized that these results may not be indicative of the own-race bias as a whole. Additionally, we purposefully only used female faces in the stimuli. We decided this partially to avoid race and gender interaction effects (Tham, Bremner, & Hay, 2015; Tham, Woo, & Bremner, 2018) and partially because infants usually have a stronger preference for female faces and therefore would attend to the stimuli better during ERP trials (e.g., Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002; Reynolds & Roth, 2018). Only using female faces is a limitation, however, and it would be interesting to see how gender may interact with the results we found in the current study. Future research should explore how male and female faces may be processed differently depending on familiarization condition.

As noted in the discussion above, the brief stimulus presentations used for familiarization in the current study may not have been optimal for complete processing and individuation. Although the current findings combined with those of Dixon et al. (2019) provide some indirect support for this, this possibility remains speculative. It may simply be the case that under these testing conditions, exposure to a single exemplar during familiarization fosters subordinate-level categorization of other-race faces as opposed to individuation and exposure to multiple exemplars is less optimal for categorization. It would be most informative to run a follow-up study utilizing an accumulated-looking familiarization procedure to determine if infants are able to demonstrate evidence of individuation and/or subordinate-level categorization using these same stimuli and testing procedure.

Including a range of different age groups would likewise add valuable information to this study. In particular, a longitudinal design testing participants at several ages throughout infancy and early childhood would provide valuable data that could present a developmental trajectory and shed light on if and when infants begin to show less efficient individuation of other-race faces compared to own-race faces. Longitudinal data could also possibly reveal a shift from individuation to categorization consistent with the categorization-individuation model (Hugenberg, Young, Bernstein, & Sacco, 2010). Alternatively, it may be the case that children continue to individuate other-race faces but become less efficient compared to own-race faces with increasing age, a possibility that would be more consistent with an attunement conceptualization of perceptual narrowing and could potentially explain the flipped Nc results in the single exemplar familiarization conditions (Aslin & Pisoni, 1980; Maurer & Werker, 2014; Narayan, Werker, & Beddor, 2010).

5.2 Conclusions

The current findings are encouraging and bode well for the flexibility of racial biases that may arise in later development, as it seems 10-month-old White infants process other-race faces similar to own-race faces. The extant literature and the current findings indicate multiple factors, including initial learning conditions, influence face processing and attentional biases for faces in infancy (Reynolds & Roth, 2018). Scott and colleagues' work also clearly shows that long term training with picture books paired with label learning can foster perceptual expertise for other-species faces, as well as other classes of stimuli, in infancy (Scott & Monesson, 2009, 2010; Scott, 2011; Pickron et al., 2018). Perceptual narrowing may lead to infants gaining expertise in processing own-race faces, but it is not likely that they completely lose sensitivity to other-race faces. Instead, their lack of experience with other-race faces may result in less efficient encoding – something that can be mitigated with training and exposure to other-race individuals. Future studies should examine what circumstances lead older infants, children, and adults to individuate or categorize other-race faces. Understanding how other-race faces are processed in different contexts, especially compared to own-race faces, will provide valuable information on the development of face processing as well as the development of social biases and racial prejudices seen in childhood and adulthood.

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