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DOI

[10.3758/s13415-022-01040-w](https://doi.org/10.3758/s13415-022-01040-w)

Publication date

2023

Document Version

Final published version

Published in

Cognitive, Affective and Behavioral Neuroscience

Citation (APA)

Penner, F., Wall, K. M., Guan, K. W., Huang, H. J., Richardson, L., Dunbar, A. S., Groh, A. M., & Rutherford, H. J. V. (2023). Racial disparities in EEG research and their implications for our understanding of the maternal brain. *Cognitive, Affective and Behavioral Neuroscience*, 23(1), 1-16.
<https://doi.org/10.3758/s13415-022-01040-w>

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Racial disparities in EEG research and their implications for our understanding of the maternal brain

Francesca Penner¹ · Kathryn M. Wall¹ · Kathleen W. Guan¹ · Helen J. Huang² · Lietsel Richardson³ · Angel S. Dunbar⁴ · Ashley M. Groh⁵ · Helena J. V. Rutherford¹

Accepted: 26 September 2022 / Published online: 22 November 2022
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Abstract

Racial disparities in maternal health are alarming and persistent. Use of electroencephalography (EEG) and event-related potentials (ERPs) to understand the maternal brain can improve our knowledge of maternal health by providing insight into mechanisms underlying maternal well-being, including implications for child development. However, systematic racial bias exists in EEG methodology—particularly for Black individuals—and in psychological and health research broadly. This paper discusses these biases in the context of EEG/ERP research on the maternal brain. First, we assess the racial/ethnic diversity of existing ERP studies of maternal neural responding to infant/child emotional expressions, using papers from a recent meta-analysis, finding that the majority of mothers represented in this research are of White/European ancestry and that the racially and ethnically diverse samples that are present are limited in terms of geography. Therefore, our current knowledge base in this area may be biased and not generalizable across racially diverse mothers. We outline factors underlying this problem, beginning with the racial bias in EEG equipment that systematically excludes individuals of African descent, and also considering factors specific to research with mothers. Finally, we highlight recent innovations to EEG hardware to better accommodate diverse hairstyles and textures, and other important steps to increase racial and ethnic representativeness in EEG/ERP research with mothers. We urge EEG/ERP researchers who study the maternal brain—including our own research group—to take action to increase racial diversity so that this research area can confidently inform understanding of maternal health and contribute to minimizing maternal health disparities.

Keywords Maternal brain · EEG/ERP · Racial disparity · Inclusivity · Diversity · Systemic racism

Improving maternal health, both physical and mental, is a global health priority (World Health Organization, 2022). The importance of maternal health is even more apparent when considering racial health disparities: Black women in the United States are three times more likely to die from a

pregnancy-related cause compared with White women, and Indigenous women are two times more likely (Callaghan, 2012; CDC, 2021; Glazer & Howell, 2021; Petersen, 2019). Moreover, mothers of color are more likely to experience mental health conditions (Parker, 2021). Maternal physical and mental health directly influence caregiving, parent-child relationships, and child development (Easterbrooks et al., 2000; Herba et al., 2016; Mayes & Truman, 2002; Warnock et al., 2016), underlining that there are considerable intergenerational consequences of maternal health. Addressing inequalities in maternal health requires bringing attention to longstanding systemic oppression and marginalization (Glazer & Howell, 2021)—existing not only in healthcare, but also in research. In this paper, we argue that electroencephalography (EEG) research holds promise to address maternal-health disparities. However, systemic racism exists in EEG research (Choy et al., 2021; Parker & Ricard, 2022). For the promise of EEG to be realized for maternal health research, we must first understand

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the extent that our current knowledge base includes mothers of color and identify the reasons underlying, and possible solutions for, the lack of representation of minoritized, racial/ethnic identities in EEG research of the maternal brain.

The current paper examines the issues of racial bias in EEG research, specifically in the context of EEG studies of maternal neural responding to infant/child cues (i.e., visual or auditory signals from the infant). We begin by providing an overview of the importance of maternal brain research using EEG and event-related potentials (ERPs). Next, we assess the current racial/ethnic representation across samples in EEG studies of mothers' neural responses to infant/child emotional expressions, using the studies included in a recent meta-analysis (Kuzava et al., 2020). We discuss factors that contribute to a lack of racial diversity in research samples, beginning with the racial bias inherent in current EEG methodology and data collection practices with mothers of color. We outline how ERP studies of the maternal brain can inform understanding of maternal mental health, caregiving, and infant outcomes among mothers of color, and therefore why the racial/ethnic diversity of samples must be increased. We conclude by suggesting future directions to increase inclusion of mothers of color in EEG research while also considering the social and structural factors that must be addressed in research studies with mothers to be more equitable and inclusive. Lack of inclusion of mothers of minoritized racial/ethnic identities in this research area represents three larger, intersecting problems: namely, the historical biases toward White participants in research (Buchanan et al., 2022; Crooks et al., 2021; Nielsen et al., 2017; Roberts et al., 2020) and toward male subjects in neuroscience (Beery & Zucker, 2011) and health (Vidaver et al., 2000) research, and the systemic racial biases present in EEG and other neuroimaging methods (Choy et al., 2021; Parker & Ricard, 2022). Taking action to increase the representation of mothers of color in EEG/ERP research is a crucial next step with value for research across these three intersecting areas.

While this urgent issue requires more centering of all child-bearing people of color and of minoritized identities, we focus on Black mothers throughout this paper because of the significant maternal health disparities reported among Black mothers, and the systemic problems in EEG research that have led to a lack of data from people of African descent (Choy et al., 2021; Parker & Ricard, 2022). Furthermore, focusing on specific groups, such as Black mothers in the United States, rather than generalizing across people of color, can help to accomplish this needed centering (Parker, 2021).

Value of EEG for understanding the maternal brain

EEG is a neuroimaging technique that uses electrodes placed on the scalp to measure cortical brain activity. The high temporal resolution of EEG is a particular strength of

the technique and, when applied to parenting research, can afford insight into parental sensitivity in terms of a parents' immediate and intuitive responding to child cues, occurring at the level of milliseconds, before observable parenting behavior (Kuzava et al., 2020; Maupin et al., 2015). Event-related potentials (ERPs) can be generated by time-locking EEG data to tasks or stimuli, such as infant faces, and averaging across multiple presentations of the same stimuli. This technique allows for analysis of the strength (i.e., amplitude, measured in microvolts) and timing (i.e., latency, measured in milliseconds) of rapid neural responses, which vary between and within individuals, to understand different stages of neural processing. ERP waveforms have both positive and negative peaks and are generally labeled based on directionality of peak, positive (P) or negative (N), and the time at which they onset. For example, the P100 ERP refers to a positive peak that typically occurs at 100 milliseconds from stimulus onset. These separate ERPs reflect neural processes that unfold over time (e.g., perception, attention, cognitive appraisal of the stimulus). ERP studies investigating neural responses in parents often utilize caregiving cues, such as infant faces and infant cries, to understand parents' intuitive responses to children. ERPs in response to images of infant distress, for instance, can be compared with those in response to happy or neutral images of infants (within-person) and noncaregiving-related cues (within-person), or they can be compared across individuals (between-person) (Maupin et al., 2015).

Parenting ERP studies have frequently assessed and highlighted the importance of several ERPs, namely the N170, P300, and late positive potential (LPP). The N170 is an early stage ERP that indexes initial encoding or processing specific to faces (Bentin et al., 1996; Noll et al., 2012). In research examining parental response to infant or child faces, greater amplitude and shorter latency of the N170 is thought to suggest a more rewarding image (Marini et al., 2011). The P300 is a later-stage ERP that represents attention to and cognitive evaluation of the stimulus (Maupin et al., 2019; Rutherford, Maupin, et al., 2017a). The LPP is also a later-stage ERP that reflects more sustained and controlled stimulus processing, which is particularly enhanced for motivationally or emotionally relevant stimuli (Hajcak et al., 2010). Additional ERPs (e.g., P100, N100) have been studied to understand parents' responses to child emotional expression, although less frequently (Kuzava et al., 2020; Maupin et al., 2015).

Findings from studies examining these three primary ERPs have found differences in ERP responses for different infant facial expressions. Recent meta-analytic work identified differences in the magnitude of the N170 response to infant emotional faces, such that crying expressions elicited larger N170 responses than laughing or neutral expressions, and laughing produced larger N170 responses than neutral

expressions (Kuzava et al., 2020). There was also a difference in N170 responses based on parental status, such that parents had a larger N170 response to crying expressions than neutral expressions, with no emotional expression differences in the N170 observed in nonparents. In regard to the LPP, differences in the magnitude of the LPP response were identified, such that crying expressions elicited larger LPP responses than laughing or neutral expressions. Of note, Kuzava et al. (2020) considered P300 responses interchangeably with the LPP given they are both late-stage ERPs that can be described as “a gradual positive deflection beginning around 300-ms post stimulus” (p. 1173). Other reviews (Maupin et al., 2015) have separately highlighted P300 and LPP sensitivity to different infant facial expressions.

Studies have also found that maternal psychopathology is linked to these three primary ERPs. During the perinatal period, women with higher levels of anxiety exhibited heightened LPP response to neutral infant faces (Malak et al., 2015; Rutherford, Byrne, et al., 2017). Maternal depression during the perinatal period has been associated with an attenuated P300 response to sad infant faces (Rutherford et al., 2016). Finally, the N170 has been found to be modulated by substance use such that mothers with substance use demonstrate a delay in the N170 response to infant faces irrespective of emotional expression (Lowell et al., 2020; Rutherford, Maupin, et al., 2017a). Such evidence suggests that maternal risk factors contribute to altered responding to infant cues at the neural level as measured by ERPs, which in turn might help explain observable caregiving behavior (Bernard et al., 2015; Kuzava et al., 2020), as well as documented associations between maternal psychopathology and caregiving behavior (Easterbrooks et al., 2000; Herba et al., 2016; Mayes & Truman, 2002; Warnock et al., 2016). Collectively, this body of research demonstrates the important mechanistic lens that ERP studies can provide into maternal mental health, responsive caregiving, and infant emotions.

Racial/ethnic representation in previous ERP studies examining maternal neural responding to caregiving cues

Although ERP research on mothers’ neural responding to infant cues has advanced understanding of the human maternal brain, current knowledge might be limited by the racial/ethnic make-up of the samples comprising this research base. To assess racial/ethnic representation in maternal brain research leveraging EEG, we examined the studies included in a recent meta-analysis on adults’ responses to child emotional expressions as measured by the N170 and LPP (note: P300 and LPP were combined) (Kuzava et al., 2020). While this is not an exhaustive list of ERP studies

of maternal neural processing, the meta-analysis provides a useful jumping off point to demonstrate where this research area is in terms of the current racial/ethnic diversity of samples, and the representativeness of our current knowledge base on maternal neural responding to infant/child cues.

The meta-analysis included studies of adults that examined the N170 and LPP components in response to visual stimuli of infant or child emotional faces. Studies were included in the meta-analysis if they were available on or before July 2019, written in English, and were dissertations or peer-reviewed articles. Participants could not have significant cognitive impairments or have children with serious developmental or medical concerns. Parent status of the participants had to be known. Papers were excluded if they had overlapping samples. In total, 21 separate papers were part of the meta-analysis, some of which included subgroups (e.g., parents and nonparents, low risk vs. high risk mothers). Eighteen of 21 studies included parents, beginning as early as pregnancy up to parents with children who were on average 5 years old. These 18 studies compared maternal neural response to infant/child facial expressions (crying, laughing, and/or neutral faces) between groups, such as parents compared with nonparents (Noll et al., 2012; Peltola et al., 2014; Proverbio et al., 2006), CPS-referred mothers receiving a parenting intervention versus control intervention and nonreferred mothers (Bernard et al., 2015), mothers with substantiated neglect versus control mothers (Rodrigo et al., 2011), mothers who did and did not smoke (Rutherford, Maupin, et al., 2017a), mothers with and without children with autism spectrum disorder (Márquez et al., 2019), and securely attached vs. insecurely attached mothers (Fraedrich et al., 2010; Leyh et al., 2016). Some studies also examined differences within person, such as pregnancy vs. postpartum (Dudek et al., 2020), responses after administration of intranasal oxytocin compared to placebo (Peltola et al., 2018), or own infant versus unfamiliar infant faces (Doi & Shinohara, 2012). Finally, studies were included that examined linear associations of ERP amplitude and latency with continuous variables such as attachment security (Groh & Haydon, 2018), parental mentalizing (Rutherford, Maupin, et al., 2017b), sensitive caregiving (Kuzava et al., 2019), or depression and anxiety (Malak et al., 2015; Noll et al., 2012; Rutherford et al., 2016; Rutherford, Byrne, et al., 2017).

We examined the racial/ethnic composition of samples for the 18 papers that included parents (Table 1; Fig. 1). We used the racial/ethnic categories or descriptors as written by authors. Where this information was not explicitly written in the manuscript, we contacted authors to gather these data. To provide additional context, Table 1 also reports whether race/ethnicity was examined as a moderator or covariate, the racial/ethnic background of the infant or child face stimuli, the socioeconomic status (SES) information reported for the sample, and the location where the study took place. Finally, we calculated

Table 1 Studies including parents from the Kuzava et al. (2020) meta-analysis of ERP studies of adult neural responding to infant/child faces

Study and sample overview	N	Race/ethnicity composition of sample	Examined race/ethnicity in analyses	Race/ethnicity of stimuli	Socioeconomic status data for sample	Study location
Bernard et al. (2015), CPS-referred mothers and low-risk comparison mothers	70	72.9% African American ($n = 51$) 17.1% White ($n = 12$) 5.71% Hispanic ($n = 4$) 2.86% Biracial ($n = 2$) 1.43% Asian ($n = 1$)	No	Own child, "familiarized," and unfamiliar faces all reflecting own child/mother's ethnicity	Not reported	Mid-Atlantic area, USA
Doi and Shinohara (2012), Mothers	16	100% Asian ($N = 16$)	N/A	Own child and unfamiliar child (using other mother's own child image), 100% Japanese	Not reported	Nagasaki, Japan
Dudek et al. (2020), Mothers	39	2.56% African ($n = 1$) 25.6% Asian ($n = 10$) 46.2% Caucasian ($n = 18$) 5.13% Hispanic ($n = 2$) 10.3% Indian ($n = 4$) 10.3% Other ($n = 4$)	Examined as moderator - no effects	95% Caucasian and 5% African American	Education: High school graduate (5%), Some college or university (10%), College graduate (15%), University graduate (41%), Some graduate school (8%), Graduate degree (21%); Income: \$0-50k (47%), \$50-100k (32%), \$100k+ (21%)	Toronto, Ontario, Canada
Fraedrich et al. (2010), Mothers	17	100% White ($N = 17$)	N/A	100% White	Not reported	Erlangen, Germany
Groh and Haydon (2018), Mothers	70	70% White ($n = 49$) 13% Asian ($n = 9$) 10% Hispanic ($n = 7$) 3% African American ($n = 2$) 4% Multiracial ($n = 3$)	Examined as a covariate - no effects	Own children	Education: Range of 1 (high school degree) to 5 (advanced degree), mean = 4.19 (SD = 0.98). Median reported family income: \$51-60k; Range: <\$10k-100k+	Columbia, MO, USA
Kuzava et al. (2019), Mothers	86	62.8% Caucasian/White ($n = 54$) 5.8% Biracial ($n = 5$) 5.8% African American ($n = 5$) 4.7% Asian ($n = 4$) 17.4% Hispanic ($n = 15$) 3.5% Other ($n = 3$)	No	Balanced for race (50% White, 50% African American)	20.9% low-income (income-to-needs ratio <1.5); 16.3% low education (high school degree or less); average household income: \$82,128.56 (SD = 54,652.50)	Long Island, NY, USA
Leyh et al. (2016), Primiparous mothers	25	100% White European ($N = 25$)	N/A	100% White	Not reported	Erlangen, Germany

Table 1 (continued)

Study and sample overview	N	Race/ethnicity composition of sample	Examined race/ethnicity in analyses	Race/ethnicity of stimuli	Socioeconomic status data for sample	Study location
Malak et al. (2015), Mothers	47	45% African American ($n = 21$) 30% Caucasian ($n = 14$) 5% Hispanic ($n = 3$) 11% Hispanic/Latino ($n = 5$) 4% Asian ($n = 2$) 2% Caucasian and African American ($n = 1$) 2% Did not report ($n = 1$)	No	100% White	Not reported	New Haven, CT, USA
Márquez et al. (2019), Mothers with and without children with autism spectrum disorder	40	100% Hispanic/Latinx ($N = 40$)	N/A	100% Mexican	Reference group had more years of education, and higher socioeconomic level, than clinical parent group	Mexico City, Mexico
Noll et al. (2012), Mothers and nonmothers	17 mothers, 13 nonmothers	Mothers: 70.6% Caucasian ($n = 12$) 5.9% African American/Black ($n = 1$) 11.8% African American/Asian ($n = 2$) 5.9% Other ($n = 2$) Nonmothers: 53.8% Caucasian ($n = 7$) 7.7% African American/Black ($n = 1$) 7.7% African American/Asian ($n = 1$) 7.7% Other ($n = 1$) 23.1% Did not report ($n = 3$)	No	100% White	Not reported	New Haven, CT, USA
Peltola et al. (2014), Mothers and nonmothers	48 mothers, 46 nonmothers	100% Finnish/White ($N = 94$, $n = 48$ mothers)	N/A	100% White	Not reported	Tampere, Finland
Peltola et al. (2018), Mothers	38	100% Finnish/White ($N = 38$)	N/A	100% White	Predominantly from an urban, middle-class background (average years of education = 16.33, SD = 2.81; annual household income on average within 50,000–69,999€)	Tampere, Finland
Proverbio et al. (2006), Mothers and fathers; non-parent women and men	20 parents (10 fathers, 10 mothers); 20 non-parents (10 men, 10 women)	100% Italian/White ($N = 40$, $n = 10$ mothers)	N/A	100% White (own-race faces)	Middle-high socioeconomic status	Milan, Italy

Table 1 (continued)

Study and sample overview	N	Race/ethnicity composition of sample	Examined race/ethnicity in analyses	Race/ethnicity of stimuli	Socioeconomic status data for sample	Study location
Rodrigo et al. (2011), Mothers with substantiated neglect and control mothers	28	100% White ($N = 28$)	N/A	100% White	Largely unemployed and with education less than high school; all subjects recruited from social services; control group had higher education and employment rate	Tenerife, Canary Islands, Spain
Rutherford et al. (2016), Pregnant women	36	43.2% African American ($n = 16$) 29.7% Caucasian ($n = 11$) 8.1% Hispanic/Latino ($n = 3$) 5.4% Asian ($n = 2$) 5.4% Caucasian/ African American ($n = 2$) 2.7% Puerto Rican ($n = 1$) 2.7% African American/Asian American ($n = 1$)	No	Unfamiliar infants, balanced between Caucasian and African American	Not reported	New Haven, CT, USA
Rutherford, Byrne, et al. (2017), Pregnant women	43	48.8% Caucasian ($n = 21$) 32.6% African American ($n = 14$) 7.0% Hispanic/Latino ($n = 3$) 4.7% Asian ($n = 2$) 7.0% Other ($n = 3$)	No	Balanced for race (50% Caucasian and 50% African American)	Not reported	New Haven, CT, USA
Rutherford, Maupin, et al. (2017b), Mothers	63	49.2% Caucasian ($n = 31$) 22.2% African American ($n = 14$) 9.5% Hispanic/Latino ($n = 6$) 3.2% Asian American ($n = 2$) 1.6% Caucasian/African American ($n = 1$) 1.6% Caucasian/American Indian ($n = 1$) 1.6% Caucasian/Native Hawaiian ($n = 1$) 1.6% multiracial ($n = 1$) 9.5% did not report ($n = 6$)	No	Balanced for race (Caucasian and African American)	Education in years: $M = 15$ years; $SD = 3$ years	New Haven, CT, USA
Rutherford, Maupin, et al. (2017a), Smoking and non-smoking mothers	35 smoking and 35 non-smoking mothers	Mothers who smoke: 57.1% African American ($n = 20$) 22.9% European American ($n = 8$) 17.1% Latin American ($n = 6$) 0% Asian American ($n = 0$) 0% European American/ African American ($n = 0$) 2.9% Did not report ($n = 1$) Nonsmoking mothers: 57.1% African American ($n = 20$) 20% European American ($n = 7$) 17.1% Latin American ($n = 6$) 2.9% Asian American ($n = 1$) 2.9% European American/ African American ($n = 1$) 0% Did not report ($n = 0$)	No	Balanced for race (African American, European American)	Mothers who smoke: Education in years $M = 12.10$ years; $SD = 1.14$ years; 4 did not report. Non-smoking mothers: $M = 12.66$ years; $SD = 2.86$ years; 6 did not report	New Haven, CT, USA

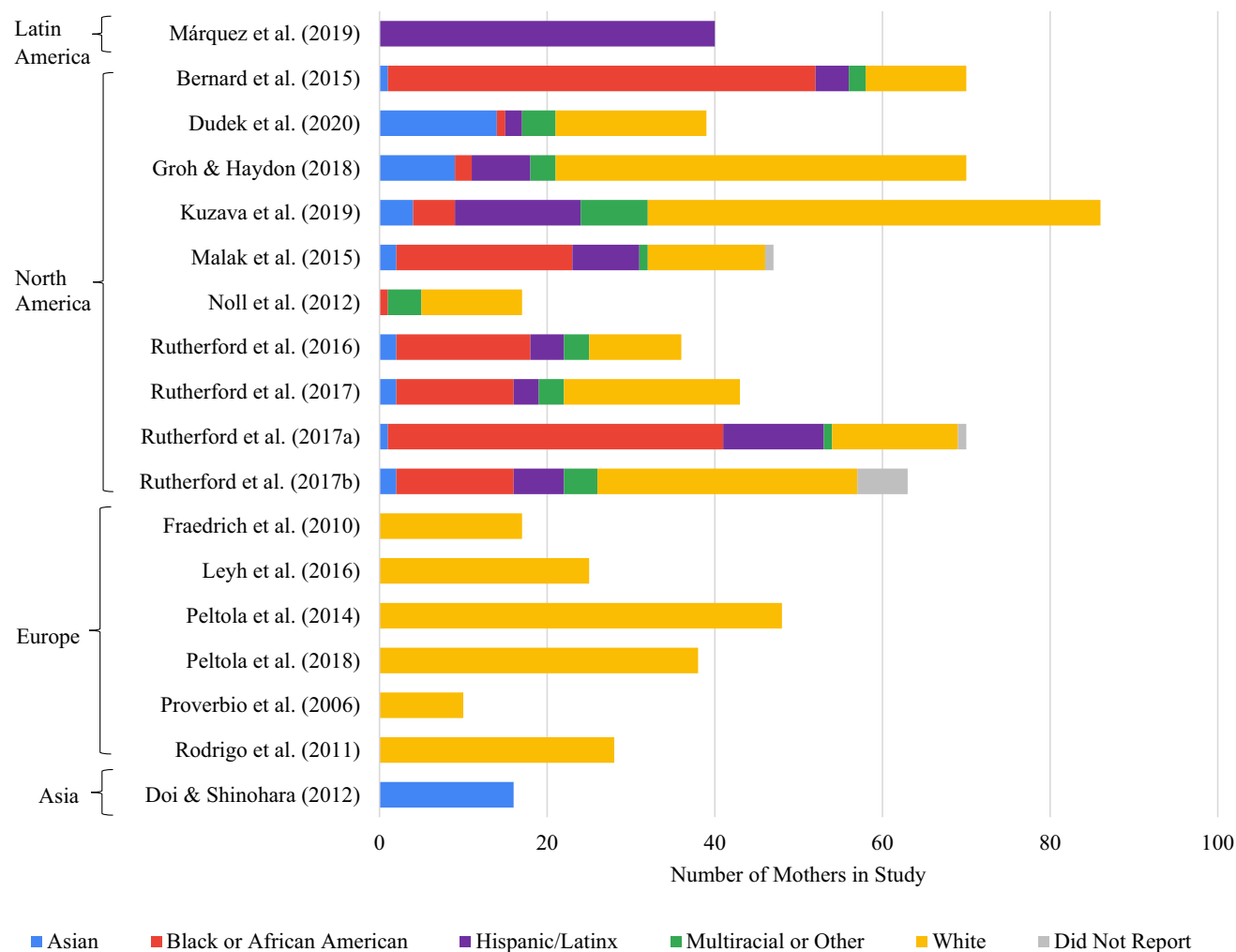


Fig. 1 Number of mothers in the 18 identified studies from Kuzava et al. (2020) by race/ethnicity and geographic location

the total percentages in each racial and ethnic category across studies, based on the numbers reported for mothers in each sample (i.e., we excluded nonparent subgroups and fathers, of whom there were only 10, from these calculations).

Across these 18 studies, there were 763 mothers total, and 52.8% ($N = 403$) identified as White/European ancestry, 21.6% ($N = 165$) as Black or African American, 13.2% ($N = 101$) as Hispanic/Latinx, 6.9% ($N = 53$) as Asian, 4.3% ($N = 33$) as multiracial or other, and 1.0% ($N = 8$) did not report. Nine mothers who were included in the multiracial category reported their race/ethnicity as either African-American and Asian or African-American and Caucasian (Table 1). There were likely more mothers who reported their race/ethnicity as biracial or multiracial who identified as Black or African American, although this specific information was not assessed. Studies were conducted in multiple countries, including the United States, Canada, Mexico, Spain, Italy, Germany, Finland, and Japan. Of note, 98.2% of the Black mothers represented were recruited as

part of studies that took place in the Northeastern United States (primarily Delaware and Connecticut), representing two research groups (a third group collecting data in New York also reported data from Black mothers, $n = 5$). Further demonstrating that there is not a consistent inclusion of Black mothers in maternal brain EEG research, the studies we examined ranged from 0–72.9% in their representation of Black mothers, with a median of only 2.86%. Similarly, 40% of the representation of Hispanic/Latino mothers came from one study conducted in Mexico, and 30% of the representation of Asian mothers came from one study conducted in Japan. Six of the studies (one-third) included only White participants.

Only one of the 18 studies (Dudek et al., 2020) examined whether mothers' race/ethnicity moderated ERP change over time and did not find any significant moderation effect. However, this study may have been underpowered to detect small or medium moderation effects. Dudek and colleagues' (2020) study, which tested within-person ERP differences

from pregnancy to postpartum, had a total of 39 mothers representing six racial/ethnic groups. Power analysis with power equal to 0.80 and $\alpha = 0.05$ suggests that this sample would allow for detection of a large-size within-between interaction ($f = 0.40$), but a larger sample would be needed to detect a medium ($f = 0.30$, $N = 42$) or small ($f = 0.20$, $N = 90$) interaction effect (power analysis assumes repeated measure correlation of 0.5, nonsphericity correction of 1; Faul et al., 2007). Even larger samples are needed for testing interactions in between-group analysis; in a factorial design testing differences between two main groups, with five racial/ethnic groups in the sample, interaction effects for race/ethnicity would require sample sizes of $N = 80$ for a large effect ($f = 0.40$), $N = 138$ for a medium effect ($f = 0.30$), and $N = 304$ for a small effect ($f = 0.20$). Moreover, unequal racial/ethnic groups are more likely to violate assumptions of analysis of variance (ANOVA); ideally, studies would not only have larger samples but also more equal group sizes in order to undertake moderation analysis based on race/ethnicity. Considering another measure of effect size, Cohen's d , which measures effect size for the difference between two groups, power analysis for t -tests (power = 0.80, $\alpha = 0.05$, two-tailed) to detect ERP differences between two racial/ethnic groups would require equal group sizes of 26 to detect a large effect ($d = 0.80$), groups of $n = 45$ to detect a medium effect ($d = 0.60$), and groups of $n = 100$ to detect a small effect ($d = 0.40$). However, when one group is twice as large as the other, the overall sample size requirement increases; for example, to detect a medium effect ($d = 0.60$) between two racial/ethnic groups when one group is twice as large as the other, the group sizes would have to be $n = 34$ and $n = 68$ (Faul et al., 2007).

It is important to note that in their meta-analysis, Kuzava et al. (2020) also called attention to this issue; they reported the percentage of each sample that was from racial/ethnic minority identities and tested racial/ethnic minority status as a moderator of effect sizes. They did not find significant moderation by racial/ethnic minority status but acknowledged that using a dichotomous measure (racial/ethnic minority vs. nonminority) may have limited these findings, because it does not allow for evaluation of any differences between racially minoritized groups.

Regarding the race/ethnicity of infant stimuli, in most studies, the infant stimuli were matched to the race/ethnicity of the sample (or to the two racial/ethnic identities most highly represented in the sample) or were pictures of the mothers' own infants. In regard to SES information reported, nine of 18 studies reported SES information on the sample.

In summary, existing ERP research on maternal responses to infant/child emotional expressions has predominantly represented White mothers, and sources of racial diversity in these samples are limited by geographic location and therefore fail to accurately represent diversity in terms of

nationality, regionality, and rurality. While this body of research is international in nature, the majority of participants are of European ancestry. Because research findings often are generalized across populations using data collected primarily from White participants (Remedios, 2022), the lack of representativeness in EEG studies of maternal neural processing of child emotional expression may introduce bias to what we know about the maternal brain, and in doing so, contribute to an incomplete, and potentially inaccurate, knowledge base that also perpetuates racial disparities in maternal health.

Sources of racial inequality in EEG research and research with Black mothers

There is systemic bias in EEG research (Choy et al., 2021), which extends to EEG research on the maternal brain. Most notably, existing EEG equipment is incompatible with curly or coarse hair and with protective hairstyles (e.g., braids and twists), leading to a systemic exclusion of individuals of African descent (Choy et al., 2021; Etienne et al., 2020; Parker & Ricard, 2022). As Etienne et al. (2020) discuss, African hair is unique for its small follicle shape, which causes the hair to curl as it grows, resulting in dense coils and thick hair (Calhoun, 2022). EEG requires placement of multiple electrodes across the scalp with or without either a gel or liquid solution facilitating signal conduction. Ideally, electrodes must touch the scalp directly to obtain optimal EEG signal. Using existing EEG equipment and data collection procedures, this direct placement on the scalp can be difficult to achieve for coarse and curly hair and for the hairstyles commonly worn by Black individuals (Parker & Ricard, 2022). Black participants may be asked to significantly change their hairstyle, straighten their hair, or not use product in their hair (Calhoun, 2022; Choy et al., 2021; Etienne et al., 2020). EEG data collection therefore may lead to emotional toll, financial cost, discomfort, and inconvenience for Black participants (Etienne et al., 2020; Parker & Ricard, 2022). Individuals of African descent may volunteer less frequently for EEG research as a result—or poorer quality EEG data may be recorded from those who volunteer (Etienne et al., 2020), resulting in further misrepresentation or in exclusion of data from Black participants in final data analysis (Choy et al., 2021; Parker & Ricard, 2022). Some existing EEG systems and methods are more compatible than others with differing hair types. For example, gel-based solution stays longer in hair than saline-based solution, and while this can help provide signal for a longer period of time, gel also is harder to remove from hair and therefore may present more of a barrier to participation (or retention) for those with coarse or curly hair. We refer readers to Choy et al. (2021) for a more in-depth discussion of how different EEG methods work, or do not work, for the hair of individuals of African descent.

Limitations to current EEG equipment are particularly concerning when considered alongside the persistent racial disparities in health outcomes and research more broadly. Although these disparities occur in research broadly, those that pertain to research with mothers are especially important to outline here. Distrust of researchers is an important factor to consider and is a consequence of historical tragedies (e.g., the Tuskegee Study; see Gamble, 1997), wherein African Americans were exploited and had their human rights horrifically violated by researchers. The atrocities committed against this community created a lasting distrust and have affected the willingness of African Americans and members of other minoritized groups to seek healthcare and participate in research (Isler & Corbie-Smith, 2012; Kennedy et al., 2007). This mistrust is further exacerbated by problematic interactions that have occurred between researchers and the wider community, such as researchers who collect data without disseminating the findings accessibly for participants' benefit (Brown Speights et al., 2017). Mental health research (including peer-review processes and journal editorship) has also been critiqued for being dominated by researchers in Western countries (Muthukrishna et al., 2020; Nielsen et al., 2017; Roberts et al., 2020). A lack of cultural competence or antiracist training also limits researchers' ability to comprehend how individuals of racially minoritized identities deal with stressors on a daily basis (Bhui et al., 2007; Crooks et al., 2021; Lim et al., 2008). Minimal racial diversity among research teams further perpetuates bias in research studies and can create less welcoming or comfortable research spaces for mothers of minoritized identities (Crooks et al., 2021; Rai et al., 2022). The "usual" or "standard" research practices in health and psychology studies are inherently biased, oppressive, and exclusionary (Parker, 2021; Rai et al., 2022). For example, Rai et al. (2022) discuss how efficiency is incentivized in research studies, resulting in falling back on "tools and timelines" that exclude harder-to-reach populations based on factors such as geographic location, language, literacy, or religion, and the social and structural stressors that make research participation difficult.

Barriers to research participation for Black individuals, and Black mothers in particular, also should be contextualized within broader cultural and socio-economic factors. Systemic racism is a primary stressor in African Americans' daily lives, with negative repercussions that preclude participation in research (Williams, 2018). For example, African Americans are more likely to rely on public transit and to work in the service sector or in essential worker roles. These factors present a key obstacle for participant recruitment, particularly during

the COVID-19 pandemic (Best et al., 2021). Systemic income inequality further complicates childcare arrangements and hinders longitudinal recruitment of women of color (Hibel et al., 2021; Johnson, 2021). Black mothers in particular face higher rates of poverty, single motherhood, and adverse life events (Damaske et al., 2017; Ertel et al., 2011; Parker, 2021). Such factors lead to barriers in terms of having the time, physical and emotional resources, transportation, and/or childcare to attend one or more research appointments. While many of these points are applicable to the entire research community and not just within neuroscience or maternal health research, they further reveal the urgency for improved research designs, including more inclusive EEG equipment, and highlight other rampant and systemic issues that must be addressed by researchers interested in understanding the maternal brain and improving maternal health.

Finally, there is sampling bias that occurs based on the location of labs that conduct ERP studies examining maternal neural responses to their child's emotional cues. As we discussed above, and illustrated in Fig. 1, nearly all of the Black mothers in prior research on this topic were primarily from studies conducted by two research groups, located in the Northeastern United States. This sampling bias neglects Black individuals from other regions of the United States—including the Southern United States where the highest proportion of Black Americans reside (Tamir et al., 2021)—and from other countries. This is partially a symptom of where researchers and universities are located and what type of institutions tend to garner research funding that can support EEG studies. For example, Buchanan et al. (2022) point out that predominantly White institutions (PWIs) have greater research resources than Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), and Tribal Colleges and Universities, which serve more diverse students and are also more likely to be located in areas where more diverse research recruitment is possible. There is also unequal representation of people of color among those who receive federal funding in the United States (Buchanan et al., 2022), which may contribute to this issue. The problem of geographic distribution extends beyond the United States. As Fig. 1 shows, the maternal brain research using ERPs that has been conducted outside the United States and Canada has largely taken place in western Europe, with only two other studies—one in Mexico and one in Japan. The current literature largely reflects WEIRD (western, educated, industrialized, rich, and democratic) researchers and research samples, which is not representative of the majority of the world's population (Henrich et al., 2010).

How ERP studies can enrich our understanding of Black motherhood

In light of the evidence reviewed above, increasing the representativeness of ERP research on the maternal brain is imperative, because such research has the potential to inform understanding and reduction of maternal health disparities by providing information at the neural level of analysis that can add nuance to extant findings from Black mothers and families. For example, multiple studies have demonstrated that Black parents tend to have a more authoritarian parenting style than White parents (Lansford et al., 2011; LeCuyer et al., 2011; Reitman et al., 2002) and that the authoritarian parenting style is associated with better outcomes for Black children than White children (Dixon et al., 2008; Greening et al., 2010; LeCuyer et al., 2011; LeCuyer & Swanson, 2017). What constitutes adaptive parenting may vary across different groups based on both cultural and socio-contextual factors (Bocknek et al., 2020). Important factors unique to Black mothers may include religiosity and spirituality, optimism and hope, perseverance and internal strength, the taking on of multiple familial roles (including head of household), racism and discrimination, income-related stress, and cumulative stress exposure, resulting in parenting styles described as “no nonsense parenting” or “tough love parenting” (Bocknek et al., 2020). Bocknek and colleagues’ (2020) study provided evidence for an adaptive parenting factor among low-income Black mothers that was comprised of reframing problems to cope with stress, use of more scaffolding during interactions with children, and use of more commands during coping after stress. Clearly, there are often differences in caregiving styles, behaviors, intentions, and strategies among Black mothers that result from multiple causes; however, it is not yet known whether these differences can also be characterized at the neural level. ERP research focused on Black mothers, particularly during the perinatal period, may help to uncover whether neural differences can be observed during early parenthood that may contribute to behavioral parenting differences as children develop.

Consider, for instance, that mothers’ early neural responses to infant emotional expressions may help to explain or predict their behavioral responses to children’s emotions. Research has shown that mothers’ responses to children’s emotions among Black families at the behavioral level differ from White families (Dunbar et al., 2017). One study of African American and European American mothers demonstrated that African American parents use more strategies, such as minimization or punitive responses to negative emotion (Nelson et al., 2012). However, these responses—termed suppression responses—can be culturally adaptive as they are likely used to help protect children from discrimination (Dunbar et al., 2017; Nelson et al., 2012).

Parents’ responses to child emotions stem in part from their own emotion socialization and racial/ethnic socialization histories (Dunbar et al., 2017). Therefore, it is possible that differences for parents in responding to child emotional cues also occur prior to the level of behavior and are observable at the neural level of responding using ERPs.

These prior findings not only reveal behavioral-level parenting differences that could be partially explained by neural mechanisms. They also exemplify how important it is to conduct research that is *focused* on Black mothers or families that considers the role of cultural and social determinants as well as strengths-based factors. More ERP research with Black mothers also can contribute to a more complete picture of Black motherhood by adding a neural level of explanation alongside behavioral, social, and cultural determinants. ERP studies of the maternal brain are also significant for potentially advancing knowledge on maternal mental health among Black mothers. Parker (2021) described how the notion that greater psychological distress among Black mothers contributes to poorer child outcomes creates a negative—and incomplete—narrative about Black mothers, which fails to consider factors that compound this issue. ERP studies of the maternal brain may help to demystify the link between maternal psychopathology and caregiving behavior.

While we have focused on Black mothers, it is important to acknowledge that parenting styles and other family-level factors—and their effects on child outcomes—have been shown to differ across cultural backgrounds (Hernández & Bámaca-Colbert, 2016; Smetana, 2017). Therefore, the above arguments may be extended to mothers of other minoritized identities, in that ERP research with more racially diverse mothers may help to add nuance, and another level of explanation, to behavioral-level differences observed across diverse racial and ethnic groups.

Future directions for researchers to reduce systemic bias in EEG/ERP studies with mothers

EEG/ERP research has provided useful insight into mechanisms of parent and child development (Maupin et al., 2015) and has the potential to enrich our understanding of motherhood, maternal mental health, caregiving, and child outcomes among Black mothers and families—as well as mothers and families of other minoritized identities. However, current research falls short given systemic bias in EEG research broadly (Choy et al., 2021) that we demonstrate also characterizes ERP research on the maternal brain. As such, taking steps to increase the representativeness of EEG/ERP research on mothers is critical. As we detail below, and summarized

in Table 2, making EEG/ERP studies of the maternal brain more diverse, equitable, and inclusive requires multiple approaches.

First, multiple research groups have begun working on novel methods for EEG data collection to begin to tackle the hardware incompatibility with coarse and curly hair. Etienne et al. (2020) demonstrated that braiding participants' hair in a modified cornrow style called "straight backs" allows for electrode placement on the scalp between braids, is efficient for participants (taking 10 minutes, with the braids able to stay in place for a few weeks), and also notably reduces impedance (noise) in the EEG reading. Therefore, one solution for research labs is to have a staff member who can braid Black participants' hair in this way prior to EEG collection—or to partner with community members, such as hair stylists, which may also improve participant recruitment efforts through community-based outreach. However, we note that this solution still places additional burden on Black participants by asking that they come to the research appointment with hair unstyled or already in this straight-back style. Therefore, this solution may not be feasible for some mothers and still presents a limitation. A number of different approaches at the level of the electrode have also been discussed (Casson, 2019; Etienne et al., 2020; Sun et al., 2012). For instance, Etienne et al. (2020) have created the Sevo electrode, a modified electrode with a clip attachment that can be used like a hair barrette to affix to hair and stay firm against the scalp. Using a system made up of these clips allows for placement of electrodes across the scalp, particularly when combined with the straight-back hairstyle (Etienne et al., 2020). Although published work on the Sevo electrodes is preliminary at this time, this innovation is a critical step forward. Further testing of the Sevo electrodes across different ages and clinical statuses and optimizing cost-effectiveness are the next steps to making them accessible to researchers. As these electrodes become more available, it is also imperative that EEG researchers use them, as this will allow investigators to increase recruitment and retention, and improve data quality, of Black participants.

Second, using more inclusive EEG equipment should occur alongside changes in the recruitment and data collection practices that often systematically exclude mothers of color. Several recent publications comprehensively discuss these issues in research broadly and ways to address them (Buchanan et al., 2022; Crooks et al., 2021; Rai et al., 2022; Roberts et al., 2020). Some key strategies put forward by these authors that are feasible for individual labs and investigators conducting EEG research with mothers include expanding recruitment sites—including more community-based sites and partnership with Black, Indigenous, and People of Color (BIPOC) organizations or institutions;

using community-based participatory research methods; increasing diversity in the research team to reduce mismatch between researcher and participant identities; critically examining reading level and language of study materials; being flexible with participants for follow-up visits, taking into account stressors that may preclude consistent communication and attendance; conducting qualitative interviews with previous participants to learn about their experience and what could have been improved; training research staff in antiracist attitudes and cultural competence; reporting the percentages of each ethnic/racial group represented in research samples; including constraints on generalizability when writing up results, so that findings of majority White samples are not described as if they are the "norm"; and sharing research findings with the community in an accessible manner.

Third, for maternal health research, it is vital to consider the sociocontextual factors that increase stress and influence willingness to participate for mothers of color. To reduce participation barriers for mothers, labs should at minimum provide flexible appointment times, transportation and childcare, adequate compensation, and culturally competent, diverse research staff who communicate with empathy and understanding. It is crucial to remember the increased experiences of adversity and trauma among mothers of color, and therefore researchers must aim to take a trauma-informed lens and create emotionally and physically safe spaces for participants (Crooks et al., 2021). Similarly, researchers should adopt an attitude of using research to support mothers of color, highlight strengths, and counter negative stereotypes (Crooks et al., 2021; Parker, 2021). It may be beneficial to use home visiting, video or phone visits, and portable EEG equipment to go into homes or community centers to meet mothers where they are and at their convenience. There has been significant recent improvement in the hardware and software of mobile EEG, as well as more equipment becoming available, leading to a growth in mobile EEG research (De Vos and Debener, 2014; Lau-Zhu et al., 2019). Mobile EEG methods make research participation more feasible, accessible, and less time consuming for participants and allow researchers to more easily reach participants who face barriers to participation (transportation, distance, childcare). Moreover, mobile EEG can increase sample sizes and ecological validity of research tasks (Lau-Zhu et al., 2019). Mobile EEG is a particularly important method for ERP researchers to consider that can increase representation in EEG research with mothers. Notably, use of mobile EEG hardware would also need to be optimized to better accommodate a wider range of hair styles and textures for it to truly reduce barriers in research participation.

Fourth, considering how the regional limitations of current maternal brain EEG/ERP researchers also create a sampling bias, there is a key opportunity for this research area to geographically expand. This points to the necessity of studies that include multiple sites across the U.S. and internationally, the development of shared research networks and databases across multiple universities and countries, and critically, collaboration between PWIs and HBCUs, HSIs, and Tribal Colleges and Universities. This also underlines the larger need for funding to be more equitably distributed across universities and racially diverse researchers. On an international scale, Fig. 1 illustrates that there is geographic bias both within the United States and much more broadly, with the majority of studies taking place in western Europe or the Northeastern United States. To go beyond the use of largely WEIRD samples, there is a need to improve the funding for and availability of EEG research in other countries and regions. The expansion of EEG research in this way is crucial to generating an understanding of whether our current knowledge of maternal neural responding to infant cues holds true across cultures and individuals of differing racial/ethnic identities.

For research using ERPs to examine maternal neural responses to infant/child cues to move forward, it is important to understand whether mismatch between the race/ethnicity of the participants and stimuli presents a significant confound, because this is not yet known. If this is demonstrated as a confounding factor, researchers should ensure that diverse visual stimuli reflecting the sample or matched to each participant are included. We also encourage maternal brain EEG and ERP researchers to report SES information on the sample (e.g., education level or income), because our investigation found that this information is often lacking from publications, yet it provides important contextual information on the sample distinct from race and ethnicity. Furthermore, collecting these data would allow for researchers to examine whether SES is associated with mothers' ERPs and therefore whether it should be controlled for in statistical analyses. Together with an increase in racially and ethnically diverse samples, this would help to increase knowledge of how different contextual factors affect mothers' neural responding to child cues.

Many steps must be taken to reduce systemic bias and make our studies more racially inclusive and representative, so that what is known about maternal neural responding is not biased and can meaningfully inform our understanding of maternal health disparities. We consider this a call to action for our own research groups and urge other researchers who study the maternal brain using EEG/ERP also to consider how they

may contribute to increasing racial/ethnic diversity and reducing systemic bias in EEG research. In particular, we wish to highlight the recent innovations by Etienne et al. (2020) in terms of hair styling and the novel Sevo electrodes. Such advances are especially important for our ability to increase diversity in EEG/ERP research with parents. At the same time, the implications of this paper go beyond EEG/ERP researchers of the maternal brain. Increasing racial and ethnic diversity in studies of the parental brain will generate knowledge that has implications for maternal health, motherhood, fatherhood, parent-child relationships, and child development. Importantly, increasing inclusion in this research area also can lead to improved, more generalizable parenting recommendations. Another multigenerational impact is that increasing representation of mothers of color in research may have positive effects for child and developmental researchers by increasing the likelihood that their children may participate in research in the future. Our recommended changes to recruitment and data collection practices, scheduling practices, and experimental design in studies with mothers also extend beyond EEG/ERP researchers to any scientists who work with mothers. Given the intersecting biases that have often excluded people of color and women from research, mothers of minoritized racial/ethnic identities in particular have not consistently been represented. Therefore, it is imperative to make more efforts now to increase inclusion in terms of measures and methodology (e.g., EEG hardware) as well as in data collection practices.

We also wish to acknowledge the limitations of the current paper. First, we used the Kuzava et al. (2020) meta-analysis to examine racial and ethnic representation, because it is a recent review, but we acknowledge that this was not an exhaustive list because of inclusion/exclusion criteria in the meta-analysis and given that subsequent studies have been published. Though our examination of racial and ethnic diversity was limited to these 18 studies, and to studies that examined neural response to infant/child emotional expressions specifically, this is meant as an illustrative example to show how our bases of knowledge can be biased toward White individuals. Second, we have focused on mothers, and Black mothers especially, throughout this paper, but it is crucial to emphasize that: a) increased representation and centering of Hispanic/Latina, Asian, Indigenous, and mothers of other minoritized identities in our research studies also is direly needed; b) fathers are generally understudied and even more so in the context of studies of the parental brain and racial/ethnic differences in parenting; and c) childbearing people include nonmothers, who also lack representation in research.

Table 2 Recommendations to improve racial/ethnic diversity in EEG/ERP research with mothers

Stage of research	Action items
Ongoing	<ul style="list-style-type: none"> All research staff complete up-to-date cultural competence and antiracist training Increase racial diversity in the research team Conduct interviews with mothers who have been previous participants about their research experiences Create advisory board of mothers (or parents more broadly) Share research findings with the community in an accessible manner Expand participants recruited to include fathers and child-bearing non-mothers Collect data about the racial/ethnic identity of participants
Participant recruitment and retention	<ul style="list-style-type: none"> Expand recruitment sites to include more diverse neighborhoods and communities Develop shared research networks and databases across multiple universities and countries Create collaborations between PWIs and HBCUs, HSIs, and Tribal Colleges and Universities Adopt community-based participatory research methods (e.g., more community-based sites and partnerships with Black, Indigenous, and People of Color (BIPOC) organizations or institutions) Critically examine language and reading level of study materials
Data collection	<ul style="list-style-type: none"> Communicate clearly regarding what an EEG experiment entails before the research appointment (e.g., open discussion around hair styles) Adopt inclusive EEG equipment (e.g., the Sevo electrode, a modified electrode with clip attachments to secure hair painlessly; see Etienne et al., 2020) Conduct inclusive EEG placement procedures (e.g., braiding participants' hair in a modified cornrow style; see Etienne et al., 2020) Use home, video, or phone visits and portable EEG equipment to meet mothers where they are Provide mothers with flexible appointment times, transportation and childcare, and adequate compensation for research appointments Take a trauma-informed lens and create emotionally and physically safe spaces for mothers
Data interpretation	<ul style="list-style-type: none"> Examine the contribution of racial/ethnic identity to research findings (i.e., examine whether there are differences across groups, if power allows) Discuss constraints on generalizability for all samples, so that findings of majority White samples are not described as if they are the “norm”

Bhui et al., 2007; Buchanan et al., 2022; Crooks et al., 2021; De Vos & Debener, 2014; Etienne et al., 2020; Lau-Zhu et al., 2019; Lim et al., 2008; Rai et al., 2022; Roberts et al., 2020

Conclusions

Racial disparities in maternal health outcomes, which are most striking for Black mothers, continue to persist. Improving our understanding of the maternal brain—and specifically, our focus of mothers' neural responding to their children's emotional cues using EEG/ERP—is a critical means of advancing knowledge of maternal-child health and caregiving among mothers of color. However, we have demonstrated that existing EEG/ERP studies of maternal neural responding lack adequate representation of mothers of color, underlining that much of our current scholarship in this area is based on studies of all, or a majority of, White mothers. Thus, existing findings may not accurately represent racially diverse mothers. In addition, we have drawn on the broader parenting literature to provide examples of how such exclusionary practices may contribute to bias and nongeneralizable parenting recommendations. With a focus on the detrimental effects for Black mothers in particular, we have outlined how systematic bias in EEG equipment, racial inequalities in research more broadly, and structural barriers and adversities often faced by mothers of color, all contribute to this inequality. To improve the representativeness of maternal EEG/ERP research, more studies with diverse samples are needed to understand whether findings operate similarly for mothers of different racial and

ethnic backgrounds. Specifically, it is imperative to carry out studies in which Black mothers and other childbearing people of color are centered. Furthermore, the uptake of novel electrodes that better accommodate a range of hair textures and styles, as they go through more testing and become widely available, is another critical step. Mothers' neural responding to infant cues adds an important level of analysis that may help to mechanistically explain the links between maternal mental health, mothers' caregiving behavior, and infant and child development. This level of analysis has the potential to meaningfully enhance our understanding of maternal-child health and caregiving among mothers of color in ways that may inform interventions and help to reduce racial disparities in maternal health. However, the promise of maternal brain EEG/ERP research in this regard can only be achieved if researchers take action to reduce systemic racial bias in EEG data collection and in our own research methods.

Acknowledgments Financial support was received from National Institute of Mental Health (NIMH) T32 MH018268 (Penner), National Institute on Aging (NIA) 5R01AG054621-05 (Huang), and National Science Foundation (NSF) 2017920 (Groh). This work was motivated by the efforts of Black in Neuro in their communications regarding inequity in EEG research and the racial equity workshops delivered by Connecticut State Education Resource Center to Yale Child Study Center.

Declarations

Conflicts of interest The authors declare no conflicts of interest.

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