

Neighborhood racial demographics predict infants' neural responses to people of different races

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Abstract

Early in life, greater exposure to diverse people can change the tendency to prefer one's own social group. For instance, infants from racially diverse environments show less preference for their own-race (ingroup) over other-race (outgroup) faces than infants from racially homogeneous environments. Yet *how* social environment changes ingroup versus outgroup demarcation in infancy remains unclear. A commonly held assumption is that early emerging ingroup preference is based on an *affective* process: feeling more comfortable with familiar ingroup than unfamiliar outgroup members. However, other processes may also underlie ingroup preference: Infants may attend more to ingroup than outgroup members and/or mirror the actions of ingroup over outgroup individuals. By aggregating 7- to 12-month-old infants' electroencephalography (EEG) activity across three studies, we disambiguate these different processes in the EEG oscillations of preverbal infants according to social environment. White infants from more racially diverse neighborhoods exhibited greater frontal theta oscillation (an index of top-down attention) and more mu rhythm desynchronization (an index of motor system activation and potentially neural mirroring) to racial outgroup individuals than White infants from less racially diverse neighborhoods. Neighborhood racial demographics did not relate to White infants' frontal alpha asymmetry (a measure of approach-withdrawal motivation) toward racial outgroup individuals. Racial minority infants showed no effects of neighborhood racial demographics in their neural responses to racial outgroup individuals. These results indicate that neural mechanisms that may underlie social bias and prejudices are related to neighborhood racial demographics in the first year of life.

KEYWORDS

demographics, EEG, frontal alpha asymmetry, mu-ERD, race, theta

Enduring racial inequalities across the world indicate that discrimination based on racial groups is deeply ingrained in the psychological processes that generate human social behavior. There is a resurgence of interest in understanding how social prejudice emerges during ontogeny and how early social exposure to different races impact this process, with the hope that uncovering developmental processes will

provide insights for ameliorating the negative implications of this basic human tendency (Dunham et al., 2008; Liberman et al., 2017; Rhodes & Chalik, 2013). To this aim, we seek to determine how early exposure to racial diversity may shape the ontogeny of racial biases.

In adults, racial biases are complex. Racial biases are evident in explicitly negative attitudes and stereotyped beliefs about people

according to race (Devine, 1989; Stangor et al., 1991) as well as in automatic responses. For example, even when adults outwardly endorse egalitarian values, they often show negative associations about people based on race (Amodio & Devine, 2006; Nosek et al., 2002). They also show impaired abilities to attend to and remember information about people from different racial groups relative to their own (Meissner & Brigham, 2001). These distinct elements of racial biases are in place by middle childhood (Dunham et al., 2008; Hailey & Olson, 2013), yet little is known about the origins of these elements.

The propensity to divide the social world into “us” versus “them” appears to emerge early in life: By 6 months of age, infants preferentially orient to people from their own racial or linguistic group (ingroup) compared to people from different groups (outgroup) (Kelly et al., 2007; Kinzler et al., 2007; Liu et al., 2015). By 9 months, infants start to show difficulty individuating racial outgroup faces – known as the other-race effect (Anzures et al., 2013; Quinn et al., 2016). This perceptual narrowing appears to shape infants’ category formation such that infants consider faces from races they are unfamiliar with as one category of “other race” rather than making a more fine-grained distinction: for instance, White 9-month-old infants appear to view Black and Asian faces as one category (Quinn et al., 2016). Beyond face processing, infants start to show modulation in their behaviors by racial group membership. By the second half of the first year of life, infants start to follow the gaze of racial ingroups more than outgroups (Pickron et al., 2017; Xiao, Wu, et al., 2018) and to associate racial ingroup faces with positive valence and racial outgroup faces with negative valence (Xiao, Quinn, et al., 2018).

These early emerging preferences appear to be modulated by infants’ exposure to racial diversity at home and in their communities: infants’ preferences for own-race over other-race faces are reduced by exposure to other-race faces in the lab (Anzures et al., 2013) in the family (Sangrigoli et al., 2005) and in the community (Bar-Haim et al., 2006). Yet *how* exposure to outgroup changes infants’ ingroup preference and openness to outgroup individuals remains underspecified. By understanding what neuropsychological mechanisms are modulated by exposure to diversity, we can better identify what processes are the roots of racial bias.

Infants’ early emerging preferences may be driven primarily by comfort or liking. Infants may simply feel more comfortable with and tend to like more familiar people, who are typically from their ingroup; in contrast, infants may feel less comfortable with unfamiliar people, such as outgroup individuals (Feinman, 1980). Thus, ingroup preferences may simply reflect infants’ positive or negative affective responding based on familiarity. Indeed, it is well-established in social psychological studies that propinquity generates positive feelings (Ebbesen et al., 1976; Festinger et al., 1950; Zajonc, 1968) and this basic mechanism could explain infants’ preferences for the kinds of people with whom they are most familiar. Therefore, exposure to different races early in life could increase infants’ comfort with people from different racial backgrounds.

Even so, there are other processes that may underlie infants’ social preferences. Infants and young children selectively learn

Research highlights:

- 7- to 12-month-old White infants’ neural responses (as captured by EEG) to a person of a different race was related to infants’ neighborhood racial demographics
- White infants from neighborhoods with larger racial outgroup population showed greater frontal theta power (a measure of top-down attention) toward a different race person
- White infants from neighborhoods with larger racial outgroup population also exhibited greater mu rhythm desynchronization (related to motor activation) to a different race person’s action
- Neighborhood racial demographics was not related to White infants’ frontal alpha asymmetry (an index of approach-withdrawal motivation) toward a different race person

from ingroup as compared to outgroup individuals (Buttelmann et al., 2013; Howard et al., 2015; Kinzler et al., 2011) suggesting that children view ingroup individuals as more likely to provide relevant learning opportunities than outgroup individuals. An information-seeking account proposes that infants’ ingroup preferences result from a fundamental bias to identify and attend to the optimal informant, e.g., ingroup members, in the environment (Begus et al., 2016; Diesendruck & Markson, 2011; Harris & Corriveau, 2011). In line with this possibility, an electroencephalography (EEG) study with 11-month-old infants found that the neural correlate associated with top-down attention and expectation of information (i.e., theta oscillation) is enhanced when infants view ingroup compared to outgroup individuals (Begus et al., 2016). Thus, if this top-down attentional process is involved in perceptions about ingroup versus outgroup individuals, then greater exposure to outgroup individuals may increase infants’ top-down attention to outgroup individuals.

Besides these affective and attentional processing, another potential mechanism involved in ingroup bias could be mirroring: adults show differential activity in the neural mirroring system when viewing ingroup members compared to outgroup individuals (Gutsell & Inzlicht, 2010, 2012, 2013; Liew et al., 2011; Molnar-Szakacs et al., 2007). This neural mirroring system is comprised of a network of interconnected brain regions (some of which may contain mirror neurons) and is active both to when performing an action and when observing someone else perform that action (Rizzolatti & Craighero, 2004). It has been hypothesized that this neural mirroring system underlies the understanding of others’ actions, and may be related to social engagement and socio-cognitive skills, such as imitation and empathy (Baird et al., 2011). The findings with adults raise the possibility that similar processes are present in infancy.

It is important to note that these three processes (affective, attentional, and mirroring) are not mutually exclusive; it is possible that infants’ ingroup preference involves all three of these processes



or a selective combination. For instance, early in life, ingroup preferences may be driven by an affective process – such that infants show stronger comfort toward and liking of ingroup over outgroup individuals but do not display any differential top-down attention or neural mirroring according to group membership. Alternatively, infants may initially show greater top-down attention to ingroup than outgroup individuals early in life with no affective or mirroring processing involved; affective valence and neural mirroring toward outgroup members may potentially emerge later in life. The extent to which each of these three mechanisms is involved in ingroup preference and impacted by exposure to outgroup members remains an open question.

EEG allows observation of distinct neural correlates of affective, attentional, and mirroring mechanisms that is not possible in behavioral methods. Extensive EEG research with infants demonstrate that these discrete mechanisms have distinct neural signatures. Specifically, affective processing can be captured in frontal asymmetry in the alpha band, which is associated with fear responses toward strangers in infancy and with approach-withdrawal responses across development (Davidson & Fox, 1982; Fox & Davidson, 1987; Harmon-Jones et al., 2010). Top-down attentional processing can be indexed by an increase in EEG power in the theta band over frontal recording sites. Greater frontal theta power during encoding predicts better learning in infants and adults (Begus et al., 2015, 2016; Guderian et al., 2009). The mirroring mechanism is potentially related to the suppression of the alpha band over central electrode sites (i.e., mu rhythm desynchronization) that occurs during both action execution and action observation (Fox et al., 2016; Marshall & Meltzoff, 2011). If these mechanisms are linked to infants' exposure to different races, they may hold the key to understanding the ontogeny of racial biases.

The current study therefore examined whether infants' affective, attentional, and/or mirroring mechanisms are related to exposure to racial diversity as measured through neighborhood racial demographics. Specifically, if all three processes are at work behind ingroup preference and change according to exposure to outgroup, infants from racially diverse neighborhoods may show more approach motivation (as indexed by frontal alpha asymmetry), increased top-down attention (as indexed by frontal theta oscillation), and greater neural mirroring (as indexed by mu rhythm desynchronization) of outgroup individuals than infants from racially homogeneous neighborhoods. We hypothesized that differences in frontal alpha asymmetry and frontal theta oscillation according to race would occur regardless of whether infants observed an individual as stationary or moving, but modulations in mu rhythm desynchronization may occur most when observing an individual in action. Furthermore, we hypothesized that responses from racial minority infants may differ from racial majority infants, given extensive research that indicate racial minority infants and children show less ingroup preferences compared to racial majority infants and children (Bar-Haim et al., 2006; Hailey & Olson, 2013). Additionally, because infants in the latter half of the first year potentially view different racial outgroups as one category rather than representing each

individual racial outgroup (Quinn et al., 2016), the current study examined both infants' exposure to all racial outgroups and exposure to a specific racial outgroup.

To evaluate these *a priori* developed hypotheses, we aggregated data from prior EEG experiments from a multi-laboratory collaboration by the last two authors focused on investigating the neural correlates of action understanding in infancy. Given the extensive time and resources needed to collect infant EEG data, these experiments were designed with possibilities for conducting secondary analyses by utilizing standardized protocols for EEG data collection and analyses. This approach of combining datasets using the same protocols from multiple laboratories has many benefits, including greater sample size and diversity that are difficult to achieve in a single study in isolation (Frank et al., 2017). Our data files, analysis codes, and additional analyses are available on the Open Science Framework (OSF): <https://osf.io/9zfgy/>

1 | METHOD

1.1 | Participants

Eighty-four typically developing infants' EEG data (44 females; mean age = 9.40 months, range = 7 months to 12 months; 48 White, 8 Black, 6 Hispanic/Latino, 3 East Asian, 2 South Asian, 1 Native Hawaiian, and 16 bi- or multi-racial infants) were aggregated from three studies (Debnath et al., 2019; Meyer et al., n.d. Salo, n.d.). This age range was chosen because mu rhythm desynchronization is reliably detected in infants starting around 7 to 8 months of age (Cuevas et al., 2014; Fox et al., 2016). Theta power and its relation to attention can be indexed in infants as young as 2 months of age and older (Begus & Bonawitz, 2020; Saby & Marshall, 2012). Frontal alpha asymmetry as a measure of emotional reactions in infants has been found as young as newborns and robustly around 10 months when stranger fear emerges (Coan & Allen, 2004). Infants were recruited from and tested at laboratories located in metropolitan areas in Chicago, Illinois and College Park, Maryland of the U.S. Data were collected from May 2015 to March 2018.

1.2 | Design

In all three studies, infants viewed either a White, East Asian, or South Asian female experimenter grasp an object. In total, 10 White, 6 East Asian, and 3 South Asian experimenters conducted the studies (see Table 1), suggesting that observed ingroup versus outgroup differences are unlikely to be due to responses to a particular experimenter. If infants viewed an experimenter of the same race/ethnicity as themselves, this was categorized as viewing an ingroup experimenter; if infants viewed an experimenter of a different race/ethnicity from them, this was categorized as viewing an outgroup experimenter. For White infants, this categorization

Study	Experimenter race	Number of experimenters	Number of infants tested by experimenter
Debnath et al. (Study 1)	White	4	20
	East Asian	2	7
Salo et al. (Study 2)	White	6	11
	East Asian	3	13
	South Asian	3	9
Meyer et al. (Study 3)	East Asian	1	24

TABLE 1 Number of experimenters in each racial category by study

resulted in 22 viewing an ingroup (White) experimenter and 26 viewing an outgroup (East or South Asian) experimenter. For non-White monoracial infants, this categorization resulted in three viewing an ingroup experimenter and 17 viewing an outgroup experimenter. Bi- or multi-racial infants were categorized as viewing an ingroup experimenter if at least one of their racial identifications matched that of the experimenter, which resulted in eight viewing an ingroup experimenter and eight viewing an outgroup experimenter. See Table 2 for the distribution of infants by race and experimenter group membership. Because non-White infants and children show different race-based responses compared to White infants and children (Bar-Haim et al., 2006; Hailey & Olson, 2013) and bi- or multi-racial infants have distinct lived experiences from monoracial individuals (Gaither, 2015; Gaither et al., 2012), ideally we hoped to analyze each group (White, non-White monoracial, and bi-/multi-racial) separately. However, due to the small sample size of bi-/multi-racial infants and the unbalanced distribution of ingroup versus outgroup experimenters for non-White monoracial infants, we decided to pool across these two populations and focus on analyzing racial minority infants who saw outgroup experimenters ($n = 25$) to achieve a similar sample size to the White infants. We examined non-White monoracial infants separately and found similar results as the pooled sample (see OSF).

TABLE 2 Number of infants who saw an ingroup or outgroup experimenter according to infant race and study

Study	Infant race	Ingroup	Outgroup
Debnath et al. (Study 1)	White	15	5
	Non-White monoracial	—	4
	Bi- and multi-racial	3	—
Salo et al. (Study 2)	White	7	14
	Non-White monoracial	1	4
	Bi- and multi-racial	4	3
Meyer et al. (Study 3)	White	—	7
	Non-White monoracial	2	9
	Bi- and multi-racial	1	5

1.3 | Procedure

In all three studies, infants experienced identical action observation trials, in which they observed a female experimenter grasp an object. The trials were divided into *action period* (a 1000 ms long segment in which the experimenter was moving to grasp the toy; denoted as -1000 ms to 0 ms) and *introduction period* (a 1000 ms long segment in which the experimenter was not moving; denoted -2000 ms to -1000 ms). See supplementary analyses for details on how these time periods were defined.

1.4 | EEG data acquisition and processing

EEG from all three studies were recorded using a 128-channel HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR). The data acquisition, preprocessing, time-frequency, and spectral power analysis procedures are detailed in supplementary analyses and followed the Maryland Analysis of Developmental EEG (MADE) pipeline (Debnath et al., 2020).

1.4.1 | Frontal theta power

Frontal theta power activity was calculated as the baseline-corrected mean power at the 3–5 Hz frequency band averaged across the Fp1 and Fp2 electrode clusters (e9, e14, e15, e21, e22) based on Begus et al. (2016).

1.4.2 | Mu rhythm desynchronization

Mu rhythm desynchronization was calculated as the baseline-corrected mean power at the 6–9 Hz frequency band averaged across the C3 and C4 electrode clusters (e30, e36, e37, e41, e42, e87, e93, e103, e104, e105) based on Debnath et al. (2019) and Fox et al. (2016).

1.4.3 | Frontal alpha asymmetry

Frontal alpha asymmetry was calculated as relative spectral power of the 6–9 Hz frequency band from the F3 (e19, e20, e24, e27, e28, e29) and F4 (e4, e111, e117, e118, e123, e124) electrode clusters;

asymmetry was calculated as $\ln F4$ minus $\ln F3$ based on guidelines set in previous research (Diaz & Bell, 2012; Fox & Davidson, 1987).

1.5 | Neighborhood racial diversity

Neighborhood racial diversity was quantified as the proportion of racial outgroup population in infants' home address zip code. For White infants, this was the proportion of non-White population in the zip code derived from the demographic and housing estimates survey of the 2017 American Community Survey published by the U.S. Census Bureau. For racial minority infants, the proportion of racial outgroup population was the proportion of population that was not the same race as the infant (e.g., for a bi-racial Black and White infant, this was the proportion of population that was not Black or White in the zip code).

1.6 | Analysis plan

Outliers were determined as values greater than 3 SD. One outlier in mu rhythm in the introduction period was excluded in White infants and one outlier in frontal alpha asymmetry in the action period was excluded in racial minority infants. Multilevel linear models were constructed for frontal theta, frontal alpha asymmetry, and mu rhythm with the following fixed effect predictors: Experimenter's race (ingroup vs. outgroup), racial outgroup population in the infants' zip code, interaction (experimenter's race x racial outgroup

population), and infant's age in months. Random intercepts and random slopes for each study were included in the models to control for study level differences. We conducted Holm-Bonferroni corrections for models constructed within the same EEG oscillations.

2 | RESULTS

2.1 | White infants

First, we investigated whether neighborhood racial demographics predict White infants' top-down attention to racial outgroup individuals by examining frontal theta. There were marginal main effects of experimenter's race in the introduction period ($\beta = -1.797$, $SE = 1.058$, $p = .097$) and action period ($\beta = -2.814$, $SE = 1.248$, $p = .070$), but these main effects were subsumed by significant interactions between experimenter's race and neighborhood racial diversity on frontal theta (introduction: $\beta = 4.075$, $SE = 1.920$, $p = .040$; action: $\beta = 6.827$, $SE = 2.268$, $p = .016$). When observing a racial outgroup experimenter, White infants from neighborhoods with larger racial outgroup populations showed greater frontal theta power than those from neighborhoods with smaller racial outgroup populations (introduction: $\beta = 3.514$, $SE = 1.406$, $p = 0.022$; action: $\beta = 4.022$, $SE = 1.616$, $p = 0.022$). In contrast, when observing a racial ingroup experimenter, White infants' neighborhood racial demographics did not relate to frontal theta (introduction: $\beta = -0.699$, $SE = 1.304$, $p = 0.597$; action: $\beta = -1.582$, $SE = 1.398$, $p = 0.270$). See Figures 1a and 2a,c.

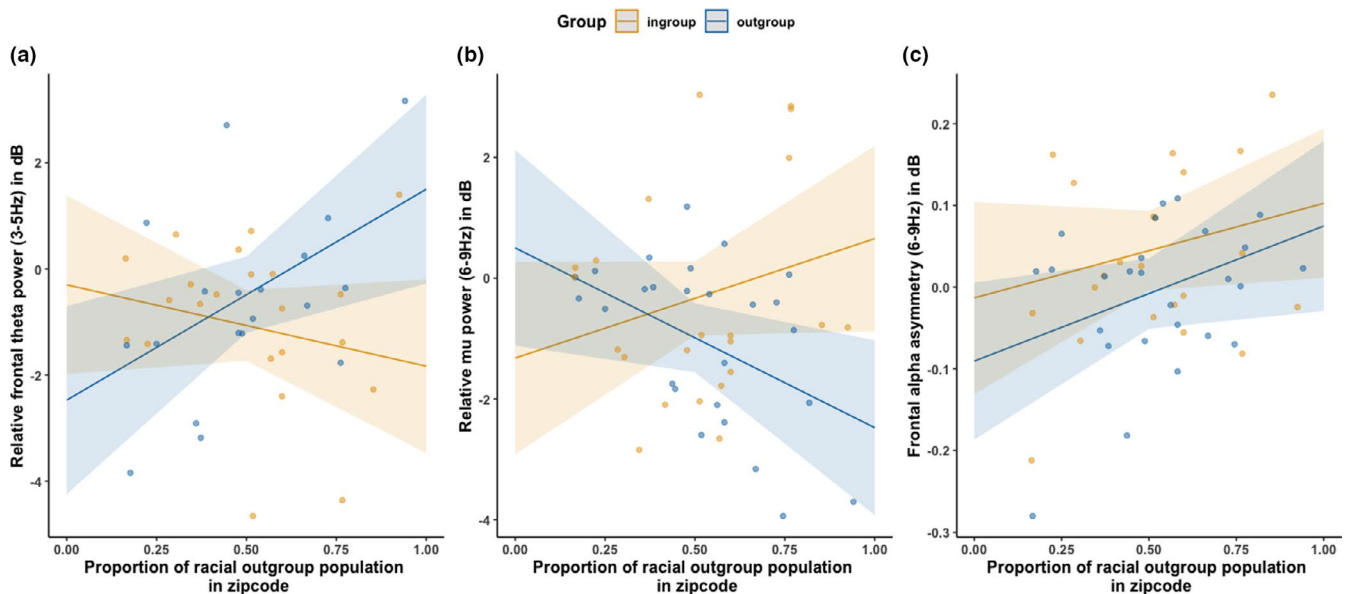


FIGURE 1 Frontal theta power (A), mu power (B), and frontal alpha asymmetry (C) of White infants when viewing an outgroup experimenter grasp an object (i.e., action period) according to experimenter race and proportion of racial outgroup population in infants' zip code. Frontal theta and mu power were baseline corrected. Each dot represents an infant. The lines represent the best fit line generated from the multilevel mixed models. Shaded areas around each line represent the 95% confidence intervals. Greater theta power in frontal regions have been related to greater top-down attentional processing. Suppression of power in the mu/alpha band over central regions have been linked to greater motor system activation or "neural mirroring" of actions. Greater positive values in frontal alpha asymmetry reflect greater relative activation in the left hemisphere compared to the right hemisphere and is related to more approach and less fear responses to strangers

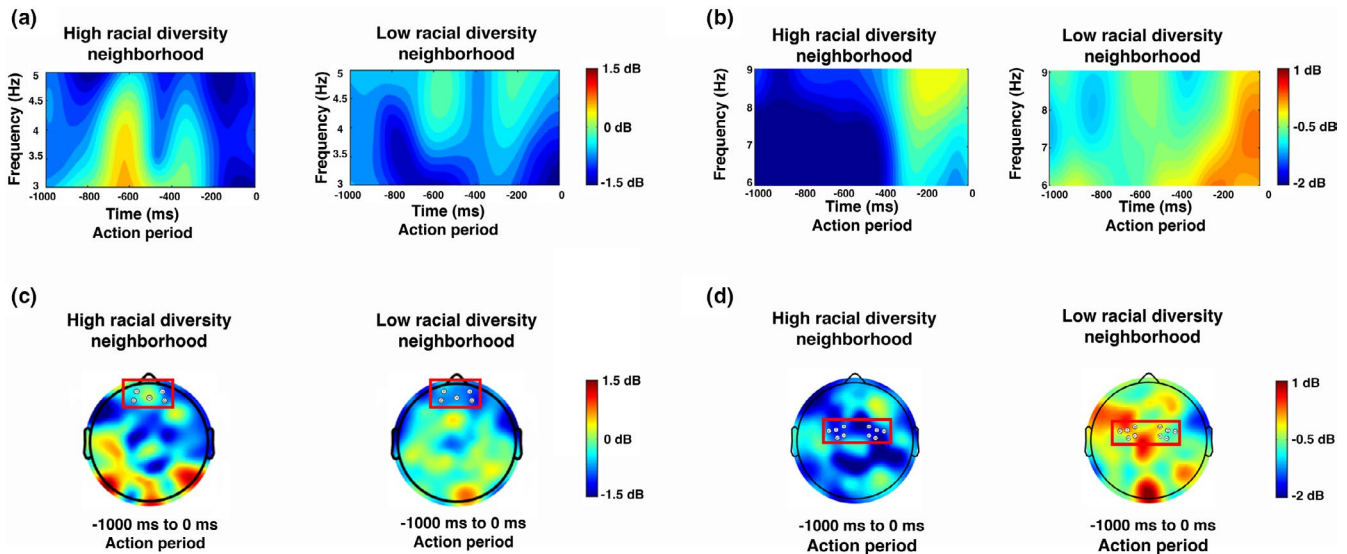


FIGURE 2 Frontal theta power (A & C) and mu power (B & D) of White infants as they viewed an outgroup experimenter grasp an object (i.e., action period) according to infants' neighborhood racial diversity. Neighborhood racial diversity is depicted here by a median split: higher than median (i.e., greater than 48.7% of population in zip code are outgroups) categorized as *high racial diversity neighborhood* and lower than median categorized as *low racial diversity neighborhood*. Time -1000 ms to 0 ms indicates the time window when infants watched the experimenter grasp an object (the action period) with 0 ms indicating the time point at which the experimenter first touches the object or completes the grasp. Power (dB) of event related spectral perturbation (ERSP) activation, which is a two-dimensional (latency by frequency) estimate of average changes in spectral power relative to baseline, is shown by the color bar. A depicts the time-frequency decomposition of theta (3–5 Hz) band grand average ERSP over frontal regions. B depicts the time-frequency decomposition of mu/alpha (6–9 Hz) band grand average ERSP over central regions. C depicts the topographic map of theta band ERSP. D depicts the topographic map of alpha band ERSP. Red windows indicate the electrodes and regions of interest

Second, we examined whether neighborhood racial demographics predict White infants' neural mirroring (as indexed by mu rhythm desynchronization) of racial outgroup individuals. There were no main effects of experimenter's race (introduction: $\beta = 0.596$, $SE = 1.170$, $p = .613$; action: $\beta = 1.826$, $SE = 1.156$, $p = .243$) and no interaction between experimenter's race and neighborhood racial diversity on mu rhythm during the introduction period ($\beta = -3.418$, $SE = 2.206$, $p = .129$), but there was a significant interaction during the action period ($\beta = -4.959$, $SE = 2.049$, $p = 0.040$). When watching a racial outgroup experimenter's grasping action, White infants from neighborhoods with larger racial outgroup populations showed greater mu rhythm desynchronization than those from neighborhoods with smaller racial outgroup populations ($\beta = -3.248$, $SE = 1.166$, $p = 0.010$). Neighborhood racial demographics did not predict mu rhythm desynchronization when White infants watched a racial ingroup experimenter's grasping action ($\beta = 2.112$, $SE = 1.596$, $p = 0.199$). See Figures 1b and 2b, d. Thus, differentiation in mu rhythm desynchronization according to racial outgroup population was not found when the experimenter was stationary and only found when an action was executed.

Third, we analyzed whether neighborhood racial demographics predict White infants' approach-withdrawal motivation (as indexed by frontal alpha asymmetry) toward racial outgroup individuals. There were no effects of experimenter's race (introduction: $\beta = -0.025$, $SE = 0.074$, $p = .738$; action: $\beta = -0.077$,

$SE = 0.076$, $p = .644$) or interaction between experimenter's race and neighborhood racial diversity on frontal alpha asymmetry (introduction: $\beta = -0.010$, $SE = 0.131$, $p = 1$; action: $\beta = 0.050$, $SE = 0.124$, $p = 1$) (See Figure 1c). Thus, we found no evidence that White infants' frontal alpha asymmetry differed by experimenter's race or neighborhood racial demographics in this sample. However, frontal alpha asymmetry was related to childcare attendance in additional analyses (see OSF), replicating previous findings (Fox et al., 2001) and suggesting that infants' frontal alpha asymmetry toward strangers like the experimenters was sensitive to variations in infant's social experiences but not neighborhood racial demographics.

We additionally examined whether Asian population at the zip code level predicted neural responses toward the East or South Asian experimenter but found no significant effects ($ps > .153$). Occipital alpha desynchronization (an index of low-level visual processing) toward an outgroup experimenter was not related to experimenter's race or racial outgroup population in the neighborhood ($ps > .278$), suggesting that our results are specific to frontal theta and mu rhythm. See supplementary analyses for full model results.

2.2 | Racial minority infants

Racial minority infants' frontal theta, mu rhythm desynchronization, and frontal alpha asymmetry toward racial outgroup experimenters



were not related to experimenter's race or racial outgroup population in the neighborhood ($ps > .408$). Of those infants who saw an East or South Asian outgroup experimenter, Asian population in the neighborhood did not relate to their EEG activity ($ps > .308$). See supplementary analyses for full model results.

2.3 | General discussion

The current findings indicate that White infants' neural responses to people of different races were related to their neighborhood environments, whereas racial minority infants' neural responses were not. Specifically, neighborhood racial diversity was related to White infants' frontal theta power and mu rhythm desynchronization to a person of a different race. In contrast, racial diversity did not influence their frontal alpha asymmetry toward a person of a different race. Thus, these results suggest that early exposure to racial diversity may change two neuro-cognitive responses – the modulation of top-down attention and the propensity to activate one's own motor system when viewing others' actions – to racial outgroup members. Our findings speak to important theoretical questions about how ingroup preference emerges during development that behavioral studies to date were unable to answer.

The current study suggests that within the first year of life, infants are potentially differentiating whom they pay attention to depending on the racial diversity found in their community. These findings align with previous findings from Begus et al. (2016), in which infants exhibited greater theta power to linguistic ingroup (native language) speakers over linguistic outgroup (foreign language) speakers. Our findings suggest that similar attentional processes may be at work when infants view racial ingroup and outgroup individuals. The current study expands upon this previous work by demonstrating that racial diversity found in the social environment is related to frontal theta power. Whether exposure to linguistic diversity also modulates infants' theta power is unknown, but given previous behavioral findings (Howard et al., 2014), it seems likely that infants' theta power to linguistic outgroup members are also related to exposure to different language speakers. Whether this greater theta power is directly a result of infants viewing ingroup members as more informative than outgroup members require further investigation.

Infants' frontal theta power was not the only neural correlate related to neighborhood racial diversity: the level of motor system activation and potentially neural mirroring (as indexed by mu rhythm desynchronization) was also sensitive to variations in racial diversity. When observing a person of a different race, White infants showed greater mu rhythm desynchronization if they lived in a neighborhood with more different race people. Further work is needed to better understand how mu rhythm desynchronization according to racial diversity may have cascading impacts on other socio-cognitive processes, such as intention understanding and empathy, that are critical for social group functioning and social bias formation.

In contrast with positive evidence that top-down attentional (frontal theta) and neural mirroring (mu rhythm desynchronization) mechanisms are involved in infants' processing of different race individuals, there was no evidence that infants show differential approach-withdrawal responses (frontal alpha asymmetry) to individuals according to race or exposure to racial diversity. This lack of affective response is in contrast with adults, who often demonstrate implicit negative associations based on race (Amodio & Devine, 2006; Nosek et al., 2002). Although the null effect of White infants' frontal alpha asymmetry should be interpreted with caution, in the same infants, we found that frontal alpha asymmetry was sensitive to other variations in social experience, namely childcare attendance. This finding suggests that frontal alpha asymmetry variation may depend more on infants' exposure to people other than their parents rather than according to race or exposure to racial diversity. Taken together with the significant effects of neighborhood racial diversity on frontal theta and mu rhythm desynchronization, our results suggest that an affective response indexed by frontal alpha asymmetry may not be the only (and potentially not the most salient) mechanism behind how exposure to racial diversity impacts infants' early perceptions of different race individuals.

2.4 | Limitations

Our findings raise a number of questions that require further investigation. First, because the current study is a secondary analysis, the main variables of interests (zip code and race of the experimenter) were not experimentally manipulated, which limits interpretations about causality. Even so, we know that infants cannot choose their own neighborhoods; thus, it seems plausible that the significant results in infants' neural responses are reflecting neighborhood level exposure to outgroup individuals. Neighborhood racial demographics at the zip code level may represent the mere exposure infants have to different race individuals at public spaces, like the park or on the bus, and may or may not correspond to the frequency of interactive experiences infants have with different race individuals. Whether racial diversity in infants' daily interactions have differing impact or interactive effects with racial diversity at the neighborhood level remains to be investigated. It is also important to note that neighborhood racial demographics could covary with a range of demographic and socioeconomic characteristics. Although additional analyses revealed no evidence of median income or population density at the zip code level relating to the EEG oscillations of interests (see OSF), future studies with larger sample sizes are needed to fully investigate the relation among infants' EEG activity, racial demographics, and other socioeconomic variables when responding to racial outgroup members.

Second, our findings are based on White infants viewing one type of racial outgroup (i.e., East or South Asian). Thus, whether White infants respond in a similar pattern for other races is an open empirical question. Furthermore, White infants' EEG activity toward the East or South Asian experimenters were related

to non-White population, but not to Asian population, in the neighborhood. This may be due to the low percentage of Asian population ($M = 8.80\%$; $SD = 6.97\%$) compared to non-White population ($M = 49.87\%$; $SD = 20.51\%$) in our sample's zip codes. Nonetheless, this pattern of results suggests that White infants' neural responses to a racial outgroup individual can be predicted by exposure to anyone who is of a different race. Future research should examine whether infants' neural responses show similar signatures of the other-race effect found in face perception (Quinn et al., 2016).

The null effects of neighborhood racial demographics on racial minority infants' EEG activity is perhaps due to racial minority infants (especially bi- or multi-racial infants) having more exposure to multiple races in their daily lives regardless of neighborhood racial diversity. However, the null results should be interpreted with caution due to the unbalanced distribution of racial minority infants who saw ingroup versus outgroup experimenters. Future research with greater sample size of non-White monoracial infants and bi- or multi-racial infants and more fine-grained measures of exposure to racial diversity will help answer these open questions.

3 | CONCLUSION

The current study indicates that neural mechanisms potentially behind social biases are related to the neighborhood environment in the first year of life. Infants' social worlds are often assumed to be dominated by their relationships to caregivers, but our findings highlight the role that broader communities may play in shaping the social brain early in life. When White infants from racially diverse neighborhoods view racial outgroup individuals, they responded with higher levels of attention (frontal theta) and action engagement (mu rhythm desynchronization) compared to those from racially homogeneous neighborhoods. However, affective responding (frontal alpha asymmetry) was not related to neighborhood racial demographics. While this possibility requires further investigation, it raises the questions of when and how the negative, and most destructive, aspects of social bias emerge during development.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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