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Authentic justice, equity, diversity and inclusion in the neurosciences

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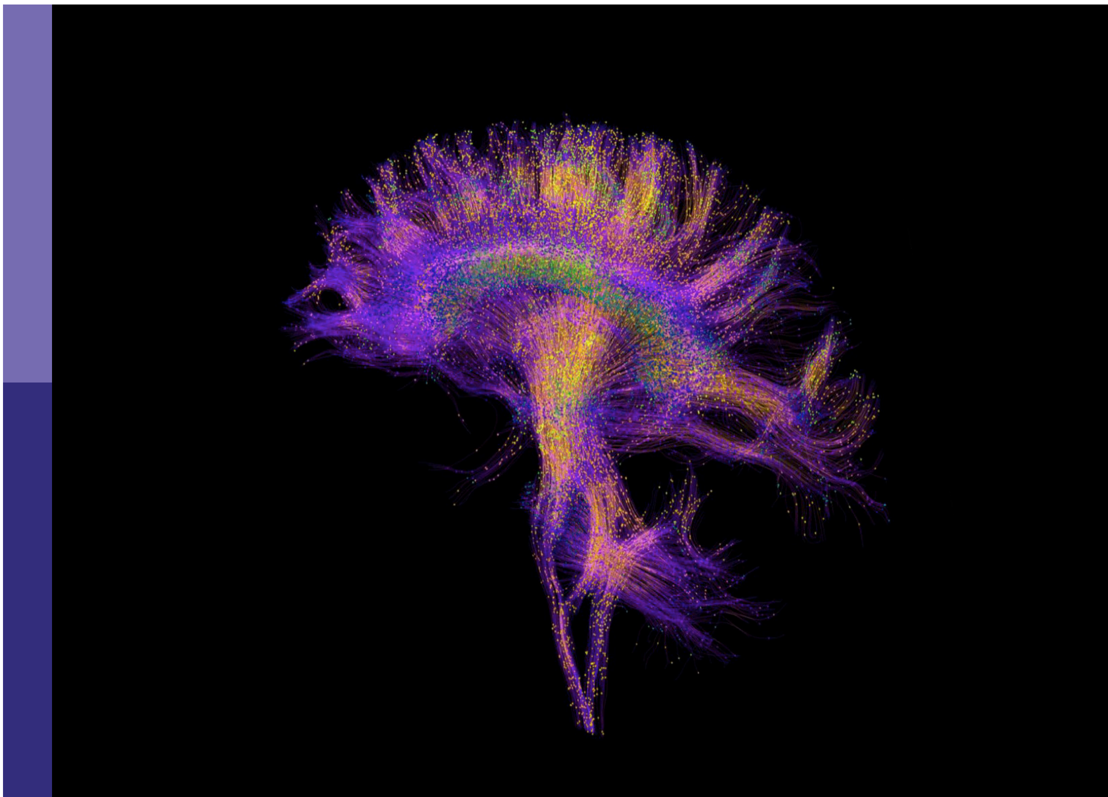

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Authentic justice, equity, diversity and inclusion in the neurosciences

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A perspective on enhancing representative samples in developmental human neuroscience: Connecting science to society

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Marginalized groups are often underrepresented in human developmental neuroscientific studies. This is problematic for the generalizability of findings about brain-behavior mechanisms, as well as for the validity, reliability, and reproducibility of results. In the present paper we discuss selection bias in cohort studies, which is known to contribute to the underrepresentation of marginalized groups. First, we address the issue of exclusion bias, as marginalized groups are sometimes excluded from studies because they do not fit the inclusion criteria. Second, we highlight examples of sampling bias. Recruitment strategies are not always designed to reach and attract a diverse group of youth. Third, we explain how diversity can be lost due to attrition of marginalized groups in longitudinal cohort studies. We provide experience- and evidence-based recommendations to stimulate neuroscientists to enhance study population representativeness *via* science communication and citizen science with youth. By connecting science to society, researchers have the opportunity to establish sustainable and equal researcher-community relationships, which can positively contribute to tackling selection biases.

KEYWORDS

neuroscience, development, representativeness, diversity, society, samples, adolescence, marginalized groups

Introduction

Developmental neuroscientists generally aim to include representative samples in their scientific studies, yet marginalized groups are often underrepresented (Fakkel et al., 2020). In this paper, when discussing marginalized groups, we refer to a heterogenous group which includes–but is not limited to–Black, Indigenous, and People of Color (BIPOC), individuals with bi-or multi-cultural origin, individuals from low socioeconomic status, individuals from the LHBTQIA + community, and individuals with disabilities or functional impairments. Although marginalized groups may differ per country and continent, and some of these groups may be considered marginalized predominantly in Europe and North America, the described groups still have historically been underrepresented in neuroscientific studies (Dotson and Duarte, 2020). Researchers generally attract and engage convenience samples, i.e., participants that have affinity with a specific research topic or are easy to contact and recruit. Convenience samples commonly do not reflect the heterogeneity of human populations. As a consequence, the underrepresentation of marginalized groups in neuroscientific studies is problematic for the generalizability of findings about (developmental) brain-behavior mechanisms, as well as for the validity, reliability, and reproducibility of results (Falk et al., 2013; Nielsen et al., 2017a; Dotson and Duarte, 2020). In turn, this may limit our general understanding of neurodevelopmental processes investigated in the population (Lewinn et al., 2017). Importantly, researchers should not solely focus on diversity; but also address inclusion and equity. Inclusion refers to the intentional process and effort to ensure that individuals with diverse identities can equally participate within an organization or group and that their contribution is equally valued by others (Tan, 2019). Equity refers to the leveling of the playing field for marginalized groups, the process of establishing access to the same opportunities and resources for all (Tan, 2019). Diverse research samples cannot be realized without committing to inclusive research and equity, since most issues regarding underrepresentation of marginalized groups are about unequal opportunities. In the present paper, we highlight three types of selection bias: (1) exclusion bias, (2) sampling bias and, (3) attrition bias in cohort studies. Second, we offer practical recommendations to minimize selection bias with a special focus on citizen science.

Selection bias

The term selection bias encompasses the failure to select, attract or maintain a representative sample or study population (Hernán et al., 2004). Selection biases limit our possibilities to draw accurate conclusion from scientific findings, as there are systematic differences between the individual characteristics of the sample and the target population. Below, we discuss three forms of selection biases in developmental human neuroscience.

Exclusion bias

Decades of studies in developmental cognitive neuroscience have greatly improved our understanding of a wide range of psychological processes and their neural underpinnings throughout development (Nelson and Bloom, 1997; Decety and Meyer, 2008). At the same time, these developmental processes were not always successfully measured among youth from marginalized groups, partly due to the selection of certain inclusion or exclusion criteria. Traditional rationales to exclude certain groups may be outdated and invalid, or systematically limit participation of marginalized individuals. For instance, specific neuroscientific tools and methodologies, including electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS), skin conductance and eye tracking, often systematically exclude participants based on phenotypic differences, such as hair structure, skin pigmentation, pupil color (Webb et al., 2022). An example of this is how BIPOC youth with curly and tightly coiled hair have been excluded from EEG studies, due to the limited knowledge on ensuring good brain activity quality among diverse hairstyles or hair structures (Etienne et al., 2020; Choy et al., 2022). As a result, findings are often biased and difficult to generalize to BIPOC youth–limiting our understanding of their neurodevelopment–and how these individuals may be optimally supported during development (e.g., using prevention, intervention, and treatment).

These problems are often amplified by predominant reliance on group-based statistical comparisons in which neural measures are averaged across a group of homogenous participants to maximize statistical power (Willems et al., 2014)–despite evidence that grouping is often difficult and arbitrary as many population characteristics exist on a spectrum (i.e., show marked heterogeneity, or individual differences). In addition, how these characteristics are defined and operationalized in the first place widely differs between studies and countries (see Paus, 2010 for various examples on brain outcomes, and environmental factors like socioeconomic status). Hence, it is important to take steps to inclusively account for diversity and heterogeneity in our research samples, in operationalization, sampling strategies and data analysis.

Sampling bias

Sampling bias may occur in studies when researcher do not properly select the study population (Nielsen et al., 2017a). Current recruitment strategies do not always allow us to successfully reach out to marginalized groups. Subsequently, systematic barriers prevent us from reaching diverse target groups from various marginalized groups (Habibi et al., 2015; Nielsen et al., 2017a). One of those barriers is the lack of accessibility to information and resources (Habibi et al., 2015). For example, individuals from lower socioeconomic backgrounds may have less access to financial and digital resources, which could prevent them from initial participation in neuroimaging studies (Jang and Vorderstrasse, 2019). Another example is how individuals with disabilities or functional impairment may face more difficulties when it comes to transportation to centers where neuroscientific studies are conducted (e.g., mobility issues, obstacles in public transport, or financial costs). A lack of diversity in research teams (Tzovara et al., 2021) may also limit recruitment amongst diverse groups of participants (Flores et al., 2017). Having representative scientists in research teams may result in feelings of familiarity and similarity among participants, which in turn may positively contribute to increased trust in science (Wallace and Bartlett, 2013; Flores et al., 2017). The importance of diversifying teams to promote equality was also evident in a study by Auelua-toomey and Roberts (2022). The authors showed that journals with diverse editorial boards were perceived more positively by both BIPOC and white graduate students than editorial boards without BIPOC members. Recently, the Organization for Human Brain Mapping (OHBM) has established a Diversity and Inclusivity Committee to promote the presence of underrepresented scientists and to create diverse role models in the field of neuroimaging [for a detailed overview of their code of conduct and their activities aimed at enhancing and fostering diversity, equity, and inclusion in academic teams see Tzovara et al. (2021)]. It is beyond the scope of this short paper to provide recommendations on how to diversify research teams in neuroscience, still it is important to acknowledge that having members of underrepresented groups is necessary for moving forward (Nielsen et al., 2017b; Harrington, 2021; Auelua-toomey and Roberts, 2022).

Attrition bias

The third source causing potential selection bias is attrition. Longitudinal (neuroimaging) studies tend to end up with less representative research samples after each wave due to relatively high levels of attrition of participants from marginalized groups or low educated groups (Ewing et al., 2018). There is growing statistical literature on how to deal with missing data (e.g., multiple imputation methods) and attrition (e.g., inverse probability weighting) in longitudinal analyses. However, there is limited information on how to prevent systematic attrition marginalized groups in follow-up studies. To illustrate the loss of individuals from marginalized groups in cohort studies we highlight two neuroimaging studies, although attrition bias is common issue among most longitudinal studies. For example, in the Generation R Study, a population-based cohort study in Rotterdam, Netherlands the research sample became less diverse in terms of ethnicity and educational level with each wave, despite several efforts to keep youth form marginalized groups within the study. At the onset of the study, 48% of the participants were identified as Dutch, while this percentage increased to 55.8% 9 years later (Jaddoe et al., 2006; White et al., 2018). Researchers had invested in several efforts, including support for verbal translation of questionnaires in Turkish and Arabic by research assistants who even visited the participants at home (Jaddoe et al., 2008). Unfortunately, this was not enough to combat attrition among marginalized groups. Likewise, in the IMAGEN study, 17% of the parents had a low education level at baseline, while at the 5-year follow-up this was 13% (Modabbernia et al., 2021).

There may be multiple causes of this unfortunate loss of diversity, including logistical barriers (Nicholson et al., 2015; Flores et al., 2017; Raphael et al., 2017). Neuroimaging techniques, like Magnetic Resonance Imaging (MRI), can be time consuming. Some MRI sequences require laboratory visits of at least 3 h. Visit to research centers in general can be intensive, as behavioral and psychiatric assessments also tend to consume quite some time. Although this might not be a problem for some participants, it may prevent specific groups from participating multiple times. Additionally, studies have shown that adolescents from certain ethnically/culturally diverse groups and lower socioeconomic backgrounds tend to grow up in home environment with larger household, family or work responsibilities possibly making it more difficult for them to arrange free time for each assessment (Tseng, 2004; Sánchez et al., 2010).

Connecting science to society

Bridging the gap between science and society allows for more representative, innovative and generalizable research, which may ultimately benefit healthcare practices, education and policy efforts (Ellis et al., 2021). Here, we provide some experience- and evidence-based recommendations to enhance diversity, equity, and inclusion in developmental human neuroscience through activities that are aimed at connecting science to society.

Science communication and outreach

One way to connect science to society, specifically youth, is *via* science communication and outreach activities (Vollbrecht et al., 2019; Lichtenberg et al., 2020; a. Science communication can positively aid in building trust within communities, which in turn can have positive effects on dismantling selection biases (Saragosa-Harris et al., 2022). Prior research has shown that building trust within communities encourages participation among marginalized groups (Jang and Vorderstrasse, 2019; Nooner et al., 2021). Science communication should be inclusive, and this requires expanding communication styles to other forms, such as such as writing blogs, making videos (with subtitles and preferable in multiple languages), and giving lectures and workshops at schools or community centers. For example, the authors of the present paper engage in science communication *via* social media platforms like Instagram, in which they share their scientific findings with youth and youth organizations. The variety of science communication methods is needed to enhance accessibility to information in marginalized groups and to let adolescents become familiar with neuroscience. Making neuroscientific findings accessible and understandable is not only essential in reaching out to marginalized groups, but also for society in general. Scientific discoveries belong to all of us and hence researchers should not only be open and transparent about their knowledge and findings toward each other, but also to the broader public (Vandenbroucke et al., 2021). Informing and educating young people about brain development and behavioral processes contributes to their understanding of developmental human neuroscience, and thus themselves. In addition, science communication and education can aid in making youth enthusiastic about science and academia (Tzovara et al., 2021). Enabling children from underrepresented groups to get familiar with (neuro) science is, one of the many actions in a chain of changes, needed to diversify academia.

In outreach programs scientists and/or students provide active learning experiences to adolescents and engage adolescents in science (Vollbrecht et al., 2019). Outreach programs are most common within the field of STEM (Science, Technology, Engineering and Mathematics), where the program aim is to attract a wider variety of students into STEM. However, some outreach programs still fail to reach adolescents from marginalized groups (Bultitude, 2014; Vollbrecht et al., 2019). The ABCD study has designed an outreach framework to raise awareness and promote sustainable support from different societal partners, including adolescents (Hoffman et al., 2018). Their framework follows four principles: (1) the identification and segmentation of target audience; (2) gaining support from community leaders and societal organizations; (3) the development and refinement from outreach materials disseminated *via* various platforms; and (4) feedback and evaluation of messaging and branding (Hoffman et al., 2018). Similar to the Generation R study (Jaddoe et al., 2008; Kooijman et al., 2016), the ABCD study maintains regular and dynamic contact with their participants *via* retention materials like newsletters, birthday cards, thank you presents, and reminders.

Citizen science

A second method for connecting science to society is by taking the views and opinions of adolescents from diverse backgrounds actively into account through citizen science. Citizen science is a method in which adolescents are engaged as "citizens" in research projects rather than research participants (Te Brinke et al., 2022). By engaging in citizen science, researchers can learn from youth themselves. For example, what is the best way to contact them, what do they need to have access to longitudinal cohort studies, which barriers should be prioritized, and what do they think is needed for inclusive research? These are all questions for which adolescents from marginalized communities can give essential and valuable information, and thus aid researchers in tackling selection biases.

A crucial requirement for citizen science to work and to be beneficial for both society and science, is the establishment of equal researcher-community partnerships (Hoffman et al., 2018; Weng et al., 2020; Vandenbroucke et al., 2021). Engaging in researcher-community partnerships also entails giving youth partial responsibility and ownership. This will positively contribute to their sense of agency and will likely keep them involved and committed to project. In addition, citizen science should not only be beneficial for the researchers, but also for the adolescents within the community. Citizen science requires commitment from adolescents. Therefore, researchers should ask themselves: "what's in it for adolescents? what can they get out of this commitment." Although this may differ per individual or group, for most adolescents one of the requirements would be that that their ideas and perspectives will contribute to making impact. To ensure that adolescents feel heard and taken seriously when sharing their experiences and knowledge with researchers, it is crucial that researchers are transparent and open about how they incorporate the input from the community into their research. Additionally, involvement from communities, especially from marginalized groups, should also be reckoned and valued through financial compensation or by granting them a certificate.

For successful integration of citizen science initiatives, it is key that perspectives from adolescents, are included from the start of the research project (Vandenbroucke et al., 2021). Early inclusion of adolescents from marginalized groups in neuroscientific research (i.e., when writing the research proposal or setting up the research design) may aid in recognizing implicit biases that affect societal and scientific progress. Research projects should be more tailored to the needs, possibilities, and limitations of adolescents who participate in cohort studies (Jaddoe et al., 2006; Garavan et al., 2018; Hoffman et al., 2018; Nooner et al., 2021). We argue that having the right sampling and engagement strategies cannot be fulfilled without a sustainable researcher-community partnership, in which youth,

youth workers, parents, teachers or communities are involved from the beginning of the research process (Weng et al., 2020; Saragosa-Harris et al., 2022). For instance, in the ABCD study, the researchers employed a probability sampling of schools as primary method for recruiting participants (Garavan et al., 2018). However, they also used additional strategies, such as outreach to summer activities and snowballing referral, whereby enrolled families would receive compensation for getting other families to participate in the study. This latter approach enables word-of mouth enrollment, where individuals can act as ambassadors of the study, and which is likely to have beneficial effects in enhancing trust among potential participants (Garavan et al., 2018).

All in all, recruitment of diverse and representative samples in neuroscientific studies requires a broad range of recruitment strategies, as the "one-size fit all" approach is vulnerable to selection biases. Recently, researchers recognize the scientific value of incorporating diverse perspectives from society into academia (Weng et al., 2020). As a result, research-community partnerships can lead to new innovative ideas, greater equity and societal impact and further scientific progress (Whitmore and Mills, 2021).

Co-creation with societal partners

Co-creation is a specific form of citizen science were researchers and citizens collaborate in the development of a tool, measurement, or design. Within developmental psychology, researchers are gaining more experiencing in how to effectively work with youth at different stages of the empirical cycle, including developing measurement materials (Te Brinke et al., 2022). For instance, adolescents can actively engage in the creation of a new questionnaire or survey, by sharing ideas and providing feedback on the duration, types of questions or the language use. Although, co-creation may seem challenging within the field of developmental human neuroscience, it is still possible to collaboratively develop something with adolescents or other societal partners. Expertise may not always be fully present within the research teams, thus working together with societal partners with specific skills could be the solution. To highlight this, we use the example of how BIPOC individuals with curly and coiled hair structure, are systematically excluded from neuroscientific studies, such as EEG. The Biomechanics, Rehabilitation, and Interdisciplinary Neuroscience (BRaIN) lab at the University of Central Florida has developed an open-source guideline for including diverse hairstyles and hair structures in EEG research.[1] Their guideline contains valuable information for both researchers and participants on hair preparation and hair care in EEG research. More importantly, they co-created this guideline in close collaboration with hair stylists from marginalized communities. This is an example of how societal partners can be of value in dismantling selection biases.

Conclusion

In this short paper, we highlighted three selection biases in developmental human neuroscience studies that may influence the validity, reliability, and reproducibility of study results and thus limit our general understanding of neurodevelopmental processes. Further, we provided experience- and evidence-based recommendations to stimulate neuroscientists to enhance study population representativeness. For future research, we will need to get more insights in when its valuable to have diversity across homogeneous groups and when it is better to have diversity within one sample (i.e., heterogeneous sample). Representativeness and promoting participation of underrepresented groups can be achieved in both ways. Equal researcher-community partnerships and co-creation of research projects with youth from marginalized groups are of great added value to tackle systemic barriers. By connecting science to society, we have the opportunity to both transfer scientific findings to youth, as well as to bring new perspectives and knowledge from society back to the lab, especially from individuals from marginalized groups who have historically been left out.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

KG: conceptualization, investigation, and writing – original draft and review and editing. IV: investigation and writing – original draft and review and editing. LT and FR: investigation and writing – original draft. RC: conceptualization. HE conceptualization, review and editing, and supervision. All authors contributed to the article and approved the submitted version.

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[1] https://hellobrainlab.com/research/eeg-hair-project/

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Auelua-toomey, S. L., and Roberts, S. O. (2022). The effects of editorial-board diversity on race scholars and their scholarship: A field experiment. *Perspect. Psychol. Sci.* doi: 10.1177/17456916211072851 [Epub ahead of print].

Bultitude, K. (2014). Science festivals: Do they succeed in reaching beyond the "already engaged"? *J. Sci. Commun.* 13, 1–3. doi: 10.22323/2.13040301

Choy, T., Baker, E., and Stavropoulos, K. (2022). Systemic racism in EEG research: Considerations and potential solutions. *Affect. Sci.* 3, 14–20. doi: 10.1007/s42761-021-00050-0

Decety, J., and Meyer, M. (2008). From emotion resonance to empathic understanding: A social developmental neuroscience account. *Dev. Psychopathol.* 20, 1053–1080. doi: 10.1017/S0954579408000503

Dotson, V. M., and Duarte, A. (2020). The importance of diversity in cognitive neuroscience. *Ann. N.Y. Acad. Sci.* 1464, 181–191. doi: 10.1111/nyas.14268

Ellis, D. A., Rhind, J., Carcone, A. I., Evans, M., Weissberg-Benchell, J., Buggs-Saxton, C., et al. (2021). Optimizing recruitment of black adolescents into behavioral research: A multi-center study. *J. Pediatr. Psychol.* 46, 611–620. doi: 10.1093/jpepsy/jsab008

Etienne, A., Laroia, T., Weigle, H., Afelin, A., Kelly, S. K., Krishnan, A., et al. (2020). "Novel electrodes for reliable EEG recordings on coarse and curly hair," in *Proceedings of the annual international conference of the IEEE engineering in medicine and biology society*, (Piscataway, NJ: EMBS), 6151–6154. doi: 10.1109/EMBC44109.2020.9176067

Ewing, S. W. F., Chang, L., Cottler, L. B., Tapert, S. F., Dowling, G. J., and Brown, S. A. (2018). Approaching retention within the ABCD study. *Dev. Cogn. Neurosci.* 32, 130–137. doi: 10.1016/j.dcn.2017.11.004

Fakkel, M., Peeters, M., Lugtig, P., Zondervan-Zwijnenburg, M. A. J., Blok, E., White, T., et al. (2020). Testing sampling bias in estimates of adolescent social competence and behavioral control. *Dev. Cogn. Neurosci.* 46:100872. doi: 10.1016/j.dcn.2020.100872

Falk, E. B., Hyde, L. W., Mitchell, C., Faul, J., Gonzalez, R., Heitzeg, M. M., et al. (2013). What is a representative brain? Neuroscience meets population science. *Proc. Natl. Acad. Sci. U.S.A.* 110, 17615–17622. doi: 10.1073/pnas.1310134110

Flores, G., Portillo, A., Lin, H., Walker, C., Fierro, M., Henry, M., et al. (2017). A successful approach to minimizing attrition in racial/ethnic minority, low-income populations. *Contemp. Clin. Trials Commun.* 5, 168–174. doi: 10.1016/j.conctc.2017.01.009

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R. Z., Heeringa, S., et al. (2018). Developmental cognitive neuroscience recruiting the ABCD sample: Design considerations and procedures. *Dev. Cogn. Neurosci.* 32, 16–22. doi: 10.1016/j.dcn.2018.04.004

Habibi, A., Sarkissian, A., Der Gomez, M., and Ilari, B. (2015). Developmental brain researchwith participants fromunderprivileged communities: Strategies for recruitment, participation, and retention. *Mind Brain Educ.* 9, 179–186.

Harrington, M. A. (2021). Diversity in neuroscience education: A perspective from a Historically Black institution. *J. Neurosci. Res.* 2020, 1538–1544. doi: 10.1002/jnr.24911

Hernán, M. A., Hernández-Díaz, S., and Robins, J. M. (2004). A structural approach to selection bias. *Epidemiology* 15, 615–625. doi: 10.1097/01.ede.0000135174.63482.43

Hoffman, E. A., Howlett, K. D., Breslin, F., and Dowling, G. J. (2018). Outreach and innovation: Communication strategies for the ABCD study. *Dev. Cogn. Neurosci.* 32, 138–142. doi: 10.1016/j.dcn.2018.04.001

Jaddoe, V. W. V., Mackenbach, J. P., Moll, H. A., Steegers, E. A. P., Tiemeier, H., Verhulst, F. C., et al. (2006). The generation R study: Design and cohort profile. *Eur. J. Epidemiol.* 21, 475–484. doi: 10.1007/s10654-006-9022-0

Jaddoe, V. W. V., Van Duijn, C. M., Van Der Heijden, A. J., MacKenbach, J. P., Moll, H. A., Steegers, E. A. P., et al. (2008). The generation R study: Design and cohort update until the age of 4 years. *Eur. J. Epidemiol.* 23, 801–811. doi: 10.1007/s10654-008-9309-4

Jang, M., and Vorderstrasse, A. (2019). Socioeconomic status and racial or ethnic differences in participation:web-based survey. *JMIR Res. Protoc.* 8, 1–10. doi: 10.2196/11865

Kooijman, M. N., Kruithof, C. J., van Duijn, C. M., Duijts, L., Franco, O. H., van IJzendoorn, M. H., et al. (2016). The Generation R Study: Design and cohort update 2017. *Eur. J. Epidemiol.* 31, 1243–1264. doi: 10.1007/s10654-016-0224-9

Lewinn, K. Z., Sheridan, M. A., Keyes, K. M., Hamilton, A., and McLaughlin, K. A. (2017). Sample composition alters associations between age and brain structure. *Nature Communications* 8:874. doi: 10.1038/s41467-017-00908-7

Lichtenberg, N. T., Thompson, A. B., Iguchi, M. Y., Evans, C. J., and Romero-Calderón, R. (2020). An undergraduate student-led neuroscience outreach program shows promise in shifting teen attitudes about drugs. *Mind Brain Educ.* 14, 387–399. doi: 10.1111/mbe.12261

Modabbernia, A., Reichenberg, A., Ing, A., Moser, D. A., Doucet, G. E., Artiges, E., et al. (2021). Linked patterns of biological and environmental covariation with brain structure in adolescence: A population-based longitudinal study. *Mol. Psychiatry* 26, 4905–4918. doi: 10.1038/s41380-020-0757-x

Nelson, C. A., and Bloom, F. E. (1997). Child development and neuroscience. *Child Dev.* 68, 970–987.

Nicholson, L. M., Schwirian, P. M., and Groner, J. A. (2015). Recruitment and retention strategies in clinical studies with low-income and minority populations: Progress from 2004-2014. *Contemp. Clin. Trials* 45, 34–40. doi: 10.1016/j.cct.2015.07.008

Nielsen, M., Haun, D., Kärtner, J., and Legare, C. H. (2017a). The persistent sampling bias in developmental psychology: A call to action. *J. Exp. Child Psychol.* 162, 31–38. doi: 10.1016/j.jecp.2017.04.017

Nielsen, M. W., Alegria, S., Börjeson, L., Etzkowitz, H., Falk-Krzesinski, H. J., Joshi, A., et al. (2017b). Gender diversity leads to better science. *Proc. Natl. Acad. Sci. U.S.A.* 114, 1740–1742. doi: 10.1073/pnas.1700616114

Nooner, K. B., Chung, T., Feldstein Ewing, S. W., Brumback, T., Arwood, Z., Tapert, S. F., et al. (2021). Retaining adolescent and young adult participants in research during a pandemic: Best practices from two large-scale developmental neuroimaging studies (NCANDA and ABCD). *Front. Behav. Neurosci.* 14:1–8. doi: 10.3389/fnbeh.2020.597902

Paus, T. (2010). Population neuroscience: Why and how. *Hum. Brain Mapp.* 31, 891–903. doi: 10.1002/hbm.21069

Raphael, J. L., Lion, K. C., and Bearer, C. F. (2017). Policy solutions to recruiting and retaining minority children in research. *Pediatr. Res.* 82, 180–182. doi: 10.1038/pr.2017.119

Sánchez, B., Esparza, P., Colón, Y., and Davis, K. E. (2010). Tryin ' to make it during the transition from high school: The role of family obligation attitudes and economic context for latino–emerging adults. *J. Adolesc. Res.* 25, 858–884. doi: 10.1177/0743558410376831

Saragosa-Harris, N. M., Chaku, N., Macsweeney, N., Guazzelli, V., Scheuplein, M., Feola, B., et al. (2022). A practical guide for researchers and reviewers using the ABCD Study and other large longitudinal datasets. *Dev. Cogn. Neurosci.* 55:101115. doi: 10.1016/j.dcn.2022.101115

Tan, T. Q. (2019). Principles of inclusion, diversity, access, and equity. *J. Infect. Dis.* 220, S30–S32. doi: 10.1093/infdis/jiz198

Te Brinke, L. W., van der Cruijsen, R., and Green, K. H. (2022). Positive and negative risk-taking in adolescence and early adulthood: A citizen science study during the COVID-19 pandemic. *Front. Psychol.* 13:885692. doi: 10.3389/fpsyg.2022.885692

Tseng, V. (2004). Family interdependence and academic adjustment in college: Youth from immigrant and U.S.–Born families. *Child Dev.* 75, 966–983.

Tzovara, A., Amarreh, I., Borghesani, V., Chakravarty, M. M., DuPre, E., Grefkes, C., et al. (2021). Embracing diversity and inclusivity in an academic setting: Insights from the organization for human brain mapping. *NeuroImage* 229:117742. doi: 10.1016/j.neuroimage.2021.117742

Vandenbroucke, A. R. E., Crone, E. A., Erp, J. B. F., van Güroğlu, B., Hulshoff Pol, H. E., de Kogel, C. H., et al. (2021). Integrating cognitive developmental neuroscience in society: Lessons learned from a multidisciplinary research project on education and social safety of youth. *Front. Integr. Neurosci.* 15:1–20. doi: 10.3389/fnint.2021.756640

Vollbrecht, P. J., Frenette, R. S., and Gall, A. J. (2019). An effective model for engaging faculty and undergraduate students in neuroscience outreach with middle schoolers. *J. Undergrad. Neurosci. Educ.* 17, A130–A144.

Wallace, D. C., and Bartlett, R. (2013). Recruitment and retention of african american and hispanic girls and women in research. *Public Health Nurs.* 30, 159–166. doi: 10.1111/phn.12014

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Weng, H. Y., Ikeda, M. P., Lewis-peacock, J. A., Chao, M. T., Fullwiley, D., Goldman, V., et al. (2020). Toward a compassionate intersectional neuroscience: Increasing diversity and equity in contemplative neuroscience. *Front. Psychol.* 11:573134. doi: 10.3389/fpsyg.2020.573134

White, T., Muetzel, R. L., El Marroun, H., Blanken, L. M. E., Jansen, P., Bolhuis, K., et al. (2018). Paediatric population neuroimaging and the Generation R Study: The second wave. *Eur. J. Epidemiol.* 33, 99–125. doi: 10.1007/s10654-017-0319-y

Whitmore, L. B., and Mills, K. L. (2021). Co-creating developmental science. *Infant Child Dev.* 31:e2273. doi: 10.1002/icd.2273

Willems, R. M., Der Haegen, L., Van Fisher, S. E., and Francks, C. (2014). On the other hand: Including left-handers in cognitive neuroscience and neurogenetics. *Nat. Rev. Neurosci.* 15, 193–201. doi: 10.1038/nrn3679

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Radically reframing studies on neurobiology and socioeconomic circumstances: A call for social justice-oriented neuroscience

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Socioeconomic circumstances are associated with symptoms and diagnostic status of nearly all mental health conditions. Given these robust relationships, neuroscientists have attempted to elucidate how socioeconomic-based adversity "gets under the skin." Historically, this work emphasized individual proxies of socioeconomic position (e.g., income, education), ignoring the effects of broader socioeconomic contexts (e.g., neighborhood socioeconomic disadvantage) which may uniquely contribute to chronic stress. This omission represented a disconnect between neuroscience and other allied fields that have recognized health is undeniably linked to interactions between systems of power and individual characteristics. More recently, neuroscience work has considered how sociopolitical context affects brain structure and function; however, the products of this exciting line of research have lacked critical sociological and historical perspectives. While empirical evidence on this topic is burgeoning, the cultural, ethical, societal, and legal implications of this work have been elusive. Although the mechanisms by which socioeconomic circumstances impact brain structure and function may be similar across people, not everyone is exposed to these factors at similar rates. Individuals from ethnoracially minoritized groups are disproportionally exposed to neighborhood disadvantage. Thus, socioeconomic inequities examined in neuroscience research are undergirding with other forms of oppression, namely structural racism. We utilize a holistic, interdisciplinary approach to interpret findings from neuroscience research and interweave relevant theories from the fields of public health, social sciences, and Black feminist thought. In this perspective piece, we discuss the complex relationship that continues to exist between academic institutions and underserved surrounding communities, acknowledging the areas in which neuroscience research has historically harmed and/or excluded structurally disadvantaged communities. We conclude by envisioning how this work can be used; not just to inform policymakers, but also to engage and partner with communities and shape the future direction of human neuroscience research.

KEYWORDS

socioeconomic position (SEP), neighborhood disadvantage, neurobiology of stress, social justice, structural racism

Introduction

> *"Radical simply means 'grasping things at the root'."*
>
> –Angela Davis

Much of human research has centered on how adversity, including lower individual socioeconomic position (SEP), becomes biologically embedded (Turner and Lloyd, 1995; McEwen, 2012a; McLaughlin and Sheridan, 2016). With evidence from physiology, genomics, and neuroimaging, our knowledge regarding the impact of socioeconomic circumstances on mental health has progressed remarkably (Hackman and Farah, 2009; Gianaros and Hackman, 2013; Brito and Noble, 2014; Johnson et al., 2016; Farah, 2017, 2018). Despite considerable empirical evidence demonstrating the biological burden of socioeconomic factors, attempts to deliver evidence-based interventions to address these types of adversity have been laborious and with few victories (Wainberg et al., 2017; Campion et al., 2022). We propose this impasse is because the majority of human neuroscience work does not systematically include these factors in study designs or situate findings within existing social inequities, including structural racism [definitions of terms used throughout the article are provided in **Table 1** (Gee and Ford, 2011; Sewell, 2015; Riley, 2018; Yearby, 2020)].

Historically, mental health research braved the matter of social inequities. However, in the 1980's, a shift towards biological perspectives caused the focus to diminish (Muntaner et al., 2000; Bernard, 2006; Dean, 2018). More explicitly, while research on physical health has increasingly built upon social determinants of health and disease (Krieger, 2011, 1994), the dominant narrative in mental health research embraced biological models of disease. This shift decreased the number of studies investigating how structural drivers of social determinants (e.g., sociopolitical context, legal frameworks, and policies) impacted individuals (Muntaner et al., 2000; Krieger, 2001; Crear-Perry et al., 2021).

In a similar vein, the association between neurobiology and neighborhood socioeconomic factors (e.g., neighborhood disadvantage) has received even less attention than associations with individual-level variables (e.g., income or education Farah, 2017, 2018). This may reflect study design limitations; there is simplicity in collecting individual-level measures directly from the participant, and the benefit of evading the expenses associated with larger sample sizes, which are often required to observe significant effects of neighborhood factors. Another explanation of this trend is that neuroscience research has been implicitly biased towards using a "Freedom" model of health, which suggests people are solely responsible for their health and related behaviors i.e., individual-oriented theories of disease causation (Dougherty, 1993; Muntaner et al., 2000; Krieger, 2001, 2011). This line of thinking perpetuates harmful stereotypes of genetic inferiority and pathologizes those living amongst poor socioeconomic conditions (Farah, 2018), as it attributes health disparities along sociodemographic categories to the individual or essential characteristics of members of the marginalized group.

Though many issues arise when defaulting to the Freedom model, perhaps most insidious is that it complements the "deserving poor" argument or "boot-strap" ideology, which alleges people are in specific socioeconomic positions because of individual differences in ambition or talent. To be clear, this stance is not reflected in data. In fact, upward mobility rates in the United States have continued to decline over the past 10 years. Variables capturing the effects of structural racism, such as race and place (e.g., region, neighborhood) remain the strongest predictors of mobility (Connor and Storper, 2020). Thus, the "Freedom" model—and those akin to it—disregards the longstanding inequities in opportunity in the United States and, when applied (consciously or not) to neuroscience research, exonerates the oppressive structures which maintain inequities.

Broad mechanistic questions about socioeconomic circumstances can be challenging to capture because the measures are generally considered macro factors, instead of proximate mechanisms which interact directly with an individual's neurobiology. "For this reason," as it refers to the reason why socioeconomic circumstances can be challenging to captur. However, various models have highlighted the myriad ways our social systems can interact with the brain, as the brain works in part as a social organ, consistently informed by our interactions with our environment (Lende and Downey, 2012; Berman et al., 2019). Further, dimensions of socioeconomic circumstances, such as social and material conditions, are

TABLE 1 Terminology and definitions.

Term	Definition
Inequities	Differences (e.g., between ethnoracial groups, between socioeconomic positions, etc.) which are unjust, unfair, and avoidable (Bailey et al., 2017; Krieger, 2021). *Inequalities*, a closely-related concept, refer to the measured difference in a particular outcome (Krieger, 2001).
Chronic stress	Repeated exposures to myriad multi-level risk factors (e.g., work stress, trauma, environmental toxins, community violence, police brutality, etc.) and unstable access to necessary resources (e.g., education, food, transportation, etc.) (McEwen and Gianaros, 2010; Kim et al., 2018).
Structural racism	"The macro-level systems, social forces, institutions, ideologies, and processes that interact with one another to generate and reinforce inequalities among racial and ethnic groups" (Gee and Ford, 2011).
Law	The mechanisms of legal systems, including the political processes, policies, and legal practices such as enforcement (Yearby, 2020).
Critical race theory	A framework used to analyze the historical and contemporary forms of structural racism (Crenshaw, 2010).
Positionality	How a person's sociopolitical identity (e.g., gender identity, sexual identity, race, ethnicity, socioeconomic position, religion, etc.) and lived experiences shape their position in society. Ultimately, this position influences how a person interacts with and perceives the world (Roberts S. O. et al., 2020).
Intersectionality	Rooted in Black feminist pedagogy, a framework used to analyze "relations between systems of oppression which construct our multiple identities and our social locations in hierarchies of power and privilege" (Crenshaw, 1991; Carastathis, 2014).

related to other, more proximal factors, which have causal roles in mental health risk. On the environmental side, these proximal factors can include prenatal and postnatal nutritional deficiencies and SEP-linked exposures to environmental toxins. They also include the interaction of crucial non-physical socioeconomic factors such as parental education.

We focused on studies of neighborhood disadvantage and neurobiology in this perspective because research in this area inherently emphasizes *place* and *context* rather than the *individual*. This work marks a recent and fervent shift toward recognizing that the broader sociopolitical context affects how individuals interpret stimuli and navigate within social groups. This further highlights the need for the field to firmly declare that societal inequities exist and are relevant to the understanding of brain structure and function. Few neuroscientists (if any) would endorse the contrary, but by excluding these variables and disregarding societal influences, the resulting scientific products lack this context. By including variables at multiple levels that better capture the forces and dynamics related to SEP in human neuroscience experiments, researchers acknowledge that some of the variability in individual differences—whether in biological functioning, behavioral task performance, or clinical symptoms—is attributable to the sociopolitical stratification in society (Gianaros and Hackman, 2013).

Studies on the relationship between socioeconomic factors and neurobiology are at the forefront and intersection of public health, neuroscience, and sociology, and in this perspective paper, we leverage knowledge across these disciplines. After briefly reviewing theories linking socioeconomic factors to mental health, we highlight evidence that neighborhood disadvantage is associated with neurobiology. This work would be strengthened by positioning research questions and findings within sociological and historical context. Although we center neighborhood disadvantage, the issues presented in this article are shared with studies on individual SEP and are relevant to all human neuroscience research. Individual SEP and neighborhood disadvantage may impact biological systems through different mechanisms. However, socioeconomic variables at multiple levels share structural racism as an upstream determinant.

We call for future studies to name structural racism, define neighborhood disadvantage as an institutionalized form of racial inequity, and interpret how the effects of racism are captured in methods and manifest in results (Sewell, 2015, 2016; Riley, 2018). Finally, we describe areas and steps for improvement, including acknowledging historical and current inequities, reporting relevant data, and funding research that prioritizes the needs and participation of historically excluded communities. These recommendations are based in the belief that neuroscience could more critically address mental health disparities if an anti-racist radical framework—which considers the root causes of inequities—was applied.

Theories linking socioeconomic factors to health

Researchers have developed various socioecological theories to better understand how environmental exposure can uniquely interact with genotypes and phenotypes to differentially impact human development and mental health (Ellis et al., 2011). For example, Social Causation Theory posits that poorer socioeconomic circumstances increase an individual's risk for mental health conditions, including post-traumatic stress disorder (PTSD), depressive disorder, and generalized anxiety disorders (Hollingshead and Redlich, 1958). This increased risk is partially due to greater environmental resource scarcity and higher environmental stress, which may affect neurocognitive development in childhood and adolescence (Farah, 2018; Ferschmann et al., 2022). For an individual, alterations in neurocognitive development may represent biological risk for mental health conditions. Over time, these effects may reduce socioeconomic achievement in adulthood, creating intergenerational patterns of socioeconomic-related stress for oppressed communities (Hackman et al., 2010).

The timing and accumulation of factors associated with poorer socioeconomic circumstances across the lifecourse are also identified as a crucial element in frameworks focusing on the embodiment and embedding of social, structural, and environmental factors and their relevance to biological development and functioning. Though a detailed discussion of "lifecourse exposome" studies is outside the scope of this article (see Evans and Kim, 2012; Kelly-Irving and Delpierre, 2021; Vineis and Barouki, 2022), these approaches highlight the importance of dynamic upstream structural, sociopolitical, and temporal factors in the study of biological and psychological functioning.

Another set of theories focuses on individual differences in genomic variations and how these may be related to an individual's susceptibility to eventual mental health symptoms. Differential Susceptibility Theory advances the claim that individuals can inherently differ in their susceptibility to stressors, and that individuals' environments may interact with genetic variations and behavioral outcomes "for better or worse" (Belsky and Pluess, 2009; Ellis et al., 2011). Through this theory, researchers have focused on identifying the moderating influence of environmental exposures on developmental and life outcomes. For example, previous work in this area has focused on psychological markers such as negative emotionality as potentially significant individual susceptibility factors (Ellis et al., 2011). In Differential Susceptibility Theory, both positive (e.g., supportive parenting) and negative (e.g., neighborhood disadvantage) environmental conditions are theorized to influence an individual's susceptibility to mental health outcomes.

A contrasting model is the Diathesis-Stress Model, which suggests that individuals have a baseline level of predisposing factors (i.e., diathesis) for any given mental health condition. The point at which individuals develop symptoms depends on the interaction between the risk factors and the degree of stress. One form of diathesis is biological and includes neurophysiological dysregulation. When repeated instances of stress occur, this can cause biological changes that result in more sensitivity to stress in the future, meaning that less stress becomes necessary to activate the requisite processes that may facilitate mental health symptoms (Post, 1992; Ingram and Luxton, 2005). Notably, the Diathesis-Stress Model is considered a deficit-only model, focusing on susceptibility to negative environments.

Together, the reviewed theories highlight the importance of considering mechanisms and factors at various levels in studying mental health outcomes and neurobiology. Though these theories did not originally consider how structural racism explained differences in environmental conditions, new applications of these theories identify racism as a determinant. In order to conduct research on the impact of socioeconomic factors on neurobiology properly and equitably, it is crucial to include structural, social, and historical context, and how this may contribute to differential susceptibility and vulnerability and their impact on health (Diderichsen et al., 2019).

Neural correlates of neighborhood socioeconomic disadvantage

Neighborhood disadvantage measures [e.g., poverty rate, composite measures such as the area deprivation index or social vulnerability index, concentrated disadvantage, etc.; (Sampson et al., 1997; Coulton et al., 2002; Singh, 2003; Flanagan et al., 2011; Kind et al., 2014; Kind and Buckingham, 2018)], established with a geographical ID and through a process of geo-coding (Fan et al., 2021), predict mental health symptoms, even above individual socioeconomic measures. Greater neighborhood disadvantage is associated with higher stress levels (Steptoe and Feldman, 2001; Aneshensel, 2009; Hackman et al., 2012; Barrington et al., 2014; Chattarji et al., 2015; Snedker and Herting, 2016) and symptoms of depression (Blair et al., 2014), anxiety (Casciano and Massey, 2012; Vine et al., 2012), and PTSD (Gapen et al., 2011; Hall Brown and Mellman, 2014; Douglas et al., 2021).

Biological correlates of neighborhood disadvantage span various biological systems. Researchers have examined the effects across different measures of stress responding, such as cortisol reactivity (Karb et al., 2012; Barrington et al., 2014; Finegood et al., 2017; Zilioli et al., 2017), stress-accelerated aging (Olden et al., 2015; Lei et al., 2018, 2019; Lawrence et al., 2020), and immune system regulation (Kepper et al., 2016; Neergheen et al., 2019; Roberts L. et al., 2020). In nearly all proposed mechanistic models, neighborhood disadvantage is conceptualized as chronic stress and therefore hypothesized to influence mental health *via* stress-responding pathways (e.g., persistent hypothalamic-pituitary-adrenal axis activation; Hackman and Farah, 2009; McEwen and Gianaros, 2010; McEwen, 2012b; Gianaros and Hackman, 2013; Farah, 2017).

The impact of neighborhood disadvantage on neurobiology continues to grow as an exciting line of research (**Figure 1**). Thanks to large-scale studies such as the Adolescent Brain Cognitive Development (ABCD) study, a number of findings have illustrated the impact of neighborhood disadvantage on brain development, structure, and function (Mullins et al., 2020; Taylor et al., 2020; Vargas et al., 2020; Hackman et al., 2021; Rakesh et al., 2021). Notably, the majority of previous work does not name factors and dynamics related to structural racism. Although a comprehensive and systematic

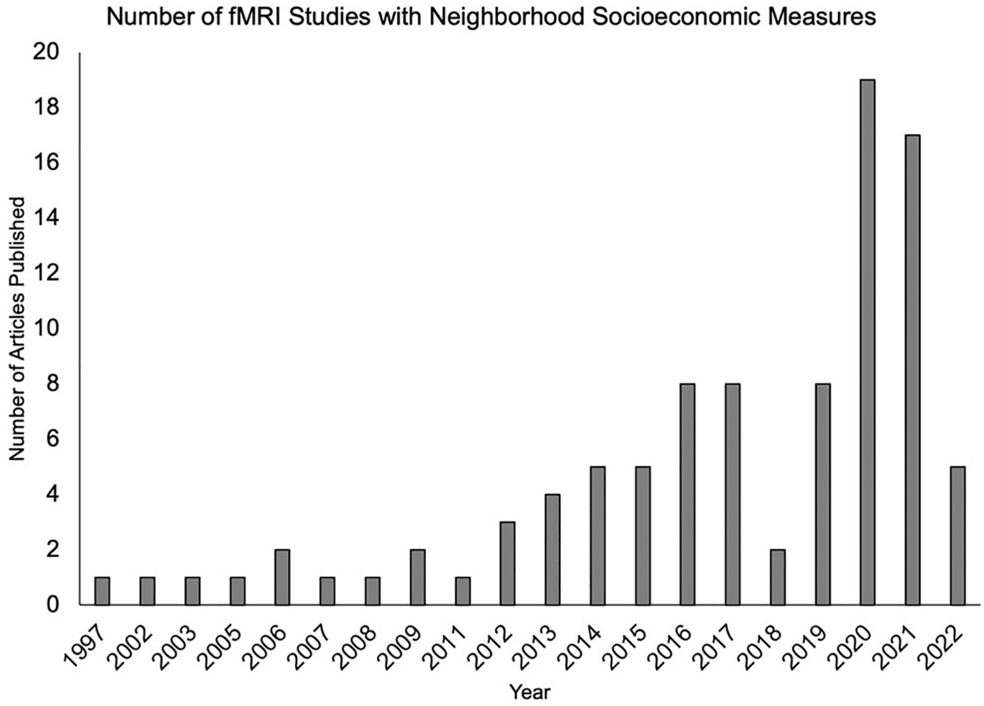

FIGURE 1
An increasing number of functional magnetic resonance imaging studies are examining neighborhood-level socioeconomic factors. Articles were identified by the authors using a PubMed search which included functional magnetic resonance imaging (fMRI) and at least one neighborhood term (neighborhood disadvantage, neighborhood deprivation, neighborhood poverty, concentrated disadvantage, and concentrated poverty).

review was outside the scope of this article, we highlight key findings suggesting neighborhood disadvantage is associated with widespread alterations in brain structure and function across the lifespan.

Perhaps most well-documented is a significant association between greater neighborhood disadvantage and decreased prefrontal thickness and smaller hippocampal volumes (Brito and Noble, 2014; Whittle et al., 2017; Wrigglesworth et al., 2019; Hunt et al., 2020; Taylor et al., 2020; Vargas et al., 2020; Webb et al., 2021). Several studies have also found neighborhood disadvantage is associated with lower total surface area and subcortical volume (Hunt et al., 2020; Hackman et al., 2021). In identifying the neurobiological mechanisms linking neighborhood disadvantage to mental health, these structural changes are compelling targets; thinner prefrontal cortex and smaller hippocampus are associated with PTSD and depression (Karl et al., 2006; MacQueen and Frodl, 2011).

Even after accounting for individual SEP, neighborhood disadvantage has been linked to delayed structural and functional neurodevelopmental trajectories (e.g., Ramphal et al., 2020; Tooley et al., 2020; Gard et al., 2021; Rakesh et al., 2021). Rakesh et al. (2021) teased apart the distinct and shared effects of neighborhood disadvantage and household SEP, demonstrating interactive effects between the two different measures on resting-state networks, and further highlighting individual SEP does not fully account for neighborhood effects. Task-based neuroimaging indicates neighborhood disadvantage helps explain individual differences in affective and cognitive domains (Gard et al., 2018; Tomlinson et al., 2020; Huggins et al., 2022; Tomas et al., 2022). For example, Tomlinson and colleagues demonstrated neighborhood disadvantage was related to neural and behavioral correlates of response inhibition (i.e., cognitive domain). In adolescents, neighborhood disadvantage was associated with greater amygdala reactivity to ambiguous neutral faces (Gard et al., 2018) and, in adults, neighborhood disadvantage was related to diminished amygdala threat-related activity (Harnett et al., 2017; i.e., affective domains). These findings point to environmentally driven changes, suggesting living in disadvantaged neighborhoods elicits activity in various neural processes which may place additional demands on cognitive resources. These resources may be bidirectionally exacerbated by the structural changes evoked by living in a chronically stressful environment. Together, these modifications to brain structure and function may create susceptibility to mental health disorders.

Although more empirical work is needed, this theory helps explain why individuals residing in more disadvantaged neighborhoods report more mental health symptoms (Gapen et al., 2011; Casciano and Massey, 2012; Vine et al., 2012; Blair et al., 2014; Hall Brown and Mellman, 2014; Douglas et al., 2021). Although the mechanisms by which neighborhood disadvantage impacts brain structure and function may be fundamentally the same across people, not everyone is exposed to this factor at the same rates. Individuals from ethnoracially minoritized groups are disproportionally exposed to neighborhood disadvantage.

In all the aforementioned work, researchers were faced with methodological decisions concerning the intersections between race, ethnicity, SEP, and neighborhood disadvantage. Despite strong theoretical support that ethnoracial inequities and socioeconomic inequities are related but not equivalent (Williams, 1999), the ability to statistically tease apart these effects is challenging. Others (e.g., Nuru-Jeter et al., 2018) have provided recommendations on how to statistically approach measures of ethnoracial and socioeconomic inequities. Given that upstream sociopolitical and structural factors interact with processes at all levels of analysis, it is critical to acknowledge the overlapping patterns of ethnoracial and socioeconomic inequities in studies of neurobiology and related factors, both in their operationalization and conceptualization, to ensure a science that is reproducible, rigorous, and responsible[1] (Williams and Mohammed, 2013; Nuru-Jeter et al., 2018; Williams, 2018).

Naming structural racism as a root cause

Socioeconomic inequities influence health independent of race and ethnicity, however, both individual and neighborhood socioeconomic indicators are ethnoracialized (i.e., stratified by race and ethnicity; Williams, 1999; Williams and Mohammed, 2013; Nuru-Jeter et al., 2018; Williams et al., 2019). In this way, the socioeconomic inequities discussed in studies on neighborhood disadvantage and neurobiology are undergirding and intersecting with other forms of oppression, particularly racism (Sewell, 2015). In fact, *all* of the canonically defined social determinants of health (e.g., economic stability, education access, and quality, etc.) can take form and hold power through structural racism (Sewell, 2015, 2016; Nuru-Jeter et al., 2018; Riley, 2018; Yearby, 2020). Certain exposures, such as neighborhood disadvantage, exist as a racialized risk factor because of structural racism (Riley, 2018). Recent empirical evidence underscores the racialization of neighborhoods: Black Americans in middle SEPs are still more likely to live in disadvantaged neighborhoods compared to white Americans in *lower* SEPs (Turner and Greene, 2021).

Further, for racially minoritized communities, such as Black, Indigenous, Latinx, Asian, and Pacific Islanders, acute stressors coupled with historical stressors and trauma (e.g., discrimination) have been linked to long-term adverse health outcomes (Williams and Mohammed, 2013). Chronically elevated cortisol levels and a dysregulated hypothalamic–pituitary–adrenal (HPA) axis have been found to mediate the effects of racial discrimination on allostatic load and disease for communities of color (Berger and Sarnyai, 2015). Neuroimaging studies on the effects of discrimination and social exclusion have suggested greater activity in areas associated with threat processing and vigilance [e.g., anterior cingulate cortex, amygdala, insula (Berger and Sarnyai, 2015; Clark et al., 2018; Han et al., 2020; Fani et al., 2021; Webb et al., 2022)]. Together, these studies suggest compounded stress effects for members of historically minoritized groups, above and beyond those expected from experiencing neighborhood disadvantage.

There have been resounding calls in public health and allied fields for structural racism to be named as the root cause of ethnoracial health disparities and related racialized socioeconomic inequities (Yosso, 2005; Ford and Airhihenbuwa, 2010a,b; Gee and Ford, 2011; Bailey et al., 2017; Hardeman et al., 2018; Yearby, 2020). Still the majority of human neuroscience research has been reluctant to confront structural racism; infrequently naming structural racism in introductions or discussions. To echo a question raised by Sewell (2016): why not "spell out the connections between health disparities and institutional (in)actions rooted in racism?" The addition of historical and sociological perspectives and the explicit naming of structural racism do not hinder or diminish neuroscience; rather, these perspectives complement, advance, and aptly challenge and hold accountable the current state of the research.

Situating studies within historical and contemporary context

Differential exposure to neighborhood disadvantage is maintained by historical and current ethnoracial residential segregation. Historic redlining is perhaps the most well-known practice contributing to residential segregation (McClure et al., 2019). **Laws** from the 1930's until 1968 (when redline mapping was made illegal), allowed the government-led Homeowners' Loan Corporation to create maps for lending institutions (Massey and Denton, 1993; Hillier, 2003; Sewell, 2015; Connolly et al., 2018; McClure et al., 2019). These maps were used to prevent people of color from residing in specific neighborhoods by limiting bank credit and altering real-estate practices (Massey and Denton, 1993). The resulting

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[1] The majority of work on socioeconomic circumstances and neurobiology has been based in the United States and therefore this paper discusses this research within the American sociopolitical context. However, the authors encourage researchers outside of the United States to consider how global, national, and regional structures of oppression, including racism, may operate, and manifest in research.

changes across the entire homebuying process ultimately forced people to buy houses in less “desirable” (redlined) neighborhoods (Massey and Denton, 1993). In addition, these policies and practices resulted in expansive divestment in redlined neighborhoods and disproportionate investment in predominately white neighborhoods.

Redlining may have historic roots, but the legacy in redlined neighborhoods manifests in the lasting neighborhood disadvantage and ultimately in the residents’ mental and physical health (Massey and Denton, 1993; Sewell, 2015; Williams et al., 2019; Park and Quercia, 2020). For instance, recent research suggests Black and Latinx communities in disadvantaged neighborhoods have an increased likelihood of being exposed to air pollution and toxins, the largest environmental health risk factor in the United States, which can have potentially deleterious effects on physical and mental health (Tessum et al., 2019). Studies show this disproportionate burden of pollution exposure is partially caused by the overconsumption of goods and services from white populations, producing toxins that are disproportionality inhaled by Black and Latinx communities (Tessum et al., 2019).

Current housing law and practices are also culpable, people of color are still disproportionately denied fair mortgage loans (Hanifa, 2021) and Black and Latinx communities continue to be under-valued and under-funded (Park and Quercia, 2020). Withholding certain types of investment (e.g., under-funding of schools) while also misallocating funds to non-community approved budgets (e.g., policing) maintains neighborhood disadvantage. Historic and current racist policies and practices force(d) people of color, particularly Black Americans, to disproportionally reside in neighborhood’s experiencing socioeconomic disadvantage. Thus, neighborhood advantage is a protective factor that can be—and has been—bestowed upon white people by law. Even the terms “neighborhood advantage” or “neighborhood disadvantage” fundamentally aligns with language used—in theories of Black feminism and **intersectionality**—to discuss structural racism; white individuals unfairly benefit from these structural advantages and ethnoracially minoritized individuals are harmed.

Recommendations for radicalizing human neuroscience

In our work as neuroscientists, we must recognize that people live within environmental contexts shaped by sociopolitical stratification. When we study neighborhood disadvantage, we are studying an exposure that is relevant to mental health because of its connection to structural racism (Sewell, 2015; Riley, 2018). In essence, this perspective is a call for the radicalization of human neuroscience work—a necessary paradigm shift that grasps at the roots of the issue rather than dodging them. By remaining silent (i.e., not acknowledging structural racism) in our work, we fail to hold the institutions protecting structural racism responsible. When we name structural racism, we direct attention to the laws, processes, and practices which produce and maintain health inequities (Sewell, 2016, 2015). This offers an incredible opportunity to connect research findings to upstream policies (e.g., non-discriminatory housing laws), thus identifying appropriate points of intervention and moving away from statements related to broad proxies of SEP.

The following recommendations are based upon a diverse array of evidence from previous findings as well as the authors’ beliefs. One highly influential framework is the Public Health Critical Race Praxis model proposed by Ford and Airhihenbuwa (2010a,b). This model states racism is a root cause of social stratification and health inequity and highlights the researcher’s role in either challenging or perpetuating such hierarchies (Ford and Airhihenbuwa, 2010a,b, 2018). If a radical anti-racist framework, such as this model, was applied to neuroscience research then the field could play a larger role in addressing mental health inequities. This will require an unlearning of prior negligent research practices and an ongoing committed effort to learn ethical alternative strategies. While there may be discomfort or defensiveness in interrogating past approaches and holding ourselves accountable in the future, a genuine commitment toward equitable neuroscience research could guide the field forward and further strengthen the interpretative power of studies.

Report inequities and acknowledge diversity in research samples

In general, few studies examining neighborhood disadvantage have methodologically confronted ethnoracial and socioeconomic inequities (c.f., Harnett, 2020; Taylor et al., 2020; Douglas et al., 2021)—though many call for future work to explore these intersections (e.g., Hunt et al., 2020; Rakesh et al., 2021; Sripada et al., 2021; Webb et al., 2021). Recent theoretical work has proposed moving toward an intersectional neuroscience framework. Such a framework would require reporting and addressing between-group differences in socioeconomic measures in order to help contextualize sample and position inequities at the forefront (Weng et al., 2020). Rooted in Black feminist pedagogy, Crenshaw’s (1991) intersectionality framework was originally used to describe the unique experiences of Black women who experience the intersections of racial and gendered oppression. Within the field of neuroscience, this framework can also be applied to research procedures and methods in order to understand the relationships between systems of oppression related to multiple identities and hierarchies of power and privilege (Carastathis, 2014).

Even outside of the work on socioeconomic factors, reporting of complete demographic variables is not commonplace (Roberts S. O. et al., 2020). Race and ethnicity are still not frequently reported, despite being "required" by many journals. Ethnoracial differences in study measures can only be observed and interpreted if the data are presented. Therefore, we echo calls to report demographic data that is meaningfully and appropriately disaggregated (i.e., based on historical and structural inequities) (Flanagin et al., 2021; Kauh et al., 2021).

The absence of sufficient research on these systemic factors in neurobiology research is also due to the fact that neuroscience research samples are often non-representative of racial and economic diversity within the United States (Henrich et al., 2010; LeWinn et al., 2017; Muthukrishna et al., 2020). This is linked to a history of scientific racism. This history includes the exploitations of communities of color for unethical research purposes and the perpetuation of harmful stereotypes rooted in neuroscience research (Brandt, 1978; Leslie, 1990; Turda, 2010; Saini, 2019). Therefore, improved and intentional recruitment methods are needed to better understand the neural basis of mental health inequities.

Reporting race and ethnicity in neuroscience studies is not enough: proper contextualization of race and ethnicity is essential. In what Nancy Krieger has dubbed "the double-edged sword of data," structural injustice may operate through data use in one of two ways: (1) preventing documentation that structural injustice exists, and (2) using data in problematic ways that further perpetuate oppression of historically minoritized groups (Krieger, 2021). Undoing these structural issues may be remedied by explaining and justifying the conceptualization and operationalization of racialized groups, and also by analyzing racialized groups in relation to available societal inequity variables (Krieger, 2021).

Specific to neuroscience research, we advocate for more studies to include environmental and structural factors. Critical to this is contextualizing the *racialization* of structural and environmental variables. In the absence of this lens, neuroscience studies attempting to avoid the impact of racism when considering social inequity/disadvantage may reinforce notions of biosocial determinist notions of minoritized groups and being "neurobiologically poor" (Pitts-Taylor, 2019; Krieger, 2021).

Fund neuroscience work on sociopolitical factors

Support for the inclusion of sociopolitical and structural factors in neuroscience needs to occur not only at the level of specification and analysis, but also at the level of funding and epistemic inclusion. Given that many researchers exploring these topics tend to be members of racialized and historically minoritized groups, the lack of funding to pursue these avenues of research has also been associated with the attrition of diverse scholars (Gilpin and Taffe, 2021). This serves as a disadvantage to the field, as these scholars offer pivotal and unique perspectives that could contribute immensely to the field of neuroscience in general. Greater support from large funding entities will help inform our understanding of the effects of socioeconomic distress on neurobiology across diverse populations.

Explore resilience factors

Neuroscience research on neighborhood factors has largely focused on risk modeling, evaluating variables believed to worsen mental health. Institutionalized forms of racial inequities, including neighborhood disadvantage, and community violence, are risk factors dominating the emerging field (Butler et al., 2018; Saxbe et al., 2018; Gellci et al., 2019; Wrigglesworth et al., 2019; Borg et al., 2021; Rakesh et al., 2021; Reda et al., 2021; Webb et al., 2021). Discussions backed by **critical race theory** being held in other fields including education, law, and psychology, should inform neuroscience work moving forward (e.g., Yosso, 2005; Gillborn and Ladson-Billings, 2009; Giraldo et al., 2017). A key tenant of critical race theory is that deficit-only perspectives, which minimize the strengths of ethnically and racially minoritized groups/individuals, are harmful (Yosso, 2005; Giraldo et al., 2017). Theoretically, risk-only models are incomplete; and practically, they may further stigmatize marginalized populations. There is ample room and need for resilience modeling (also known as strength-based approach) in studies on socioeconomic circumstances and neurobiology. In the field of neuroscience, exploring the effects of individual, familial, and community factors that are known to mitigate risk of poor mental health outcomes, such as social support/engagement, civic action, critical consciousness, neighborhood cohesion, and racial-ethnic identity, may be extraordinarily beneficial (e.g., Bracey et al., 2004; Dassopoulos and Monnat, 2011; Gapen et al., 2011; Forsyth and Carter, 2012; Johns et al., 2012; Karb et al., 2012; Neblett et al., 2012; Neergheen et al., 2019; Burt et al., 2021; Lardier et al., 2021).

Engage in community-based participatory and community-engaged research

The final recommendation is the most transformative in the context of traditional Western conceptualizations of research. Human neuroscience has relied primarily on "top-down" scientific processes. In this approach, the power (i.e., decision-making, funding, control over dissemination process, etc.) rests entirely with the study team and its institutions (Wallerstein and Duran, 2010). Although those researched provide data, they are not consulted to ensure the research question(s) or outcomes align with their experiential knowledge or the community's needs. Even with the best intentions, this Western knowledge production pipeline is inequitable because power is not equally distributed between the researchers and the researched (Minkler and Wallerstein, 2003; Wallerstein and Duran, 2010). Community-based participatory research (CBPR) and Community Engaged Research (CEnR) are different approaches to knowledge production which involve various stakeholders (i.e., community members and academic partners) collaborating throughout the research process (Minkler and Wallerstein, 2003; Wallerstein and Duran, 2010). At its core, CPBR and CEnR hope to build health equity by practicing equity through co-production of knowledge (Minkler and Wallerstein, 2003; Wallerstein and Duran, 2010).

Psychology has started to answer the calls for community-driven research and human neuroscience should follow (Wallerstein and Duran, 2010, 2017; Collins et al., 2018; Arredondo, 2021; Wallerstein, 2021). A first step for research teams is for members to reflect on how their own **positionality** manifests in their work and in interactions with fellow team members and participants (Muhammad et al., 2015). Just as we cannot isolate participants from the sociopolitical environment, we cannot ignore the intrinsic influences of society on research practices or hide behind a façade of self-proclaimed objectivity (Momin, 1972; Muhammad et al., 2015). Furthermore, conducting research without developing proper relationships with the community and necessary scientific experts contributes to "health equity tourism," which results in diluting existing efforts of committed health equity researchers (Lett et al., 2022). CPBR and CEnR entail community-building (which takes time) as well as sharing wealth and final products (which requires funding and time; Wallerstein and Duran, 2010, 2017; Collins et al., 2018; Wallerstein, 2021) and prioritizing research questions that are important to communities, not researchers.

Within this realm, neuroscience researchers can offer pivotal information on causal mechanisms influencing the neurobiology of disadvantaged groups and further establish the basis for innovative intervention and policy work that can improve the conditions of individuals living amongst socioeconomic distress (Farah, 2018). To make progress in neuroscience community participatory research, funding agencies like the National Institutes of Health must be receptive to funding studies that are likely longer and more expensive. These organizations must also value including community members on research teams, even if these members do not have traditional (i.e., Western knowledge production) research training or traditional indicators of research contributions. As researchers, we can advocate for more funding opportunities while also introducing CBPR and CEnR practices into existing studies (e.g., collaborating with an established community organization during data analysis and dissemination).

Conclusion

As Angela Davis once noted, "if we are not afraid to adopt a revolutionary stance—if, indeed, we wish to be radical in our quest for change—then we must get to the root of our oppression. After all, radical simply means grasping things at the root" (Davis, 1990). Her call to action—at the time for Black American women—to participate in grassroot organizing, become involved in political/policy work, and serve as activists in order to fundamentally transform socioeconomic conditions contributing to systemic oppression is still very relevant today. We challenge the neuroscience community to also participate in this quest for systemic change. The burden of progressive change is one we all should bear.

The call to address health inequities and build health equity must be met with a radical anti-racist response. As the field of human neuroscience continues to identify biological mechanisms underlying mental health, it must cautiously avoid biological reductionism and essentialism. We encourage all to remain vigilant about discussions of neurobiological effects of sociopolitical variables using only biological terms, and without actually naming oppressive structures (e.g., racism, sexism). In the context of studies on socioeconomic circumstances, defining factors as an institutionalized form of racial inequity (Sewell, 2016) is an initial move toward "grasping at the root" (Davis, 1990). Additional steps include more thorough reporting of demographics which requires comprehensive evaluations of structural and environmental variables. Ultimately, however, more radical anti-racist steps such as challenging Western knowledge production, embracing community research, and reforming funding agencies' priorities, will lead to transformative change.

Positionality statement

As in all research, it is helpful to understand the authors' positionality and, therefore, their lens on the data. All authors are early-career researchers and shared first authorship. EKW is a United States—born white woman, with expertise in investigating associations between sociopolitical factors and neurobiology in the context of mental health inequities. RD is a southern Black American woman, with expertise in community violence, systemic disadvantage, and racial trauma amongst youth of color. CC-I is a first-generation immigrant cisgender man from Mexico who identifies as Mexican and Latinx, and has expertise in neuroscience research exploring structural and environmental factors and their impact on brain development. All authors worked as a team and had regular discussions to ensure the perspective was guided by their collective cultural knowledge and expertise. This was a collaborative team project that ensured the study was sensitive and appropriate to the context in which it was conducted.

Author contributions

EKW wrote the first draft of the manuscript. All authors wrote the sections of the manuscript, contributed to manuscript revision and approved the submitted version, and shared first authorship.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aneshensel, C. S. (2009). "Neighborhood as a social context of the stress process," in *Advances in the Conceptualization of the Stress Process*, eds W. Avison, C. Aneshensel, S. Schieman, and B. Wheaton (Berlin: Springer), 35–52. doi: 10.1007/978-1-4419-1021-9_3

Arredondo, M. M. (2021). Shining a light on cultural neuroscience: Recommendations on the use of fNIRS to study how sociocultural contexts shape the brain. *Cultur. Divers. Ethnic Minor. Psychol.* [Epub ahead of print]. doi: 10.1037/cdp0000469

Bailey, Z. D., Krieger, N., Agénor, M., Graves, J., Linos, N., and Bassett, M. T. (2017). Structural racism and health inequities in the USA: evidence and interventions. *Lancet* 389, 1453–1463. doi: 10.1016/S0140-6736(17)30569-X

Barrington, W. E., Stafford, M., Hamer, M., Beresford, S. A. A., Koepsell, T., and Steptoe, A. (2014). Neighborhood socioeconomic deprivation, perceived neighborhood factors, and cortisol responses to induced stress among healthy adults. *Health Place* 27, 120–126. doi: 10.1016/j.healthplace.2014.02.001

Belsky, J., and Pluess, M. (2009). Beyond diathesis stress: Differential susceptibility to environmental influences. *Psychol. Bull.* 135, 885–908. doi: 10.1037/a0017376

Berger, M., and Sarnyai, Z. (2015). "More than skin deep": stress neurobiology and mental health consequences of racial discrimination. *Stress Amst. Neth.* 18, 1–10. doi: 10.3109/10253890.2014.989204

Berman, M. G., Kardan, O., Kotabe, H. P., Nusbaum, H. C., and London, S. E. (2019). The promise of environmental neuroscience. *Nat. Hum. Behav.* 3, 414–417. doi: 10.1038/s41562-019-0577-7

Bernard, V. W. (2006). Some principles of dynamic psychiatry in relation to poverty. *Am. J. Psychiatry* 122, 241–253. doi: 10.1176/ajp.122.3.254

Blair, A., Ross, N. A., Gariepy, G., and Schmitz, N. (2014). How do neighborhoods affect depression outcomes? A realist review and a call for the examination of causal pathways. *Soc. Psychiatry Psychiatr. Epidemiol.* 49, 873–887. doi: 10.1007/s00127-013-0810-z

Borg, B. A., Rabinak, C. A., and Marusak, H. A. (2021). Violence exposure and mental health consequences among urban youth. *Curr. Psychol.* [Preprint]. doi: 10.1007/s12144-021-02141-4

Bracey, J. R., Bámaca, M. Y., and Umaña-Taylor, A. J. (2004). Examining ethnic identity and self-esteem among biracial and monoracial adolescents. *J. Youth Adolesc.* 33, 123–132. doi: 10.1023/B:JOYO.0000013424.93635.68

Brandt, A. M. (1978). Racism and research: the case of the tuskegee syphilis study. *Hastings Cent. Rep.* 8:21. doi: 10.2307/3561468

Brito, N. H., and Noble, K. G. (2014). Socioeconomic status and structural brain development. *Front. Neurosci.* 8:276. doi: 10.3389/fnins.2014.00276

Burt, S. A., Klump, K. L., Vazquez, A. Y., Shewark, E. A., and Hyde, L. W. (2021). Identifying patterns of youth resilience to neighborhood disadvantage. *Res. Hum. Dev.* 18, 181–196. doi: 10.1080/15427609.2021.1935607

Butler, O., Yang, X.-F., Laube, C., Kühn, S., and Immordino-Yang, M. H. (2018). Community violence exposure correlates with smaller gray matter volume and lower IQ in urban adolescents. *Hum. Brain Mapp.* 39, 2088–2097. doi: 10.1002/hbm.23988

Campion, J., Javed, A., Lund, C., Sartorius, N., Saxena, S., Marmot, M., et al. (2022). Public mental health: required actions to address implementation failure in the context of COVID-19. *Lancet Psychiatry* 9, 169–182. doi: 10.1016/S2215-0366(21)00199-1

Carastathis, A. (2014). The concept of intersectionality in feminist theory. *Philos. Compass* 9, 304–314. doi: 10.1111/phc3.12129

Casciano, R., and Massey, D. S. (2012). Neighborhood disorder and anxiety symptoms: new evidence from a quasi-experimental study. *Health Place* 18, 180–190. doi: 10.1016/j.healthplace.2011.09.002

Chattarji, S., Tomar, A., Suvrathan, A., Ghosh, S., and Rahman, M. M. (2015). Neighborhood matters: divergent patterns of stress-induced plasticity across the brain. *Nat. Neurosci.* 18, 1364–1375. doi: 10.1038/nn.4115

Clark, U. S., Miller, E. R., and Hegde, R. R. (2018). Experiences of discrimination are associated with greater resting amygdala activity and functional connectivity. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 3, 367–378. doi: 10.1016/j.bpsc.2017.11.011

Collins, S. E., Clifasefi, S. L., Stanton, J., Straits, K. J., Gil-Kashiwabara, E., Rodriguez Espinosa, P., et al. (2018). Community-based participatory research (CBPR): towards equitable involvement of community in psychology research. *Am. Psychol.* 73:884. doi: 10.1037/amp0000167

Connolly, N. D. B., Winling, L., Nelson, R. K., and Marciano, R. (2018). "Mapping inequality:'Big data'meets social history in the story of redlining," in *The Routledge Companion to Spatial History*, eds I. Gregory, D. DeBats, and D. Lafreniere (London: Routledge), 502–524. doi: 10.4324/9781315099781-29

Connor, D. S., and Storper, M. (2020). The changing geography of social mobility in the United States. *Proc. Natl. Acad. Sci. U.S.A.* 117, 30309–30317. doi: 10.1073/pnas.2010222117

Coulton, C. J., Korbin, J. E., and Su, M. (2002). "Measuring neighborhood context for young children in an urban area," in *Ecological Research to Promote Social Change: Methodological Advances from Community Psychology*, eds T. A. Revenson, A. R. D'Augelli, S. E. French, D. L. Hughes, D. Livert, E. Seidman, et al. (Berlin: Springer), 99–126. doi: 10.1007/978-1-4615-0565-5_5

Crear-Perry, J., Correa-de-Araujo, R., Lewis Johnson, T., McLemore, M. R., Neilson, E., and Wallace, M. (2021). Social and structural determinants of health inequities in maternal health. *J. Womens Health* 2002, 230–235. doi: 10.1089/jwh.2020.8882

Crenshaw, K. (1991). Mapping the margins: intersectionality, identity politics, and violence against women of color. *Stanford Law Rev.* 43:1241. doi: 10.2307/1229039

Crenshaw, K. W. (2010). Twenty years of critical race theory: Looking back to move forward. *Conn. Rev.* 43:1253.

Dassopoulos, A., and Monnat, S. M. (2011). Do perceptions of social cohesion, social support, and social control mediate the effects of local community participation on neighborhood satisfaction? *Environ. Behav.* 43, 546–565. doi: 10.1177/0013916510366821

Davis, A. Y. (1990). *Women, Culture & Politics*. New York, NY: Vintage Books.

Dean, L. T. (2018). After 121 years, it's time to recognize WEB Du Bois as a founding father of social epidemiology. *J. Negro Educ.* 87, 230–245. doi: 10.7709/jnegroeducation.87.3.0230

Diderichsen, F., Hallqvist, J., and Whitehead, M. (2019). Differential vulnerability and susceptibility: how to make use of recent development in our understanding of mediation and interaction to tackle health inequalities. *Int. J. Epidemiol.* 48, 268–274. doi: 10.1093/ije/dyy167

Dougherty, C. J. (1993). Bad faith and victimblaming: the limits of health promotion. *Health Care Anal.* 1, 111–119. doi: 10.1007/BF02197104

Douglas, R. D., Alvis, L. M., Rooney, E. E., Busby, D. R., and Kaplow, J. B. (2021). Racial, ethnic, and neighborhood income disparities in childhood posttraumatic stress and grief: exploring indirect effects through trauma exposure and bereavement. *J. Trauma. Stress* 34, 929–942. doi: 10.1002/jts.22732

Ellis, B. J., Boyce, W. T., Belsky, J., Bakermans-Kranenburg, M. J., Ijzendoorn, M. H., and van. (2011). Differential susceptibility to the environment: An evolutionary–neurodevelopmental theory. *Dev. Psychopathol.* 23, 7–28. doi: 10.1017/S0954579410000611

Evans, G. W., and Kim, P. (2012). Childhood poverty and young adults' allostatic load: the mediating role of childhood cumulative risk exposure. *Psychol. Sci.* 23, 979–983. doi: 10.1177/0956797612441218

Fan, C. C., Marshall, A., Smolker, H., Gonzalez, M., Tapert, S., Barch, D., et al. (2021). Adolescent Brain Cognitive Development (ABCD) study linked external data (LED): protocol and practices for geocoding and assignment of environment data. *Dev. Cogn. Neurosci.* 52:101030. doi: 10.1016/j.dcn.2021.101030

Fani, N., Carter, S. E., Harnett, N. G., Ressler, K. J., and Bradley, B. (2021). Association of racial discrimination with neural response to threat in black women in the US exposed to Trauma. *JAMA Psychiatry* 78, 1005–1012. doi: 10.1001/jamapsychiatry.2021.1480

Farah, M. J. (2017). The Neuroscience of Socioeconomic Status: Correlates, Causes, and Consequences. *Neuron* 96, 56–71. doi: 10.1016/j.neuron.2017.08.034

Farah, M. J. (2018). Socioeconomic status and the brain: prospects for neuroscience-informed policy. *Nat. Rev. Neurosci.* 19, 428–438. doi: 10.1038/s41583-018-0023-2

Ferschmann, L., Bos, M. G. N., Herting, M. M., Mills, K. L., and Tamnes, C. K. (2022). Contextualizing adolescent structural brain development: Environmental determinants and mental health outcomes. *Curr. Opin. Psychol.* 44, 170–176. doi: 10.1016/j.copsyc.2021.09.014

Finegood, E. D., Rarick, J. R. D., and Blair, C. (2017). Exploring longitudinal associations between neighborhood disadvantage and cortisol levels in early childhood. *Dev. Psychopathol.* 29, 1649–1662. doi: 10.1017/S0954579417001304

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., and Lewis, B. (2011). A Social vulnerability index for disaster management. *J. Homel. Secur. Emerg. Manag.* 8, 1–22. doi: 10.2202/1547-7355.1792

Flanagin, A., Frey, T., Christiansen, S. L., and Ama Manual of Style Committee (2021). Updated guidance on the reporting of race and ethnicity in medical and science journals. *JAMA* 326, 621–627. doi: 10.1001/jama.2021.13304

Ford, C. L., and Airhihenbuwa, C. O. (2010a). The public health critical race methodology: praxis for antiracism research. *Soc. Sci. Med.* 71, 1390–1398. doi: 10.1016/j.socscimed.2010.07.030

Ford, C. L., and Airhihenbuwa, C. O. (2010b). Critical Race Theory, race equity, and public health: toward antiracism praxis. *Am. J. Public Health* 100, S30–S35. doi: 10.2105/AJPH.2009.171058

Ford, C. L., and Airhihenbuwa, C. O. (2018). Just What is critical race theory and what's it doing in a progressive field like public health? *Ethn. Dis.* 28, 223–230. doi: 10.18865/ed.28.S1.223

Forsyth, J., and Carter, R. T. (2012). The relationship between racial identity status attitudes, racism-related coping, and mental health among Black Americans. *Cultur. Divers. Ethnic Minor. Psychol.* 18, 128–140. doi: 10.1037/a0027660

Gapen, M., Cross, D., Ortigo, K., Graham, A., Johnson, E., Evces, M., et al. (2011). Perceived neighborhood disorder, community cohesion, and PTSD symptoms among low-income African Americans in an urban health setting. *Am. J. Orthopsychiatry* 81, 31–37. doi: 10.1111/j.1939-0025.2010.01069.x

Gard, A. M., Maxwell, A. M., Shaw, D. S., Mitchell, C., Brooks-Gunn, J., McLanahan, S. S., et al. (2021). Beyond family-level adversities: exploring the developmental timing of neighborhood disadvantage effects on the brain. *Dev. Sci.* 21:e12985. doi: 10.1111/desc.12985

Gard, A. M., Shaw, D. S., Forbes, E. E., and Hyde, L. W. (2018). Amygdala reactivity as a marker of differential susceptibility to socioeconomic resources during early adulthood. *Dev. Psychol.* 54, 2341–2355. doi: 10.1037/dev0000600

Gee, G. C., and Ford, C. L. (2011). Structural racism and health inequities: old issues, new directions. *Du Bois Rev.* 8, 115–132. doi: 10.1017/S1742058X11000130

Gellci, K., Marusak, H. A., Peters, C., Elrahal, F., Iadipaolo, A. S., and Rabinak, C. A. (2019). Community and household-level socioeconomic disadvantage and functional organization of the salience and emotion network in children and adolescents. *Neuroimage* 184, 729–740. doi: 10.1016/j.neuroimage.2018.09.077

Gianaros, P. J., and Hackman, D. (2013). Contributions of neuroscience to the study of socioeconomic health disparities. *Psychosom. Med.* 75, 610–615. doi: 10.1097/PSY.0b013e3182a5f9c1

Gillborn, D., and Ladson-Billings, G. (2009). *Education and critical race theory*. London: Routledge.

Gilpin, N. W., and Taffe, M. A. (2021). Toward an anti-racist approach to biomedical and neuroscience research. *J. Neurosci.* 41, 8669–8672. doi: 10.1523/JNEUROSCI.1319-21.2021

Giraldo, L., Huerta, A., and Solorzano, D. (2017). "From incarceration to community college: Funds of knowledge, community cultural wealth, and critical race theory," in *Funds of knowledge in higher education: Honoring students' cultural experiences and resources as strengths*, eds C. Rios-Aguilar, and J. M. Kiyama, (London: Routledge). doi: 10.4324/9781315447322-4

Hackman, D. A., Betancourt, L. M., Brodsky, N. L., Hurt, H., and Farah, M. J. (2012). Neighborhood disadvantage and adolescent stress reactivity. *Front. Hum. Neurosci.* 6:277. doi: 10.3389/fnhum.2012.00277

Hackman, D. A., Cserbik, D., Chen, J.-C., Berhane, K., Minaravesh, B., McConnell, R., et al. (2021). Association of local variation in neighborhood disadvantage in metropolitan areas with youth neurocognition and brain structure. *JAMA Pediatr.* 175:e210426. doi: 10.1001/jamapediatrics.2021.0426

Hackman, D. A., and Farah, M. J. (2009). Socioeconomic status and the developing brain. *Trends Cogn. Sci.* 13, 65–73. doi: 10.1016/j.tics.2008.11.003

Hackman, D. A., Farah, M. J., and Meaney, M. J. (2010). Socioeconomic status and the brain: mechanistic insights from human and animal research. *Nat. Rev. Neurosci.* 11, 651–659. doi: 10.1038/nrn2897

Hall Brown, T., and Mellman, T. A. (2014). The influence of PTSD, sleep fears, and neighborhood stress on insomnia and short sleep duration in urban, young adult, African Americans. *Behav. Sleep. Med.* 12, 198–206. doi: 10.1080/15402002.2013.784704

Han, S. D., Lamar, M., Fleischman, D., Kim, N., Bennett, D. A., Lewis, T. T., et al. (2020). Self-reported experiences of discrimination in older black adults are associated with insula functional connectivity. *Brain Imaging Behav.* 15, 1718–1727. doi: 10.1007/s11682-020-00365-9

Hanifa, R. (2021). *High-Income Black Homeowners Receive Higher Interest Rates than Low-Income White Homeowners*. Available online at: https://www.jchs.harvard.edu/blog/high-income-black-homeowners-receive-higher-interest-rates-low-income-white-homeowners (accessed Oct. 11, 2021).

Hardeman, R. R., Murphy, K. A., Karbeah, J., and Kozhimannil, K. B. (2018). Naming institutionalized racism in the public health literature: a systematic literature review. *Public Health Rep.* 133, 240–249. doi: 10.1177/0033354918760574

Harnett, N. G. (2020). Neurobiological consequences of racial disparities and environmental risks: a critical gap in understanding psychiatric disorders. *Neuropsychopharmacology* 45, 1247–1250. doi: 10.1038/s41386-020-0681-4

Harnett, N. G., Wood, K. H., Wheelock, M. D., Knight, A. J., and Knight, D. C. (2017). "Anticipation and the neural response to threat," in *Anticipation and Medicine*, ed. M. Nadin (Berlin: Springer International Publishing), 219–228. doi: 10.1007/978-3-319-45142-8_13

Henrich, J., Heine, S. J., and Norenzayan, A. (2010). Most people are not WEIRD. *Nature* 466:29. doi: 10.1038/466029a

Hillier, A. E. (2003). Redlining and the home owners' loan corporation. *J. Urban Hist.* 29, 394–420. doi: 10.1177/0096144203029004002

Hollingshead, A. B., and Redlich, F. C. (1958). *Social class and mental illness: Community study, Social class and mental illness: Community study*. Hoboken, NJ: John Wiley & Sons Inc, doi: 10.1037/10645-000

Huggins, A. A., McTeague, L. M., Davis, M. M., Bustos, N., Crum, K., Polcyn, R., et al. (2022). Neighborhood disadvantage associated with blunted amygdala reactivity to predictable and unpredictable threat in a community sample of youth. *Biol. Psychiatry Glob. Open Sci.* 2, 242–252. doi: 10.1016/j.bpsgos.2022.03.006

Hunt, J. F. V., Buckingham, W., Kim, A. J., Oh, J., Vogt, N. M., Jonaitis, E. M., et al. (2020). Association of neighborhood-level disadvantage with cerebral and hippocampal volume. *JAMA Neurol.* 77, 451–460. doi: 10.1001/jamaneurol.2019.4501

Ingram, R. E., and Luxton, D. D. (2005). *Vulnerability-Stress Models, in: Development of Psychopathology: A Vulnerability-Stress Perspective*. Thousand Oaks, CA: Sage Publications, Inc, 32–46. doi: 10.4135/9781452231655.n2

Johns, L. E., Aiello, A. E., Cheng, C., Galea, S., Koenen, K. C., and Uddin, M. (2012). Neighborhood social cohesion and posttraumatic stress disorder in a community-based sample: findings from the detroit neighborhood health study. *Soc. Psychiatry Psychiatr. Epidemiol.* 47, 1899–1906. doi: 10.1007/s00127-012-0506-9

Johnson, S. B., Riis, J. L., and Noble, K. G. (2016). State of the art review: poverty and the developing brain. *Pediatrics* 137:e20153075. doi: 10.1542/peds.2015-3075

Karb, R. A., Elliott, M. R., Dowd, J. B., and Morenoff, J. D. (2012). Neighborhood-level stressors, social support, and diurnal patterns of cortisol: the chicago community adult health study. *Soc. Sci. Med.* 1982, 1038–1047. doi: 10.1016/j.socscimed.2012.03.031

Karl, A., Schaefer, M., Malta, L. S., Dörfel, D., Rohleder, N., and Werner, A. (2006). A meta-analysis of structural brain abnormalities in PTSD. *Neurosci. Biobehav. Rev.* 30, 1004–1031. doi: 10.1016/j.neubiorev.2006.03.004

Kauh, T. J., Read, J. G., and Scheitler, A. J. (2021). The Critical Role of Racial/Ethnic Data Disaggregation for Health Equity. *Popul. Res. Policy Rev.* 40, 1–7. doi: 10.1007/s11113-020-09631-6

Kelly-Irving, M., and Delpierre, C. (2021). Framework for understanding health inequalities over the life course: the embodiment dynamic and biological mechanisms of exogenous and endogenous origin. *J. Epidemiol. Community Health* 75, 1181–1186. doi: 10.1136/jech-2021-216430

Kepper, M., Sothern, M., Zabaleta, J., Ravussin, E., Velasco-Gonzalez, C., Leonardi, C., et al. (2016). Prepubertal children exposed to concentrated disadvantage: An exploratory analysis of inflammation and metabolic dysfunction. *Obesity* 24, 1148–1153. doi: 10.1002/oby.21462

Kim, P., Evans, G. W., Chen, E., Miller, G., and Seeman, T. (2018). "How Socioeconomic Disadvantages Get Under the Skin and into the Brain to Influence Health Development Across the Lifespan," in *Handbook of Life Course Health Development*, eds N. Halfon, C. Forrest, R. Lerner, and E. Faustman (Cham: Springer). doi: 10.1007/978-3-319-47143-3_19

Kind, A. J., Jencks, S., Brock, J., Yu, M., Bartels, C., Ehlenbach, W., et al. (2014). Neighborhood socioeconomic disadvantage and 30 day rehospitalizations: an analysis of medicare data. *Ann. Intern. Med.* 161, 765–774. doi: 10.7326/M13-2946

Kind, A. J. H., and Buckingham, W. R. (2018). Making neighborhood-disadvantage metrics accessible — the neighborhood atlas. *N. Engl. J. Med.* 378, 2456–2458. doi: 10.1056/NEJMp1802313

Krieger, N. (1994). Epidemiology and the web of causation: has anyone seen the spider? *Soc. Sci. Med.* 39, 887–903. doi: 10.1016/0277-9536(94)90202-x

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *Int. J. Epidemiol.* 30, 668–677. doi: 10.1093/ije/30.4.668

Krieger, N. (2011). *Epidemiology and the people's health: theory and context*. Oxford: Oxford University Press.

Krieger, N. (2021). Structural racism, health inequities, and the two-edged sword of data: structural problems require structural solutions. *Front. Public Health* 9:655447. doi: 10.3389/fpubh.2021.655447

Lardier, D. T. Jr., Opara, I., and Roach, E. (2021). A latent profile analysis of psychological sense of community and ethnic identity among racial–ethnic minority young adults from the southwestern United States. *J. Community Psychol.* 50, 857–875. doi: 10.1002/jcop.22686

Lawrence, K. G., Kresovich, J. K., O'Brien, K. M., Hoang, T. T., Xu, Z., Taylor, J. A., et al. (2020). Association of neighborhood deprivation with epigenetic aging using 4 clock metrics. *JAMA Netw. Open* 3:e2024329. doi: 10.1001/jamanetworkopen.2020.24329

Lei, M.-K., Beach, S. R. H., and Simons, R. L. (2018). Biological embedding of neighborhood disadvantage and collective efficacy: influences on chronic illness via accelerated cardiometabolic age. *Dev. Psychopathol.* 30, 1797–1815. doi: 10.1017/S0954579418000937

Lei, M.-K., Simons, R. L., Beach, S. R. H., and Philibert, R. A. (2019). Neighborhood disadvantage and biological aging: using marginal structural models to assess the link between neighborhood census variables and epigenetic aging. *J. Gerontol. Ser. B* 74, e50–e59. doi: 10.1093/geronb/gbx015

Lende, D. H., and Downey, G. (2012). *The encultured brain: an introduction to neuroanthropology*. Cambridge, MA: MIT press.

Leslie, C. (1990). Scientific racism: Reflections on peer review, science and ideology. *Soc. Sci. Med.* 31, 891–905. doi: 10.1016/0277-9536(90)90025-n

Lett, E., Adekunle, D., McMurray, P., Asabor, E. N., Irie, W., Simon, M. A., et al. (2022). Health Equity Tourism: Ravaging the Justice Landscape. *J. Med. Syst.* 46:17. doi: 10.1007/s10916-022-01803-5

LeWinn, K. Z., Sheridan, M. A., Keyes, K. M., Hamilton, A., and McLaughlin, K. A. (2017). Sample composition alters associations between age and brain structure. *Nat. Commun.* 8:874. doi: 10.1038/s41467-017-00908-7

MacQueen, G., and Frodl, T. (2011). The hippocampus in major depression: evidence for the convergence of the bench and bedside in psychiatric research? *Mol. Psychiatry* 16, 252–264. doi: 10.1038/mp.2010.80

Massey, D., and Denton, N. A. (1993). *American apartheid: Segregation and the making of the underclass*. Cambridge, MA: Harvard university press.

McClure, E., Feinstein, L., Cordoba, E., Douglas, C., Emch, M., Robinson, W., et al. (2019). The legacy of redlining in the effect of foreclosures on Detroit residents' self-rated health. *Health Place* 55, 9–19. doi: 10.1016/j.healthplace.2018.10.004

McEwen, B. S. (2012a). The ever-changing brain: cellular and molecular mechanisms for the effects of stressful experiences. *Dev. Neurobiol.* 72, 878–890. doi: 10.1002/dneu.20968

McEwen, B. S. (2012b). Brain on stress: How the social environment gets under the skin. *Proc. Natl. Acad. Sci. U.S.A.* 109, 17180–17185. doi: 10.1073/pnas.1121254109

McEwen, B. S., and Gianaros, P. J. (2010). Central role of the brain in stress and adaptation: links to socioeconomic status, health, and disease. *Ann. N. Y. Acad. Sci.* 1186, 190–222. doi: 10.1111/j.1749-6632.2009.05331.x

McLaughlin, K. A., and Sheridan, M. A. (2016). Beyond cumulative risk: a dimensional approach to childhood adversity. *Curr. Dir. Psychol. Sci.* 25, 239–245. doi: 10.1177/0963721416655883

Minkler, M., and Wallerstein, N. (2003). "Introduction to community-based participatory research," in *Community-Based Participatory Research for Health*, eds M. Minkler, and N. Wallerstein (San Fransisco, CA: Jossey-Bass).

Momin, A. R. (1972). The facade of objectivity: an inquiry into the epistemology of value-free sociology. *Econ. Polit. Wkly.* 7, 2195–2202.

Muhammad, M., Wallerstein, N., Sussman, A. L., Avila, M., Belone, L., and Duran, B. (2015). Reflections on researcher identity and power: The impact of positionality on community based participatory research (CBPR) processes and outcomes. *Crit. Sociol.* 41, 1045–1063. doi: 10.1177/0896920513516025

Mullins, T. S., Campbell, E. M., and Hogeveen, J. (2020). Neighborhood deprivation shapes motivational-neurocircuit recruitment in children. *Psychol. Sci.* 31, 881–889. doi: 10.1177/0956797620929299

Muntaner, C., Eaton, W. W., and Diala, C. C. (2000). Social inequalities in mental health: a review of concepts and underlying assumptions. *Health Interdiscip. J. Soc. Study Health Illn. Med.* 4, 89–113. doi: 10.1177/136345930000400105

Muthukrishna, M., Bell, A. V., Henrich, J., Curtin, C. M., Gedranovich, A., McInerney, J., et al. (2020). Beyond Western, Educated, Industrial, Rich, and Democratic (WEIRD) psychology: measuring and mapping scales of cultural and psychological distance. *Psychol. Sci.* 31, 678–701. doi: 10.1177/0956797620916782

Neblett, E. W. Jr., Rivas-Drake, D., and Umaña-Taylor, A. J. (2012). The promise of racial and ethnic protective factors in promoting ethnic minority youth development. *Child Dev. Perspect.* 6, 295–303. doi: 10.1111/j.1750-8606.2012.00239.x

Neergheen, V. L., Topel, M., Van Dyke, M. E., Sullivan, S., Pemu, P. E., Gibbons, G. H., et al. (2019). Neighborhood social cohesion is associated with lower levels of interleukin-6 in African American women. *Brain. Behav. Immun.* 76, 28–36. doi: 10.1016/j.bbi.2018.10.008

Nuru-Jeter, A. M., Michaels, E. K., Thomas, M. D., Reeves, A. N., Thorpe, R. J., and LaVeist, T. A. (2018). Relative roles of race versus socioeconomic position in studies of health inequalities: a matter of interpretation. *Annu. Rev. Public Health* 39, 169–188. doi: 10.1146/annurev-publhealth-040617-014230

Olden, K., Olden, H. A., and Lin, Y.-S. (2015). The role of the epigenome in translating neighborhood disadvantage into health disparities. *Curr. Environ. Health Rep.* 2, 163–170. doi: 10.1007/s40572-015-0048-x

Park, K. A., and Quercia, R. G. (2020). Who lends beyond the red line? The community reinvestment act and the legacy of redlining. *Hous. Policy Debate* 30, 4–26. doi: 10.1080/10511482.2019.1665839

Pitts-Taylor, V. (2019). Neurobiologically Poor? Brain phenotypes, inequality, and biosocial determinism. *Sci. Technol. Hum. Values* 44, 660–685. doi: 10.1177/0162243919841695

Post, R. M. (1992). Transduction of psychosocial stress into the neurobiology of recurrent affective disorder. *Am. J. Psychiatry* 149, 999–1010. doi: 10.1176/ajp.149.8.999

Rakesh, D., Seguin, C., Zalesky, A., Cropley, V., and Whittle, S. (2021). Associations between neighborhood disadvantage, resting-state functional connectivity, and behavior in the adolescent brain cognitive development study: the moderating role of positive family and school environments. *Biol. Psychiatry Cogn. Neurosci. Neuroimaging* 6, 877–886. doi: 10.1016/j.bpsc.2021.03.008

Ramphal, B., DeSerisy, M., Pagliaccio, D., Raffanello, E., Rauh, V., Tau, G., et al. (2020). Associations between amygdala-prefrontal functional connectivity and age depend on neighborhood socioeconomic status. *Cereb. Cortex Commun.* 1:tgaa033. doi: 10.1093/texcom/tgaa033

Reda, M. H., Marusak, H. A., Ely, T. D., van Rooij, S. J. H., Stenson, A. F., Stevens, J. S., et al. (2021). Community violence exposure is associated with hippocampus-insula resting state functional connectivity in urban youth. *Neuroscience* 468, 149–157. doi: 10.1016/j.neuroscience.2021.06.010

Riley, A. R. (2018). Neighborhood disadvantage, residential segregation, and beyond—lessons for studying structural racism and health. *J. Racial Ethn. Health Disparities* 5, 357–365. doi: 10.1007/s40615-017-0378-5

Roberts, L., Schwartz, B., and Samuel, L. (2020). *Neighborhood characteristics associated with cardiovascular biomarkers in urban middle-aged and older adults, in: APHA's 2020 VIRTUAL Annual Meeting and Expo (Oct. 24-28).* Washington, DC: American Public Health Association.

Roberts, S. O., Bareket-Shavit, C., Dollins, F. A., Goldie, P. D., and Mortenson, E. (2020). Racial Inequality in Psychological Research: Trends of the Past and Recommendations for the Future. *Perspect. Psychol. Sci.* 15, 1295–1309. doi: 10.1177/1745691620927709

Saini, A. (2019). *Superior: the return of race science.* Boston, MA: Beacon Press.

Sampson, R. J., Raudenbush, S. W., and Earls, F. (1997). Neighborhoods and violent crime: a multilevel study of collective efficacy. *Science* 277, 918–924. doi: 10.1126/science.277.5328.918

Saxbe, D., Khoddam, H., Piero, L. D., Stoycos, S. A., Gimbel, S. I., Margolin, G., et al. (2018). Community violence exposure in early adolescence: Longitudinal associations with hippocampal and amygdala volume and resting state connectivity. *Dev. Sci.* 21:e12686. doi: 10.1111/desc.12686

Sewell, A. A. (2015). "Opening the Black Box of Segregation," in *Race and Real Estate*, eds A. Brown and V. Smith (Oxford: Oxford University Press), 87–105. doi: 10.1093/acprof:oso/9780199977260.003.0006

Sewell, A. A. (2016). The racism-race reification process: a mesolevel political economic framework for understanding racial health disparities. *Sociol. Race Ethn.* 2, 402–432. doi: 10.1177/2332649215626936

Singh, G. K. (2003). Area deprivation and widening inequalities in US Mortality, 1969–1998. *Am. J. Public Health* 93, 1137–1143. doi: 10.2105/AJPH.93.7.1137

Snedker, K. A., and Herting, J. R. (2016). Adolescent mental health: Neighborhood stress and emotional distress. *Youth Soc.* 48, 695–719. doi: 10.1177/0044118X13512335

Sripada, C., Angstadt, M., Taxali, A., Clark, D. A., Greathouse, T., Rutherford, S., et al. (2021). Brain-wide functional connectivity patterns support general cognitive ability and mediate effects of socioeconomic status in youth. *Trans. Psychiatry* 11:571. doi: 10.1038/s41398-021-01704-0

Steptoe, A., and Feldman, P. J. (2001). Neighborhood problems as sources of chronic stress: development of a measure of neighborhood problems, and associations with socioeconomic status and health. *Ann. Behav. Med.* 23, 177–185. doi: 10.1207/S15324796ABM2303_5

Taylor, R. L., Cooper, S. R., Jackson, J. J., and Barch, D. M. (2020). Assessment of neighborhood poverty, cognitive function, and prefrontal and hippocampal volumes in children. *JAMA Netw. Open* 3:e2023774. doi: 10.1001/jamanetworkopen.2020.23774

Tessum, C. W., Apte, J. S., Goodkind, A. L., Muller, N. Z., Mullins, K. A., Paolella, D. A., et al. (2019). Inequity in consumption of goods and services adds to racial–ethnic disparities in air pollution exposure. *Proc. Natl. Acad. Sci.* 116, 6001–6006. doi: 10.1073/pnas.1818859116

Tomas, C. W., Webb, E. K., Bennett, K. P., Huggins, A. A., Fitzgerald, J. M., Miskovich, T. A., et al. (2022). Neighborhood Socioeconomic Disadvantage and the Neurobiology of Uncertainty in Traumatically Injured Adults. *Biol. Psychiatry Glob. Open Sci* 2, 263–272. doi: 10.1016/j.bpsgos.2022.02.006

Tomlinson, R. C., Burt, S. A., Waller, R., Jonides, J., Miller, A. L., Gearhardt, A. N., et al. (2020). Neighborhood poverty predicts altered neural and behavioral response inhibition. *Neuroimage* 209:116536.

Tooley, U. A., Mackey, A. P., Ciric, R., Ruparel, K., Moore, T. M., Gur, R. C., et al. (2020). Influence of neighborhood SES on functional brain network development. *Cereb. Cortex* 30, 1–19. doi: 10.1093/cercor/bhz066

Turda, M. (2010). "Race, science, and eugenics in the twentieth century," in *The Oxford Handbook of the History of Eugenics*, eds A. Bashford, and P. Levine (Oxford: Oxford University Press).

Turner, M. A., and Greene, S. (2021). *Causes and Consequences of Separate and Unequal Neighborhoods. Urban Institute.* Available online at: https://www.urban.org/racial-equity-analytics-lab/structural-racism-explainer-collection/causes-and-consequences-separate-and-unequal-neighborhoods (accessed May 15, 2022).

Turner, R. J., and Lloyd, D. A. (1995). Lifetime traumas and mental health: the significance of cumulative adversity. *J. Health Soc. Behav* 360–376. doi: 10.2307/2137325

Vargas, T., Damme, K. S., and Mittal, V. A. (2020). Neighborhood deprivation, prefrontal morphology and neurocognition in late childhood to early adolescence. *Neuroimage* 220:117086. doi: 10.1016/j.neuroimage.2020.117086

Vine, M., Stoep, A. V., Bell, J., Rhew, I. C., Gudmundsen, G., and McCauley, E. (2012). Associations between household and neighborhood income and anxiety symptoms in young adolescents. *Depress. Anxiety* 29, 824–832. doi: 10.1002/da.21948

Vineis, P., and Barouki, R. (2022). The exposome as the science of social-to-biological transitions. *Environ. Int.* 165:107312. doi: 10.1016/j.envint.2022.107312

Wainberg, M. L., Scorza, P., Shultz, J. M., Helpman, L., Mootz, J. J., Johnson, K. A., et al. (2017). Challenges and opportunities in global mental health: a research-to-practice perspective. *Curr. Psychiatry Rep.* 19:28. doi: 10.1007/s11920-017-0780-z

Wallerstein, N. (2021). Engage for equity: Advancing the fields of community-based participatory research and community-engaged research in community psychology and the social sciences. *Am. J. Commun. Psychol.* 67, 251–255. doi: 10.1002/ajcp.12530

Wallerstein, N., and Duran, B. (2010). Community-based participatory research contributions to intervention research: the intersection of science and practice to improve health equity. *Am. J. Public Health* 100, S40–S46. doi: 10.2105/AJPH.2009.184036

Wallerstein, N., and Duran, B. (2017). "The theoretical, historical and practice roots of CBPR," in *Community-based participatory research for health: Advancing* *social and health equity*, eds N. Wallerstein, B. Duran, J. G. Oetzel, and M. Minkler (San Francisco, CA: Jossey-Bass).

Webb, E. K., Bird, C. M., deRoon-Cassini, T. A., Weis, C. N., Huggins, A. A., Fitzgerald, J. M., et al. (2022). Racial discrimination and resting-state functional connectivity of salience network nodes in trauma-exposed black adults in the united states. *JAMA Netw. Open* 5:e2144759. doi: 10.1001/jamanetworkopen.2021.44759

Webb, E. K., Weis, C. N., Huggins, A. A., Fitzgerald, J. M., Bennett, K., Bird, C. M., et al. (2021). Neural impact of neighborhood socioeconomic disadvantage in traumatically injured adults. *Neurobiol. Stress* 15:100385. doi: 10.1016/j.ynstr.2021.100385

Weng, H. Y., Ikeda, M. P., Lewis-Peacock, J. A., Chao, M. T., Fullwiley, D., Goldman, V., et al. (2020). Toward a compassionate intersectional neuroscience: increasing diversity and equity in contemplative neuroscience. *Front. Psychol.* 11:573134. doi: 10.3389/fpsyg.2020.573134

Whittle, S., Vijayakumar, N., Simmons, J. G., Dennison, M., Schwartz, O., Pantelis, C., et al. (2017). Role of positive parenting in the association between neighborhood social disadvantage and brain development across adolescence. *JAMA Psychiatry* 74, 824–832. doi: 10.1001/jamapsychiatry.2017.1558

Williams, D. R. (1999). Race, socioeconomic status, and health the added effects of racism and discrimination. *Ann. N. Y. Acad. Sci.* 896, 173–188. doi: 10.1111/j.1749-6632.1999.tb08114.x

Williams, D. R. (2018). Stress and the mental health of populations of color: advancing our understanding of race-related stressors. *J. Health Soc. Behav.* 59, 466–485. doi: 10.1177/0022146518814251

Williams, D. R., Lawrence, J. A., and Davis, B. A. (2019). Racism and health: evidence and needed research. *Annu. Rev. Public Health* 40, 105–125. doi: 10.1146/annurev-publhealth-040218-043750

Williams, D. R., and Mohammed, S. A. (2013). Racism and health I: Pathways and scientific evidence. *Am. Behav. Sci.* 57, 1152–1173. doi: 10.1177/0002764213487340

Wrigglesworth, J., Ryan, J., Vijayakumar, N., and Whittle, S. (2019). Brain-derived neurotrophic factor DNA methylation mediates the association between neighborhood disadvantage and adolescent brain structure. *Psychiatry Res. Neuroimaging* 285, 51–57. doi: 10.1016/j.pscychresns.2018.12.012

Yearby, R. (2020). Structural racism and health disparities: reconfiguring the social determinants of health framework to include the root cause. *J. Law. Med. Ethics* 48, 518–526. doi: 10.1177/1073110520958876

Yosso, T. J. (2005). Whose culture has capital? A critical race theory discussion of community cultural wealth. *Race Ethn. Educ.* 8, 69–91.

Zilioli, S., Slatcher, R. B., Fritz, H., Booza, J. C., and Cutchin, M. P. (2017). Brief report: Neighborhood disadvantage and hair cortisol among older urban African Americans. *Psychoneuroendocrinology* 80, 36–38.

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Incorporating Dis/ability Studies and Critical Race Theory to combat systematic exclusion of Black, Indigenous, and People of Color in clinical neuroscience

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This article reviews some of the ideological forces contributing to the systematic exclusion of Black, Indigenous, and People of Color (BIPOC) in clinical neuroscience. Limitations of functional near-infrared spectroscopy (fNIRS) and other methods systematically exclude individuals with coarse or curly hair and darker skin. Despite these well-known limitations, clinical neuroscience manuscripts frequently fail to report participant race or ethnicity or reasons for excluding participants. Grounding the discussion in Dis/ability Studies and Critical Race Theory (DisCrit), we review factors that exacerbate exclusion and contribute to the multiple marginalization of BIPOC, including (a) general methodological issues, (b) perceptions about race and disability, and (c) underreporting of methods. We also present solutions. Just as scientific practices changed in response to the replication crisis, we advocate for greater attention to the crisis of underrepresentation in clinical neuroscience and provide strategies that serve to make the field more inclusive.

KEYWORDS

underrepresentation, clinical neuroscience, BIPOC, DisCrit Theory, advocacy

Introduction

The systematic exclusion of Black, Indigenous, and People of Color (BIPOC) in clinical research is a longstanding problem, despite awareness (Durkin et al., 2015), empirical evidence (Henrich et al., 2010), and calls to action (Maye et al., 2021). Insufficient efforts to include BIPOC with disabilities (Annamma et al., 2013) and inconsistent reporting practices (Choy et al., 2021) reinforce the underrepresentation of already minoritized individuals – that is, they multiply marginalize BIPOC from clinical populations. This crisis is exacerbated by limitations in the technical and methodological features of neurotechnology (Parker and Ricard, 2022; Webb et al., 2022). These limitations also hinder reproducibility and generalizability (Open Science Collaboration, 2015), as well as the translation of scientific findings into clinical applications and interventions. The limited evidence base regarding BIPOC can only be addressed when neuroscience as a field, and individual scientists, make a concrete commitment to reversing exclusion and increasing diversity (Wilton et al., 2020). This manuscript reviews current limitations to methodology, recruitment, and reporting practices in clinical neuroscience and offers solutions.

Dis/ability Studies and Critical Race Theory (DisCrit) describes race and dis/ability as social constructs that primarily involve not the individual differences themselves, but rather, how *others* respond to those individual differences (Annamma et al., 2013, 2016). This theory centers external perceptions about race and disability as impacting the experiences of marginalized individuals (Annamma et al., 2018), with intersecting identities giving rise to multiple marginalization (Crenshaw, 1991). For example, Black children in the United States are under-identified as having speech/language impairments (Robinson and Norton, 2019); at the same time, Black children are also over-identified and misdiagnosed with conduct disorder rather than autism (Mandell et al., 2007). The perceptions of others (in this example, clinicians) about race reinforce perceptions about disability (and vice versa), leading to negative outcomes. DisCrit conceptualizes inequity at the intersection of race and dis/ability (Annamma et al., 2013), paralleling the intertwined fight for civil rights and dis/ability rights in the United States and reflecting everyday realities (Turnbull et al., 2006) (i.e., a Black autistic individual is not *only* Black or *only* autistic, but rather, navigates daily life as someone others perceive as Black and autistic).

Methodological limitations of neurotechnology for Black, Indigenous, and People of Color from clinical populations

Functional magnetic resonance imaging and functional near-infrared spectroscopy

Functional neuroimaging tools have led to dramatic advances in the diagnosis and study of communication disorders (Butler et al., 2020). Functional magnetic resonance imaging (fMRI) provides millimeter-level anatomical information, and also permits the assessment of regions of activation associated with an online behavioral task. While this information is highly informative, fMRI requires participants to remain in a confined space with little to no head movement, potentially eliciting anxiety and discomfort. MRI also involves significant environmental noise, which can be difficult to tolerate (Crosson et al., 2010). Hence, individuals from clinical populations whose sensory needs, anxiety, or difficulty in comprehending the need to remain motionless, are less able to participate in MRI studies; this includes individuals with neurodevelopmental disorders and cognitive impairment. Consequently, fMRI studies are more likely to include individuals with age-appropriate neurocognitive skills, and fewer neurodevelopmental disorder traits (Cosgrove et al., 2022).

Functional near-infrared spectroscopy uses the absorption of near-infrared light to measure hemodynamic oxyhemoglobin and deoxyhemoglobin concentrations in the cortex as a proxy for direct neural responses, similar to fMRI's BOLD signal (Jöbsis, 1977; Ferrari and Quaresima, 2012; Scholkmann et al., 2014). NIRS is more robust than MRI to head and body motion; it also permits data collection in an unrestricted environment, avoiding the need to remain motionless in a small scanner bore. Thus, fNIRS permits the assessment of neural responses in a broader range of individuals, such as those with speech/language impairments (Butler et al., 2020).

The efficacy of fNIRS (and the methodologically similar electroencephalography, EEG) varies by melanin and hair type (Yücel et al., 2021). NIRS and EEG require adequate contact with the scalp for good signal reception, and the MRI head coil does not fit individuals with large afro-textured hair, nor does it allow for data collection in individuals with hair extensions, as many use metal (Parker and Ricard, 2022; Webb et al., 2022). Thus, as currently deployed, these important neuroscience tools are less effective with coarse and/or curly hair and with darker skin. Given the multiple challenges of data collection, researchers may explicitly or implicitly exclude BIPOC by screening them out; even when BIPOC are included, their hemodynamic responses may be less usable or make BIPOC look less responsive to stimuli (Yücel et al., 2021; Webb et al., 2022). These methodological challenges lead to the systematic and disproportionate exclusion of BIPOC individuals from neuroimaging research.

Potential solution: Interdisciplinary approaches

Ignorance about systematic exclusion leads to an evidence base that is biased and unrepresentative. To counter marginalization of BIPOC from clinical populations (Annamma et al., 2018), we must transform both the scientific process and neuroimaging methods, prioritizing the collection of high-quality data from diverse participants. A The New York Times editorial suggested that effective strategies to address scientific, technological, ecological, political, and economic challenges, such as water use and conservation, require interdisciplinary thematically organized problem-focused programs including stakeholders (Taylor, 2009). We endorse this "all-in" approach with thematically organized approaches to dis/ability and race in neuroscience. For example, Parker and Ricard (2022) called for researchers, engineers, Black hairstylists and barbers, and research participants to co-develop accommodations for diverse hairstyles. Additional participants in the larger effort would include BIPOC community members (Lewis and Oyserman, 2016; Maye et al., 2021), policymakers and commercial organizations (National Institutes of Health, 2021), legal and educational theorists to generate models of underrepresentation (Powell, 2012; Annamma et al., 2013), and psychometricians to develop analytical approaches using intersectionality theory (Bauer et al., 2021).

At a broader level, funding agencies, as the National Institutes of Health (2021) has done, must promote interdisciplinary calls for proposals to develop, implement, and disseminate evidence-based practices to combat structural systemic racism. The effectiveness of diversity initiatives must also be benchmarked to funding outcomes (Wilton et al., 2020). In the United States, Black PIs – who are more likely than white PIs to propose doing BIPOC- and community-related research – are less likely than white PIs to receive major NIH (R01) grants (Ginther et al., 2016; Chen et al., 2022). Yet current interdisciplinary initiatives reflect the leadership of BIPOC in the quest to improve scientific innovation and discovery by making neuroscience inclusive; thus, mitigating inequity in grant funding is of paramount importance. For instance, Yücel and colleagues are investigating the effects of hair type and skin pigmentation on the signal quality of fNIRS via a partnership with industry, as well as autism and linguistic researchers (Facebook Research, 2021). Another team, led by Etienne et al. (2020), developed inclusive EEG electrodes for Black individuals and other persons with coarse and curly hair. These approaches are consistent with federal funding priorities of improving minority health and promoting collaborative science (National Institutes of Health, 2021).

Collective response to race and disability

Perpetuating issues impeding inclusive research

Given these and other limitations, BIPOC from clinical populations may be less likely to participate in neuroscience studies. Sampling practices, communication, and teaching can create a feedback loop that normalizes and perpetuates the systematic exclusion of such individuals from science. Over time, scientific practices can reify biased assumptions about race, dis/ability, and who can be included in research. In turn, these assumptions shape the development of research questions and recruitment methods, and impact future science via the training of junior scientists. Following DisCrit (Annamma et al., 2013), this cycle contributes to bias in the evidence base and in who is served by research practices (Lewis and Oyserman, 2016).

Convenience sampling and attrition

In clinical neuroscience, researchers recruit from a pool of participants who share a trait (e.g., autism plus language impairment); see **Figure 1A**. Researchers make assumptions about who is likely to contribute usable data and complete all study activities; such assumptions may exacerbate underrepresentation (Joseph and Dohan, 2009). Though they may aim for a sample that is representative of the population in terms of race, ethnicity, and other relevant variables (National Institutes of Health, 2017), time pressures on publications, grant applications, and career advancement, may lead to convenience sampling, which selects against BIPOC from clinical populations (Kasari et al., 2013; Durkin et al., 2015); see **Figure 1B**. As noted in "Functional magnetic resonance imaging and functional near-infrared spectroscopy", assumptions about who is likely to generate usable data (e.g., white participants with age-appropriate cognitive abilities (Cosgrove et al., 2022); can further increase the underrepresentation of BIPOC from clinical populations.

Underrepresentation means there is limited information on how to engage BIPOC from clinical populations in research, which requires being sensitive to the intersection of race and disability (Maye et al., 2021). For instance, nearly all (94%) autism studies exclude individuals with intellectual disabilities, but studies typically do not report information on intelligence or limitations to generalizability (Russell et al., 2019). Considering that researchers are less likely to approach BIPOC than white individuals as potential participants (Wendler et al., 2005), it is likely that autistic BIPOC with intellectual disabilities are even more underrepresented. Furthermore, recruitment and research methods, such as a failure to make time to build rapport, can affect study completion. For example, an autistic BIPOC young adult may initially consent to participation, but grow uneasy in an unfamiliar setting (e.g., laboratory) with unfamiliar people who do not have ties to their community, and complete the study activities in a way that increases noise in their data. Thus, even when well-intentioned researchers recruit and run BIPOC, and when data are collected, the usable data may come primarily from a less diverse, mostly white, sample (Webb et al., 2022). Underreporting of research methods can mask relevant details about the initial pool of potential participants and those participants whose data is included in the final report, resulting in bias; see **Figure 1C**.

Potential solution: Participatory methods

Mitigating underrepresentation may require researchers to share power in the research process. In community-based participatory research (CBPR), researchers develop partnerships with community stakeholders to develop research questions, methods, and studies, that benefit all parties (Ellis et al., 2021). For research with BIPOC from clinical populations, such partnerships are practical and ethical. Community advisory boards guide and hold researchers accountable for the responsible conduct and dissemination of research (Ellis et al., 2021). Such partnerships align with self-advocacy movements, which advocate for research that reflects their priorities (Gowen et al., 2019). Community partners can advocate for particular outcomes, such as the translation of study findings into policy recommendations, directions for clinical practice, and development of supports. Ultimately, participatory research can

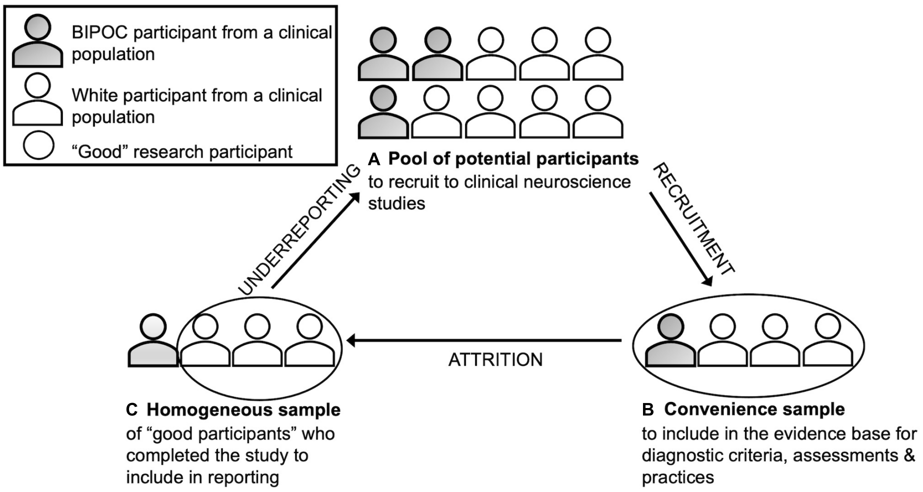

FIGURE 1
Application of Dis/ability Studies and Critical Race Theory (Annamma et al., 2018) to clinical neuroscience.

help change the collective response of clinical neuroscience to race and disability.

A first step is to identify and remove barriers to participation. In addition to logistical factors (e.g., scheduling studies after work hours and on weekends), Black families and BIPOC overall report distrust of research (George et al., 2014; Shaia et al., 2020). Researchers should spend time building trust, either with community advisory boards or community organizations, on community terms (Ellis et al., 2021). In addition, we should consider how perceptions of disability and race (and the subsequent experiences of individuals) along with systematic exclusion from research as both participants and researchers can influence a participant's comfort and subsequent performance (Shaia et al., 2020; Yücel et al., 2021). To mitigate that discomfort, researchers could plan a step by step preview of study activities with community partners prior to data collection to ensure activities are accessible to BIPOC from clinical populations.

Underreporting of participant demographics

Underreporting of participant demographics, though common practice in neuroimaging (Choy et al., 2021; Goldfarb and Brown, 2022), contributes to bias. Our team is currently performing a systematic review of the reporting of sociodemographics in empirical, refereed fNIRS studies of speech and language impairments. These studies frequently fail to report race, ethnicity, and other demographics (e.g., socioeconomic status). Failure to report participant race and ethnicity constitutes colorblindness (Webb et al., 2022) and masks the true extent and nature of bias; the information necessary to understand variability is treated as irrelevant.

Potential solution: Reporting, interpretation, and use of research studies

To develop a more authentic evidence base, scientists should implement replicable reporting standards, which should have downstream effects on the interpretation and use of findings to develop studies and make decisions about the state of the science (Kane, 2012). Though responsible reporting cannot address the systemic exclusion of BIPOC from clinical populations from research, it can enhance reproducibility and transparency (Sabik et al., 2021). Per the American Psychological Association (2020) and the American Medical Association (Flanagin et al., 2021), race and ethnicity are social constructs, meaning that authors should report: (a) race and ethnicity together with other factors known to intersect with race and ethnicity; (b) the method by which race and ethnicity information was collected, and why (e.g., to respect funding agency requirements); (c) specific or self-reported labels versus broad categories for race and ethnicity (e.g., allowing people to self-report or select "Naxi" versus "Asian"); and (d) reasons for attrition, considering that some participants are more likely to be excluded than others. Best practices include reporting ethnicity, recognizing that the ethnicity of participants may differ from the ethnicity of researchers (Yücel et al., 2021).

In addition to race and ethnicity, reporting participant characteristics relevant to understanding the generalizability of the findings within that clinical population (e.g., social communication impairment, nonverbal intelligence) can increase our understanding of generalizability. For example, autistic BIPOC with co-occurring diagnoses are often excluded, such that our current understanding of autism is based primarily on white individuals without intellectual disability or language impairment (Durkin et al., 2015; Bottema-Beutel et al., 2021). Importantly, because there is no one-to-one correspondence of race and ethnicity with hair type or skin tone, collecting and reporting measures relevant to skin tone and hair type (e.g., level of skin pigmentation and hair density) may also informative (Facebook Research, 2021).

Researchers should be precise in their interpretation of research findings. Data from neuroscience experiments constitute just one piece of evidence; the scientific community should interpret and use that evidence in a fair and equitable manner, which may necessitate collecting further evidence to support the validity of study findings (Messick, 1989; Kane, 2012; Girolamo et al., 2022). In the case of BIPOC – and especially BIPOC from clinical populations – this entails the following steps: (a) critically asking what demographic and identity variables are necessary to understand representativeness; (b) asking whether participants in a study are representative of the population of interest; (c) deciding under what conditions study findings are or are not generalizable. Researchers should be equally precise in how they use study findings, whether from their or others' work, to make decisions about the state of the evidence base. For instance, given that the quality of MRI signals is better in white participants with few neurodevelopmental disorder traits and age-appropriate intelligence (Cosgrove et al., 2022), the findings and methods of MRI studies may be less applicable to autistic BIPOC with intellectual disability.

Discussion

The factors in underrepresentation of BIPOC from clinical populations in neuroscience are myriad, with DisCrit helping conceptualize such exclusion (Annamma et al., 2013). In addition to the solutions offered above, systems-level change is needed to make neuroscience more inclusive.

Middle-out advocacy for systems change

As the leaders in research design, researchers inadvertently signal who is and is not welcome to participate (Lewis and Oyserman, 2016). As with fMRI (Cosgrove et al., 2022) and EEG (Choy et al., 2021), and fNIRS (Parker and Ricard, 2022), current neuroimaging practices insufficiently minimize racial, ethnic, and disability-relevant diversity, consistent with a model where individual differences are primarily a function of others' reactions (Annamma et al., 2013). To mitigate exclusion, researchers must be proactive advocates for change. Funders of research, universities, and commercial organizations exert influence downward on researchers by deciding who and what to fund, publish, and promote (Janda and Parag, 2013). At the bottom of the research system are participants, who, unless they are part of a participatory partnership, only exert influence upward by electing to take part in research. Researchers are situated in the middle of this system. They mutually influence each another (e.g., when reviewing manuscripts and grants, thus shaping who and what is published or funded), but also exert upward influence on funders (e.g., when advocating for research or serving on a committee), and downward influence on participants and mentees (e.g., advising on research design, analysis, and reporting, and coaching students on best practices).

Within this structure, researchers are the only stakeholders who exert influence in three directions. Researchers are also the most knowledgeable about their studies and research practices. Thus, researchers are the best advocates for change in how research is conducted, evaluated, and funded. It is also critical to cite, center, and implement the suggestions of BIPOC researchers who bring light to these issues and generate solutions, such as community-based methods for autism research (Maye et al., 2021), develop inclusive fNIRS methods and tools (Etienne et al., 2020; Parker and Ricard, 2022; Webb et al., 2022), and present best reporting practices (Yücel et al., 2021). If clinical neuroscience researchers exert advocacy in these ways, there will be material changes in the valuation and funding of research, the scientific evidence base, and research culture.

Conclusion

Overall, the self-perpetuating cycle of underrepresentation of BIPOC from clinical populations presents important challenges to the field of neuroscience. Using DisCrit as an explanatory pathway, this article discusses the factors exacerbating underrepresentation and outlines how researchers are uniquely positioned to effect change. It is our hope that researchers take up the call for advocacy and generate innovative solutions to make our field more authentically equitable and just.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

Author contributions

TG: conceptualization, methodology, formal analysis, investigation, writing – original draft, visualization, and supervision. TP: conceptualization, formal analysis, and writing – review and editing. I-ME: funding acquisition, project administration, and writing – review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

American Psychological Association (2020). *Publication Manual of the American Psychological Association: The Official Guide to APA Style*, 7th Edn. Washington, D.C: American Psychological Association.

Annamma, S. A., Connor, D., and Ferri, B. (2013). Dis/ability critical race studies (DisCrit): theorizing at the intersections of race and dis/ability. *Race Ethnicity Educ.* 16, 1–31. doi: 10.1080/13613324.2012.730511

Annamma, S. A., Connor, D. J., and Ferri, B. A. (2016). "A truncated genealogy of DisCrit," in *DisCrit: Disability Studies and Critical Race Theory in Education*, eds D. J. Connoa, B. A. Ferri, and S. A. Annamma (New York, NY: Teachers College Press).

Annamma, S. A., Ferri, B. A., and Connor, D. J. (2018). Disability critical race theory: exploring the intersectional lineage, emergence, and potential futures of DisCrit in education. *Rev. Res. Educ.* 42, 46–71. doi: 10.3102/0091732X18759041

Bauer, G. R., Churchill, S. M., Mahendran, M., Walwyn, C., Lizotte, D., and Villa-Rueda, A. A. (2021). Intersectionality in quantitative research: a systematic review of its emergence and applications of theory and methods. *SSM - Population Health* 14:100798. doi: 10.1016/j.ssmph.2021.100798

Bottema-Beutel, K., Kapp, S. K., Lester, J. N., Sasson, N. J., and Hand, B. N. (2021). Avoiding ableist language: suggestions for autism researchers. *Autism Adulthood* 3, 18–29. doi: 10.1089/aut.2020.0014

Butler, L. K., Kiran, S., and Tager-Flusberg, H. (2020). Functional near-infrared spectroscopy in the study of speech and language impairment across the life span: a systematic review. *Am. J. Speech Lang. Pathol.* 29, 1674–1701. doi: 10.1044/2020_AJSLP-19-00050

Chen, C. Y., Kahanamoku, S. S., Tripati, A., Alegado, R. A., Morris, V. R., Andrade, K., et al. (2022). Decades of systemic racial disparities in funding rates at the national science foundation. *[Preprint]*. doi: 10.31219/osf.io/xb57u

Choy, T., Baker, E., and Stavropoulos, K. (2021). Systemic racism in EEG research: considerations and potential solutions. *Affect. Sci.* 3, 14–20. doi: 10.1007/s42761-021-00050-0

Cosgrove, K. T., McDermott, T. J., White, E. J., Mosconi, M. W., Thompson, W. K., Paulus, M. P., et al. (2022). Limits to the generalizability of resting-state functional magnetic resonance imaging studies of youth: an examination of ABCD Study§baseline data. *Brain Imaging Behav.* 16, 1919–1925. doi: 10.1007/s11682-022-00665-2

Crenshaw, K. (1991). Mapping the margins: intersectionality, identity politics, and violence against women of color. *Stanford Law Rev.* 43, 1241–1499. doi: 10.2307/1229039

Crosson, B., Ford, A., McGregor, K. M., Meinzer, M., Cheshkov, S., Li, X., et al. (2010). Functional imaging and related techniques: an introduction for rehabilitation researchers. *J. Rehabil. Res. Dev.* 47, vii–xxxiv.

Durkin, M. S., Elsabbagh, M., Barbaro, J., Gladstone, M., Happe, F., Hoekstra, R. A., et al. (2015). Autism screening and diagnosis in low resource settings: challenges and opportunities to enhance research and services worldwide. *Autism Res.* 8, 473–476. doi: 10.1002/aur.1575

Ellis, C., Jacobs, M., and Kendall, D. (2021). The impact of racism, power, privilege, and positionality on communication sciences and disorders research: time to reconceptualize and seek a pathway to equity. *Am. J. Speech Lang. Pathol.* 30, 2032–2039. doi: 10.1044/2021_AJSLP-20-00346

Etienne, A., Laroia, T., Weigle, H., Afelin, A., Kelly, S. K., Krishnan, A., et al. (2020). "Novel electrodes for reliable EEG recordings on coarse and curly hair," in *IEEE Engineering in Medicine and Biology Society. Annual International Conference*, (Piscataway, NJ). doi: 10.1109/EMBC44109.2020.9176067

Facebook Research, (2021). Announcing the Winners of the 2021 Engineering Approaches to Responsible Neural Interface Design Request for Proposals. Available online at: https://research.facebook.com/blog/2021/09/announcing-the-winners-of-the-2021-engineering-approaches-to-responsible-neural-interface-design-request-for-proposals/ (accessed July 2, 2022).

Ferrari, M., and Quaresima, V. (2012). A brief review on the history of human functional near-infrared spectroscopy (fNIRS) development and fields of application. *NeuroImage* 63, 921–935. doi: 10.1016/j.neuroimage.2012.03.049

Flanagin, A., Frey, T., Christiansen, S. L., and Ama Manual of Style Committee (2021). Updated guidance on the reporting of race and ethnicity in medical and science journals. *JAMA* 326, 621–627. doi: 10.1001/jama.2021.13304

George, S., Duran, N., and Norris, K. (2014). A systematic review of barriers and facilitators to minority research participation among African Americans, Latinos, Asian Americans, and Pacific Islanders. *Am. J. Public Health* 104, e16–e31. doi: 10.2105/AJPH.2013.301706

Ginther, D. K., Kahn, S., and Schaffer, W. T. (2016). Gender, race/ethnicity, and National Institutes of Health R01 research awards: is there evidence of a double bind for women of color? *Acad. Med.* 91:1098. doi: 10.1097/ACM.0000000000001278

Girolamo, T., Ghali, S., Campos, I., and Ford, A. (2022). Interpretation and use of language assessments for diverse school-age individuals. *Perspect. ASHA Special Interest Groups* 7, 981–994. doi: 10.1159/000496969

Goldfarb, M. G., and Brown, D. R. (2022). Diversifying participation: the rarity of reporting racial demographics in neuroimaging research. *NeuroImage* 254:119122. doi: 10.1016/j.neuroimage.2022.119122

Gowen, E., Taylor, R., Bleazard, T., Greenstein, A., Baimbridge, P., and Poole, D. (2019). Guidelines for conducting research studies with the autism community. *Autism Policy Practice* 2, 29–24.

Henrich, J., Heine, S. J., and Norenzayan, A. (2010). The weirdest people in the world? *Behav. Brain Sci.* 33, 61–83. doi: 10.1017/S0140525X0999152X

Janda, K. B., and Parag, Y. (2013). A middle-out approach for improving energy performance in buildings. *Building Res. Inform.* 41, 39–50. doi: 10.1080/09613218.2013.743396

Jöbsis, F. F. (1977). Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science* 198, 1264–1267. doi: 10.1126/science.929199

Joseph, G., and Dohan, D. (2009). Diversity of participants in clinical trials in an academic medical center: the role of the 'good study patient?'. *Cancer* 115, 608–615. doi: 10.1002/cncr.24028

Kane, M. (2012). Validating score interpretations and uses. *Lang. Test.* 29, 3–17. doi: 10.1177/0265532211417210

Kasari, C., Brady, N., Lord, C., and Tager-Flusberg, H. (2013). Assessing the minimally verbal school-aged child with autism spectrum disorder. *Autism Res.* 6, 479–493.

Lewis, N. A., and Oyserman, D. (2016). Using identity-based motivation to improve the nation's health without breaking the bank. *Behav. Sci. Policy* 2, 24–38. doi: 10.1353/bsp.2016.0013

Mandell, D. S., Ittenbach, R. F., Levy, S. E., and Pinto-Martin, J. A. (2007). Disparities in diagnoses received prior to a diagnosis of autism spectrum disorder. *J. Autism. Dev. Disord.* 37, 1795–1802.

Maye, M., Boyd, B. A., Martínez-Pedraza, F., Halladay, A., Thurm, A., and Mandell, D. S. (2021). Biases, barriers, and possible solutions: steps towards addressing autism researchers under-engagement with racially, ethnically, and socioeconomically diverse communities. *J. Autism. Dev. Disord.* 52, 4206–4211. doi: 10.1007/s10803-021-05250-y

Messick, S. (1989). Meaning and values in test validation: the science and ethics of assessment. *Educ. Res.* 18, 5–11. doi: 10.2307/1175249

National Institutes of Health (2017). *Amendment: NIH Policy and Guidelines on the Inclusion of Women and Minorities as Subjects in Clinical Research*. Bethesda, MD: National Institutes of Health.

National Institutes of Health. (2021). *NIH-wide strategic plan for fiscal years 2021-2025*. Bethesda, MD: National Institutes of Health.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science* 349:aac4716. doi: 10.1126/science.aac4716

Parker, T. C., and Ricard, J. A. (2022). Structural racism in neuroimaging: perspectives and solutions. *Lancet Psychiatry* 9:e22. doi: 10.1016/S2215-0366(22)00079-7

Powell, J. A. (2012). *Racing to Justice: Transforming our Conceptions of Self and other to Build an Inclusive Society*. Bloomington, IND.: Indiana University Press.

Robinson, G. C., and Norton, P. C. (2019). A decade of disproportionality: a state-level analysis of African American students enrolled in the primary disability category of speech or language impairment. *Lang. Speech Hearing Services Schools* 50, 267–282.

Russell, G., Mandy, W., Elliott, D., White, R., Pittwood, T., and Ford, T. (2019). Selection bias on intellectual ability in autism research: a cross-sectional review and meta-analysis. *Mol. Autism* 10, 1–10. doi: 10.1186/s13229-019-0260-x

Sabik, N. J., Matsick, J. L., McCormick-Huhn, K., and Cole, E. R. (2021). Bringing an intersectional lens to "open" science: an analysis of representation in the reproducibility project. *Psychol. Women Quarterly* 45, 475–492. doi: 10.1177/03616843211035678

Scholkmann, F., Kleiser, S., Metz, A. J., Zimmermann, R., Pavia, J. M., Wolf, U., et al. (2014). A review on continuous wave functional near-infrared spectroscopy and imaging instrumentation and methodology. *NeuroImage* 85, 6–27. doi: 10.1016/j.neuroimage.2013.05.004

Shaia, W. E., Nichols, H. M., Dababnah, S., Campion, K., and Garbarino, N. (2020). Brief report: participation of black and African-American families in autism research. *J. Autism. Dev. Disord.* 50, 1841–1846. doi: 10.1007/s10803-019-03926-0

Taylor, M. C. (2009). *End the University as we know it*. New York, NY: The New York Times.

Turnbull, H. R. III, Turnbull, A. P., Stowe, M., and Huerta, N. (2006). *Free Appropriate Public Education: The Law and Children with Disabilities*, 75h Edn. Denver, CO: Love Publishing Company.

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Wendler, D., Kington, R., Madans, J., Van Wye, G., Christ-Schmidt, H., Pratt, L. A., et al. (2005). Are racial and ethnic minorities less willing to participate in health research? *PLoS Med.* 3:e19. doi: 10.1371/journal.pmed.0030019

Wilton, L. S., Bell, A. N., Vahradyan, M., and Kaiser, C. R. (2020). Show don't tell: diversity dishonesty harms racial/ethnic minorities at work. *Personal. Soc. Psychol. Bull.* 46, 1171–1185. doi: 10.1177/0146167219897149

Yücel, M. A., Lühmann, A. V., Scholkmann, F., Gervain, J., Dan, I., Ayaz, H., et al. (2021). Best practices for fNIRS publications. *Neurophotonics* 8: 012101.

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Hair me out: Highlighting systematic exclusion in psychophysiological methods and recommendations to increase inclusion

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Introduction

Within the neuroscience field, there have been efforts to address the ways systemic racism has permeated and negatively affected our research practice and body of knowledge (Abiodun, 2019; Choy et al., 2021; Carter et al., 2022; Webb et al., 2022). Neuroscience methods that require access to the hair and scalp systematically exclude groups of people, particularly Black communities, over and beyond the embedded exclusionary factors in the broader human research landscape (Gatzke-Kopp, 2016; Roberts et al., 2020; Fulvio et al., 2021; Taylor et al., 2021; Goldfarb and Brown, 2022). Indeed, recent papers have highlighted the shortcomings of current neuroscience methods (Choy et al., 2021; Parker and Ricard, 2022; Webb et al., 2022). Recently, Bradford et al. (2022) discussed underrepresentation in psychophysiological research samples and offered insightful recommendations for researchers to improve inclusion. We amplify and extend these valuable efforts, with a particular focus on methods that require access to participants' hair, such as electroencephalography (EEG) and hair sample collection. We briefly review factors that have led to the systematic exclusion of underrepresented groups in psychophysiological research and synthesize practical recommendations for researchers to increase inclusion moving forward.

To understand systematic exclusion in neuroscience methods, it is essential to name the legacy of anti-Black racism and its impact on research practices. Many early empirical pursuits often aimed to provide scientific justification for the exclusion and continued maltreatment of Black populations (Kuria, 2014). There are well-documented instances of unethical and harmful research conducted with Black populations (Washington, 2006). Additionally, there is continued mistrust in institutions given present-day experiences of racism and discrimination in medical and academic settings (for examples, see: Barber et al., 2020; Hassen et al., 2021). These historical and current experiences continue to influence neuroscience research. For instance, underrepresentation of Black, Indigenous, and people of color (BIPOC) researchers leads to a lack of diversity in research samples (Buchanan and Wiklund, 2020; Roberts et al., 2020). Many scholars have highlighted the tendency for psychological and neuroscientific research to primarily include western, educated, industrialized, rich, and democratic (WEIRD) samples (Henrich et al., 2010). Such research has also historically excluded BIPOC individuals and women (Taffe and Gilpin, 2021; Taylor et al., 2021), with individuals at the intersection of different marginalized identities (e.g., BIPOC women) being even less represented (Spates, 2012; Kuria, 2014). Exclusion in neuroscience research occurs despite evidence that suggests Black and POC participants are willing to participate in research overall (Wendler et al., 2005; Jones and Neblett, 2017; Manns-James and Neal-Barnett, 2019). This lack of representation has harmed our ability to make scientific progress, as findings commonly thought to be "generalizable" often only speak to a subset of WEIRD and White people and perpetuates harm onto BIPOC communities.

EEG and hair sample collection: Highlighting exclusion within methods that require contact with hair

The methods employed in neuroscience research often serve as an indirect source of systematic exclusion, in that the methods themselves lead to consistent exclusion of specific populations. The source of this exclusion lies in the inadequacy of a given method to accommodate people with a variety of phenotypic traits, a direct form of "phenotypic bias" (Webb et al., 2022). When access to a participant's hair is required, even without the use of equipment, as is the case for hair sample collection, phenotypic bias can still be present and affect research practices methods and contribute to underrepresentation in research samples (Manns-James and Neal-Barnett, 2019; Choy et al., 2021). To highlight this, we focus our discussion on how EEG and hair sample collection to assay for cortisol results in the exclusion of Black participants, in particular.

Lack of inclusive methodologies

Many EEG devices require access to the scalp to measure electrical brain activity. Thicker (i.e., coarser) and curlier hair can make access to the scalp more difficult when applying conductive electrode gel. Conductive gel acts as a bridge to establish the proper connection between the scalp and electrodes and can result in poor signal quality if access to the scalp is impeded. When EEG devices are used clinically, poor signal quality can affect clinical diagnosis and contribute to a burdensome experience for patients (Etienne et al., 2020). Researchers have attempted to compensate for the current limitations of EEG devices by applying more conductive gel to help establish a connection. However, this can result in the additional gel spreading across the scalp and bridging electrodes, which reduces spatial resolution (Etienne et al., 2020), and discomfort for the participant who is left with an abundance of hair gel to remove afterward. It is therefore common for EEG researchers to exclude participants with thick, curly hair due to poor data quality (Choy et al., 2021).

Most extant protocols for collecting hair samples to assay for cortisol do not account for differences in hair texture (e.g., curliness or thickness; Russell et al., 2012; Wright et al., 2018). Indeed, most require several centimeters of hair to be available for collection. Accounting for hair texture is necessary for determining the accurate length of hair samples and ensures that hair collection minimizes damage to the participant's hair (Wright et al., 2018). Using traditional protocols created for straight hair textures, hair cortisol researchers may exclude some individuals with curly hair because such individuals' hair may be considered too short (Wright et al., 2018).

In addition to methodologies being unaccommodating of thick and curly hair textures, these methodologies are also less well suited to hairstyles such as braids, twists, cornrows, or locs that are more likely to be worn by Black individuals. Individuals from various backgrounds may also wear extensions or wigs. Participants may have to partially or fully undo hairstyles for research studies, which may influence their participation. For instance, a recent study found that nearly half of Black women participants who declined to provide a hair sample reported doing so because they had hairstyles that would make accessing their natural hair more difficult (Manns-James and Neal-Barnett, 2019). Many of these hairstyles can take significant time to remove and can be quite expensive to redo, leading to increased cost and burden of participating in EEG and hair cortisol studies.

Lack of inclusive staff training

Even if participants with thick, curly hair, or the aforementioned hairstyles are enrolled, research staff may not be trained or prepared to have respectful discussions with participants about their hair to facilitate data collection. Moreover, negative interactions with untrained staff can be harmful to research participants if disparaging or devaluing statements are made about their hair. For example, study staff may make statements about certain hair textures or styles being "bad," "difficult," or "undesirable" when difficulties in data collection arise. In addition, pervasive racial bias about hair textures and hairstyles may be communicated to participants during the data collection process (MacFarlane et al., 2017; Mbilishaka et al., 2020). Such interactions likely contribute to systematic disengagement of diverse populations from participating in EEG and cortisol studies. Finally, cultural and religious differences surrounding the value of hair can also influence participation in research that requires access to the hair/scalp. For example, individuals who wear headscarves may not feel comfortable removing their headscarves around male research staff or others for various reasons. This can be a barrier to participation if there are no female researchers on the research team. To our knowledge, there are no published recommendations for accommodating participants who wear headscarves in EEG or hair cortisol studies, and, therefore, such individuals may be less likely to participate. In addition, some individuals may not want to provide hair samples because their natural hair has cultural or religious significance (Manns-James and Neal-Barnett, 2019).

Foundations of these methodological/training limitations

The limitations of both EEG and hair collection methods may have led to exclusionary practices in neuroscience research, such as biased exclusionary criteria, increased financial burden on BIPOC participants, and harmful interactions with study staff. The limitations of these methodologies and staff training are likely related to the lack of diversity among researchers who developed them. For instance, less than 5% of psychologists and neuroscientists identify as BIPOC researchers (Society for Neuroscience, 2017; Lin et al., 2018). Reviewing operating manuals for popular EEG devices (i.e., ActiveTwo, NeuroScan, Brain Products) revealed no explicit instructions for EEG setup on participants with thick, curly hair or any mention of different hair textures or styles. Visual depictions of EEG setup only included images of individuals with straight hair textures. The operating manuals from these popular EEG devices highlight the extent to which EEG device manufacturers have neglected individual differences in hair texture.

Recommendations

We present recommendations based on extant research to increase inclusivity in neuroscience research using physiological methods that involve contact with hair in Table 1. First, we recommend that researchers increase collaboration with BIPOC researchers. Author positionality directly affects the ways in which research is conducted (Taylor and Rommelfanger, 2022). The general standard to uphold scientific objectivity may often blind researchers to the legacy and current effects of anti-Black racism, and how it continues to affect our research practices. Therefore, collaborating with BIPOC researchers allows for diversity in scientific thought and ultimately improves our research questions, research ethics, and development of novel methodological solutions. For instance, Etienne et al. (2020) have introduced SEVO (Haitian Kreyól for "brain") electrodes that allow direct access to the scalp for individuals with thick and curly hair. SEVO electrodes leverage a conventional Black hairstyle (i.e., cornrows) to improve EEG application, and employ attachments designed similar to hair barrettes to secure electrode placement and reduce the signal-to-noise ratio. Etienne et al., (2020) modified EEG design provides an innovative solution that improves data quality and participants' experience by addressing the limitations of many EEG devices.

Second, we encourage increased research training on hair types and styles. Understanding differences in hair types and styles is critical for preparing hair for EEG and hair sample collection, communicating steps to research participants, and promoting a more inclusive environment. We encourage researchers to go about this process with cultural humility (as opposed to cultural competence), which involves the dual praxis of self-reflection and continuous learning (Yeager and Bauer-Wu, 2013).

Third, we recommend that researchers strive to accommodate all hair textures and styles. Equipment and protocols must be altered to make them more accommodating of thick and curly hair. Others have suggested employing a beautician well-versed in working with Black hair to redo hairstyles following EEG collection or taking hair samples for cortisol (Wright et al., 2018). Researchers could also acknowledge the increased burden on BIPOC participants by offering additional compensation to those who need hairstyles to be removed and/or scheduling study visits before hair appointments (Manns-James and Neal-Barnett, 2019).

Additionally, researchers should collaborate with participants toward successful data collection, such as allowing participants to self-collect their own hair samples or working with participants to determine how to best collect data when access to their scalp is impeded. For example, researchers interested in fronto-central or centro-parietal neural signals (the most canonical locations for many common EEG/ERP metrics) could prioritize the placement of midline sites if access to other areas of the scalp is occluded. Finally, researchers should be conscious that certain cultural/religious practices dictate that only people of the same gender can see their hair. Therefore, we recommend conducting EEG and hair sample collection in a private space and that lab visits are adjusted, if needed, to meet the participant's needs.

Conclusion

In sum, anti-Black racism continues to shape research practices that rely on physiological methods involving contact with hair. While it may not be explicit, the use of these methods has a significant impact on who participates in research studies. Blindly abiding by the limitations of equipment or protocols leads to underrepresented samples, limited science, and a body of knowledge that does not apply to many. We believe a critical starting point to move toward inclusion is to modify

TABLE 1 Recommendations for researchers to improve inclusive practices in EEG and hair cortisol research.

Recommended broad changes	Specific recommendations across methods
Collaborate with BIPOC researchers.	Review the extant literature for recommendations by BIPOC researchers to increase inclusion of research participants and cite such researchers (Cundiff, 2012; Roberts et al., 2020; Zurn et al., 2020; Buchanan et al., 2021; Smith et al., 2021; Bradford et al., 2022; Webb et al., 2022). Collaborate with BIPOC researchers at all levels (i.e., undergraduates, graduate students, staff, post-doctoral fellows, and junior and senior faculty). Think critically about how to incorporate race into neuroscience research (Carter et al., 2022; Kaiser Trujillo et al., 2022).

	Specific recommendations across methods	EEG-specific recommendations	Hair cortisol specific recommendations
Train research staff to promote inclusion in discussing and working with participants with diverse hair textures and styles.	Researchers should be well-versed in the diversity of hairstyles, textures, and care. Staff training should include refraining from value-based language about hair (e.g., "good hair" vs. "bad hair"). Researchers should accommodate participants who may hold cultural values around who is allowed to see and access their hair to best accommodate their needs.	Richardson and colleagues provide inclusive guidelines for hair preparation for EEG data collection and a description of hair characteristics and care (https://hellobrainlab.com/research/eeg-hair-project/). Consider prioritizing electrode placement based on research aims (e.g., focus on frontal or parietal electrodes needed for specific ERPs) instead of the whole scalp. If challenges during data collection arise, staff should communicate the limitations of the equipment rather than make negative statements about hair.	
Accommodate participants with diverse hairstyles and textures.	Provide participants with a video or visual demonstration of the EEG or hair collection process to increase transparency and describe how the data will be used. Provide a private setting for participants to ask questions about EEG/hair collection procedures. Schedule EEG or hair collection visits between hair appointments. Consider employing a beautician well-versed in working with Black hair to redo hairstyles following EEG collection or taking hair samples for cortisol (Manns-James and Neal-Barnett, 2019).* Consider increased compensation in cases where excess time is required for a participant to modify or undue hairstyles for participation (Manns-James and Neal-Barnett, 2019).*	Researchers should have an open dialogue with all participants about their hair including understanding the participant's comfort level after thoroughly explaining procedures. Purchase add-ons to EEG equipment (Krishnan et al., 2018; Etienne et al., 2020).* Researchers should advocate for more inclusive technology for all hair textures and styles (Robinson et al., 2022).	Consider that teaching participants self-collection of samples may increase participant comfort and sense of respect for the cultural significance of their hair. Collect a hair sample at a hair salon during a participant's scheduled hair appointment to reduce participant burden.

*We recognize that these particular recommendations require more resources than are available to some research teams to implement immediately. Therefore, we encourage researchers to strive toward these recommendations whenever possible but encourage the use of the recommendations without asterisks when resources are limited.

research lab practices. While we have specifically reviewed EEG and hair cortisol, it is vital for this critical reflection and action to take place across multiple phases of the research process for a variety of research methodologies. We hope these recommendations may provide practical steps for researchers to employ in their labs to improve inclusion and expand the applicability and relevance of neuroscience research beyond White and WEIRD individuals.

Author contributions

CL, CW, and LG conceptualized and drafted the manuscript. All authors provided critical revision of the manuscript and approved the final version for submission.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abiodun, S. J. (2019). "Seeing Color," a discussion of the implications and applications of race in the field of neuroscience. *Front. Hum. Neurosci.* 13, 280. doi: 10.3389/fnhum.2019.00280

Barber, S., Gronholm, P. C., Ahuja, S., Rüsch, N., and Thornicroft, G. (2020). Microaggressions towards people affected by mental health problems: a scoping review. *Epidemiol. Psychiatr. Sci.* 29, e82. doi: 10.1017/S2045796019000763

Bradford, D. E., DeFalco, A., Perkins, E., Carbajal, I., Kwasa, J., Goodman, F. R., et al. (2022). Whose signals are we amplifying? Towards a more equitable clinical psychophysiology. *Clin. Psychol. Sci.* doi: 10.31234/osf.io/c2naf

Buchanan, N. T., Perez, M., Prinstein, M. J., and Thurston, I. B. (2021). Upending racism in psychological science: Strategies to change how science is conducted, reported, reviewed, and disseminated. *Am. Psychol.* 76, 1097–1112. doi: 10.1037/amp0000905

Buchanan, N. T., and Wiklund, L. O. (2020). Why clinical science must change or die: Integrating intersectionality and social justice. *Women Therapy* 43, 309–329. doi: 10.1080/02703149.2020.1729470

Carter, S. E., Mekawi, Y., and Harnett, N. G. (2022). *It's about racism, not race: a call to purge oppressive practices from neuropsychiatry and scientific* discovery. *Neuropsychopharmacology*. 47, 2179–2180. doi: 10.1038/s41386-022-01367-5

Choy, T., Baker, E., and Stavropoulos, K. (2021). *Systemic Racism in EEG* Research: Considerations and Potential Solutions. *Affect Sci.* 3, 14–20. doi: 10.1007/s42761-021-00050-0

Cundiff, J. L. (2012). Is mainstream psychological research "Womanless" and "Raceless"? An updated analysis. *Sex Roles* 67, 158–173. doi: 10.1007/s11199-012-0141-7

Etienne, A., Laroia, T., Weigle, H., Afelin, A., Kelly, S. K., Krishnan, A., et al. (2020). Novel electrodes for reliable EEG recordings on coarse and curly hair. In *2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC).* (IEEE), pp. 6151–6154. doi: 10.1109/EMBC44109.2020.9176067

Fulvio, J. M., Akinnola, I., and Postle, B. R. (2021). Gender (Im)balance in citation practices in cognitive neuroscience. *J. Cogn. Neurosci.* 33, 3–7. doi: 10.1162/jocn_a_01643

Gatzke-Kopp, L. M. (2016). Diversity and representation: key issues for psychophysiological science. *Psychophysiology* 53, 3–13. doi: 10.1111/psyp.12566

Goldfarb, M. G., and Brown, D. R. (2022). Diversifying participation: the rarity of reporting racial demographics in neuroimaging research. *Neuroimage* 254, 119122. doi: 10.1016/j.neuroimage.2022.119122

Hassen, N., Lofters, A., Michael, S., Mall, A., Pinto, A. D., and Rackal, J. (2021). Implementing anti-racism interventions in healthcare settings: a scoping review. *Int. J. Environ. Res. Public Health* 18, 2993. doi: 10.3390/ijerph18062993

Henrich, J., Heine, S. J., and Norenzayan, A. (2010). The weirdest people in the world? *Behav. Brain Sci.* 33, 61–83. doi: 10.1017/S0140525X0999152X

Jones, S. C. T., and Neblett, E. W. (2017). Future directions in research on racism-related stress and racial-ethnic protective factors for black youth. *J. Clin. Child Adolesc. Psychol.* 46, 754–766. doi: 10.1080/15374416.2016.1146991

Kaiser Trujillo, A., Kessé, E. N., Rollins, O., Della Sala, S., and Cubelli, R. (2022). A discussion on the notion of race in cognitive neuroscience research. *Cortex* 150, 153–164. doi: 10.1016/j.cortex.2021.11.007

Krishnan, A., Kumar, R., Etienne, A., Robinson, A., Kelly, S., Behrmann, M., et al. (2018). Challenges and opportunities in instrumentation and use of high-density EEG for underserved regions. in *Innovations and Interdisciplinary Solutions for Underserved Areas. InterSol 2018. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 249.* eds C. Kebe, A. Gueye, A. Ndiaye, A. Garba (Cham, New York, NY: Springer). doi: 10.1007/978-3-319-98878-8_7

Kuria, E. N. (2014). Theorizing race (ism) while neuroGendering. *Gendered Neurocultures: Feminist and Queer Perspectives on Current Brain Discourses.* p. 109–123.

Lin, L., Stamm, K., and Christidis, P. (2018). *Demographics of the US Psychology Workforce*. Washington, DC: Author.

MacFarlane, J., Tropp, L. R., and Goff, P. A. (2017). *Explicit and Implicit Attitudes Toward Black Women's Hair.* Available online at: https://perception.org/wp-content/uploads/2017/01/TheGoodHairStudyFindingsReport.pdf

Manns-James, L., and Neal-Barnett, A. (2019). Development of a culturally informed protocol for hair cortisol sampling in Black women. *Public Health Nurs.* 36, 872–879. doi: 10.1111/phn.12668

Mbilishaka, A. M., Clemons, K., Hudlin, M., Warner, C., and Jones, D. (2020). Don't get it twisted: Untangling the psychology of hair discrimination within Black communities. *Am. J. Orthopsychiatry* 90, 590–599. doi: 10.1037/ort0000468

Parker, T. C., and Ricard, J. A. (2022). Structural racism in neuroimaging: perspectives and solutions. *Lancet Psychiatry* 9, e22. doi: 10.1016/S2215-0366(22)00079-7

Roberts, S. O., Bareket-Shavit, C., Dollins, F. A., Goldie, P. D., and Mortenson, E. (2020). Racial inequality in psychological research: trends of the past and recommendations for the future. *Perspect. Psychol. Sci.* 15, 1295–1309. doi: 10.1177/1745691620927709

Robinson, J. T., Rommelfanger, K. S., Anikeeva, P. O., Etienne, A., French, J., Gelinas, J., et al. (2022). Building a culture of responsible neurotech: neuroethics as socio-technical challenges. *Neuron* 110, 2057–2062. doi: 10.1016/j.neuron.2022.05.005

Russell, E., Koren, G., Rieder, M., and Van Uum, S. (2012). Hair cortisol as a biological marker of chronic stress: current status, future directions and unanswered questions. *Psychoneuroendocrinology* 37, 589–601. doi: 10.1016/j.psyneuen.2011.09.009

Smith, C. A., Williams, E. L., Wadud, I. A., Pirtle, W. N., and Collective, C. B. W. (2021). Cite black women: a critical praxis (a statement). *Fem. Anthropol.* 2, 10–17. doi: 10.1002/fea2.12040

Society for Neuroscience. (2017). *Report of Neuroscience Departments & Programs Survey.* Available online at: https://www.sfn.org/-/media/SfN/Documents/SurveyReports/NDP-Final-Report.ashx?la=en

Spates, K. (2012). "The Missing Link" the exclusion of black women in psychological research and the implications for black women's mental health. *Sage Open* 2, 2158244012455179. doi: 10.1177/2158244012455179

Taffe, M. A., and Gilpin, N. W. (2021). Equity, diversity and inclusion: racial inequity in grant funding from the US National Institutes of Health. *Elife* 10, e65697. doi: 10.7554/eLife.65697

Taylor, C. M., Pritschet, L., and Jacobs, E. G. (2021). The scientific body of knowledge – Whose body does it serve? A spotlight on oral contraceptives and women's health factors in neuroimaging. *Front. Neuroendocrinol.* 60, 100874. doi: 10.1016/j.yfrne.2020.100874

Taylor, L., and Rommelfanger, K. S. (2022). Mitigating white Western individualistic bias and creating more inclusive neuroscience. *Nat. Rev. Neurosci.* 23, 389–390. doi: 10.1038/s41583-022-00602-8

Washington, H. A. (2006). *Medical Apartheid: The Dark History of Medical Experimentation on Black Americans from Colonial Times to the Present*. New York, NY: Doubleday Books.

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Wendler, D., Kington, R., Madans, J., Wye, G. V., Christ-Schmidt, H., Pratt, L. A., et al. (2005). Are Racial and Ethnic Minorities Less Willing to Participate in Health Research? *PLoS Med.* 3, e19. doi: 10.1371/journal.pmed.0030019

Wright, K. D., Ford, J. L., Perazzo, J., Jones, L. M., Mahari, S., Sullenbarger, B. A., et al. (2018). Collecting hair samples for hair cortisol analysis in African Americans. *J. Vis. Exp.* 57288. doi: 10.3791/57288

Yeager, K. A., and Bauer-Wu, S. (2013). Cultural humility: essential foundation for clinical researchers. *Appl. Nurs. Res.* 26, 251–256. doi: 10.1016/j.apnr.2013.06.008

Zurn, P., Bassett, D. S., and Rust, N. C. (2020). The citation diversity statement: a practice of transparency, a way of life. *Trends Cogn. Sci.* 24, 669–672. doi: 10.1016/j.tics.2020.06.009

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Creating a sustainable action-oriented engagement infrastructure—a UMN-MIDB perspective

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Following the murder of George Floyd on May 25, 2020, Minneapolis represented the epicenter of protests that would reverberate internationally and re-instantiate a reckoning of the systemic and institutional racism that plagues American society. Also in the summer of 2020, and after several years of planning, the University of Minnesota (UMN) launched the Masonic Institute for the Developing Brain (MIDB), an interdisciplinary clinical and community research enterprise designed to create knowledge and engage all members of our community. In what follows, we describe the mission of the MIDB Community Engagement and Education (CEEd) Core and adjacent efforts within the UMN neuroscience and psychology community. Inherent to these efforts is the explicit attempt to de-center the dominant academic voice and affirm knowledge creation is augmented by diverse voices within and outside of traditional academic institutions. We describe several initiatives, including the Neuroscience Opportunities for Discovery and Equity (NODE) network, the NextGen Psych Scholars Program (NPSP), the Young Scientist Program, among others as exemplars of our approach. Developing and fortifying sustainable pathways for authentic community-academic partnerships are of central importance to enhance mutually beneficial scientific discovery. We posit that traditional academic approaches to community engagement to benefit the institution are severely constrained and perpetuate inherently exploitative power dynamics between academic institutions and communities.

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community engagement, diversity, infrastructure building, diversifying STEAM, neuroscience, inequities in education

Introduction

Traditionally, youth education has avoided teaching hard truths about the history of enslavement, genocide, institutionalization, forced sterilization and other forms of sexist, ableist, and racialized realities of our past, often excluding communities that it tries to assist in the name of Equity, Diversity and Inclusion (EDI). This culture of exclusion has not escaped our academic institutions despite the recent surge in awareness around EDI issues. Academic institutions have been historically structured such that the voice of the academic is centered and amplified by itself—an echo chamber on what we often call "University Island" (Reingewertz and Lutmar, 2018; Williams, 2019). For example, while working collaboratively with community organizations, it is often mandatory to utilize the university academic calendar for funding, and institutional requirements generally direct the forms of programming, access, participant availability, frequency, and the scope of work. Due to the gender, race, ability, and other inequities found in academic circles (Freund et al., 2016; Cole, 2020), centering of academic voices can directly lead to the perpetuation of White supremacist ideologies and systems in well-meaning community engagement. These ideologies are found across the entirety of education, from K-12 to higher-ed. In today's political climate more than ever, community engagement and EDI initiatives are being openly challenged by many conservative organizations (Yancy, 2018; Liu et al., 2021; López et al., 2021). Those intended to benefit from these efforts are excluded, marginalized, and silenced. Even with recent pushes towards more inclusive education models, structural inequities are resoundingly clear.

Historically, many institutional attempts to address root causes of structural and systemic inequities have been well-crafted statements without concrete action (Gilliam et al., 2021). Recently, there has been fervent resistance to such performative allyship (Coley and Holly, 2021). We must transition from overgeneralizing and diluting issues to identifying specific problems and recognizing the impact that we as academics have in addressing complex problems throughout our society. When speaking on community engagement work in the Science, Technology, Engineering, Agriculture, and Mathematics (STEAM) fields, there is a tendency to believe that "harder" sciences, including neuroscience, operate outside of the need for community voices and ways of knowing, and that this academic, "professional" centering is the only way to assure accuracy (Gilliam et al., 2021). If academics continue to be the only ones funded to pursue research questions, the results are often missed opportunities for communities, leading to disengagement and disenfranchisement (Gilliam et al., 2021).

Immediate changes are needed to shift the institutional climate to open dialogues, continuous education, and feedback at every level. With these issues in mind, the University of Minnesota (UMN) launched the Masonic Institute for the Developing Brain (MIDB) in 2021 to showcase how social change drives institutional reform. MIDB is a community-centered institution with an interdisciplinary clinical and community research enterprise that invests time to recognize and amplify the voices of community members and leaders in the design and implementation of our facilities, research questions, and clinical care. We aim to co-create knowledge that is accessible and trusted, and promotes healthy brain development and wellness. The unique collaborative MIDB approach is founded by its strategic research service hubs. These service hubs are actively engaged across departments to accelerate discovery, facilitate integration, and identify opportunities for community services and public policy by listening more than speaking, taking risks, and disrupting and rebuilding. The UMN is 171 years old, and has >50,000 students and >20,000 staff across 19 colleges. Building a collaborative "Community-first" culture within MIDB as part of this historic institutional backdrop is difficult and will be a long road. Here we describe our approach toward investment and building an inclusive environment to accelerate our impact on our community.

Our approach to establishing community engagement

We believe that de-centering the dominant voice of academia involves recognizing that knowledge is located in many places, and that diverse ways of knowing will lead to better outcomes for research, clinical care, education, policies, and overall community wellbeing. With these guiding principles, the MIDB Community Engagement and Education (CEEd) Core was formed to create a culture of interactive community engagement, build strong reciprocal community connections, and collaboratively create infrastructure to foster bidirectional benefits.

The listening model to co-create programming and infrastructure

The CEEd Core works alongside the community and elevates their voices. Rather than offering a menu of services asking the community to select from a predetermined list of programs, we formed programming based on the community's expressed needs *via* direct and continuous engagement. To successfully co-create programming and infrastructure, the CEEd Core heavily utilized and adapted the principles of Heffner and Zandee's work to create our listening model—a practice that initiates relationships with the community by first being present, listening, and acknowledging community voices without mention of any academia-originated programming (Heffner et al., 2003). For the first year of the CEEd Core's inception, the Director, Dr. Anita Randolph, met with over 300 community organizations, attended dozens of community events, and volunteered throughout the community. Dr. Randolph networked with numerous diverse community groups, primarily grassroots organizations that dealt with equity and social justice work, but also larger nonprofits that worked in public health, brain development, and policy fields. There was a purposeful effort to talk to as many people on the ground as possible, not solely targeting upper leadership, to get a grasp for pressing issues in the community. This included individuals not representing a formal organization. By being a trusted community supporter first, and a faculty member second, Dr. Randolph was able to learn the community's priorities, successes, concerns, needs, stakeholders, and what community members know as effective approaches for change. Only after multiple events and recognition in the community as a familiar face did Dr. Randolph introduce the CEEd Core and its goals, request feedback on existing programs, and propose a collaboration to form new community programming. It is important to stress that the introduction of the CEEd Core came after a request from community leaders. This approach to relationship building has been imperative in fostering reciprocal communication with the communities surrounding MIDB and establishing confidence that the CEEd Core values community feedback. Listening in this way has uncovered community needs in specific focus areas: mental health, addiction, programming to expose youth to STEAM careers, food sustainability, the impact of nutrition on neurodevelopment, and programming to demystify healthy brain development.

Community building relies on trusting the knowledge that people hold about their community. For example, during the design process of the MIDB building, community members and leaders were heavily involved, providing feedback on color themes throughout the building, wall textures, room signage, languages, accessibility features, and artwork. During our focus groups, Indigenous community members relayed that owls create an uncomfortable environment, which led to their removal from the artwork in the clinic. Additionally, focus groups including people with intellectual and developmental disabilities and their families resulted in the addition of several building features such as sit-to-stand adjustable tables in the conference and meeting rooms, adult changing tables in the restrooms, and adjustable lighting in common meeting spaces.

In addition to establishing infrastructure to create a more accessible, inclusive clinical environment, mistrust of research resonated throughout every conversation with the community. Although research is a fundamental step toward reducing disparities, it is often conducted "on" communities rather than "with" communities. In many cases, this has led to general distrust and, worse, total disengagement from research and clinical trial opportunities. Based on community feedback, it became evident that much of their mistrust towards research at the University stemmed from the lack of formal community-engaged research training of the UMN scientific community. From interviews with scientists in the neurosciences and brain-focused fields conducting community-engaged research and clinical trials, it was clear that researchers are often ill-prepared to be on the ground with community members and are unclear of basic community-engaged principles (e.g., appropriate use of community-engaged research methods, ethical practices, bidirectional community-institution benefits, etc.). This has resulted in burned bridges between the University and its community partners, because scientists often used top-down practices common in academic settings, did not share decision-making appropriately with the community, and failed to acknowledge the community's knowledge and expertise. The lack of methodological training in community-engaged research has caused harm within the community, misappropriation of community members' time, trauma, extraction of their knowledge, and generational mistrust of University researchers in general, limiting outcomes for both the scientific community and the greater community as a whole.

This problematic dynamic has been further complicated by recent National Institutes of Health guidelines requiring the creation of novel community-engagement cores that serve a given grant. What this means is that institutions are under newfound pressure to begin research efforts that involve the community's active participation. This has created another issue, as these historically underfunded engagement programs do not have the resources, capacity, or infrastructure in place to handle this new push to support basic research scientists. The CEEd Core has tackled this complex issue with a multipronged approach. First, the CEEd Core has prioritized time, funding, and effort into producing training modules for students, staff, faculty, and community researchers to gain knowledge in community-engaged research methods, equitable and sustainable partnerships, evaluation, dissemination, and best practices of ethical exits to minimize harm to communities after the completion of the project. Our community-engaged research training modules are community-informed, utilizing both external experts and community leaders as co-facilitators and co-owners of the materials. The infrastructure of the community-engaged training modules was built to allow ongoing, yearly training that is both reactive (i.e., the immediacy of a need dictates the order of the module development) and community-informed (i.e., the modules are built to be used by an assortment of stakeholders). The goals of these modules are to produce a new generation of community-informed researchers who will utilize the concepts of community-engaged research, minimize harm when working with the community, and produce community-engaged scholarly products aligned with their basic science research.

Additionally, the CEEd Core has adopted the practice of centering research priorities identified by the community rather than only topics selected by research teams at the University, training teams on how to share research findings with the community in real time, and collaborate with the greater MIDB system to create solutions to decrease the years it takes for research findings to be integrated into clinical practice to ensure tangible change in the community.

The CEEd Core also founded the development of the Neuroscience Opportunities for Discovery and Equity (NODE), a centralized arena for the development of neuroscience-focused engagement programs across 10 separate departments at UMN. NODE's collaborative nature prevents silos between engagement-focused groups across the University to reduce duplicated efforts, cost, and staffing barriers.

Neuroscience opportunities for diversity and equity (NODE)

In our experience, the effectiveness of community engagement is difficult to quantify; trust is observed in subtle changes in community interactions. For example, establishment of trust may be represented by unsolicited invitations to community events in informal safe spaces that include youth and elders who are typically shielded from formal discussions. A community member's receptiveness to services and perspective may be represented by spontaneous communication *via* text/phone to request information or to share an experience or just to be heard. A community's willingness for collaboration has been signaled by direct communication with community leaders in sacred places not intended for outsiders. Waiting patiently for permission to engage with the community takes time, which is not valued or easily translated into community-engaged scholarly products.

With this in mind, Dr. Randolph interfaced with multiple departments and programs at UMN to learn the many challenges of community-engaged research within the University system, identified silos to dismantle to enhance our work, and gauged receptiveness to developing community-engaged research infrastructure. With a vision of increasing capacity through collaboration, a group called the Neuroscience Opportunities for Discovery and Equity (NODE) was formed to form a pool of shared resources to enhance engagement with the community across 10 different departments.

Through bimonthly meetings, NODE members have been able to request help in a variety of ways. While some departments have a lot of funding and no staff, they are now able to ask for help from others' research assistants, student workers, and volunteer networks from those who have adequate staffing or gaps in their engagement calendars. This imitable model can help departments overcome challenges associated with limited time, funding, and staffing to reduce burn-out, and ensure tangible solutions that improve people's lives in the community while inspiring the next generation of underrepresented learners to become scientists.

In its first year, NODE members worked together to fund comprehensive validated surveys and personalized evaluation services for many of the engagement projects across these departments. Members have been able to utilize the evaluation services in order to apply for private donors and NIH grants to secure a future for their group. With that essential piece covered, translating community engagement into scholarly work is now a much more affordable and easier task. NODE was also able to secure thousands of dollars worth of engagement supplies, ranging from multiple brain and spinal cord models, plastinated human brains, a 3D printer, and various engagement games and interactive activities. NODE works with a goal of collaborating on engagement events and grant applications. By combining different departmental missions and engagement work into cohesive, fundable projects, this small shift has opened up the possibility of well-funded, researched collaborative efforts focused on community engagement.

Leveraging the "community first" engagement infrastructure to diversify the STEAM workforce

As noted above, one outcome of the established CEEd Core engagement models was learning about the community's desire for programming to expose youth to STEAM research and careers. To diversify STEAM, we must embrace "variability"—our diversity—and provide access to this pursuit to all of the talents that exist in our society. Ironically, in the sciences, our ability to proportionally value the importance of this principle has been limited. Although neuroscience is considered one of the fastest growing disciplines, the lack of URMs and/or disabled scientists has led to a lack of diversity in research studies, inadequate representation in higher academic positions, limited scholarly perspectives, and the perpetuation of inequities in the science fields (Bertolero et al., 2020; Jones-London, 2020).

Recruiting, training and retaining a diverse pool of highly skilled individuals in neuroscience is imperative for maximizing our investments and potential in research and education. In the US, despite many national efforts, URMs and/or those with disabilities continue to be underrepresented as neuroscience undergraduates, trainees, faculty, and in the overall research workforce. According to the Society for Neuroscience, 23% of students enrolling in neuroscience Ph.D. programs and 14% of Ph.D. awardees in 2016/2017 were students from underrepresented backgrounds and 15% of postdoctoral trainees and 8% of program faculty identified with underrepresented backgrounds (Society for Neuroscience, 2017). Given that the 2020 US Census reported that 42.1% of the US population identifies as coming from an underrepresented backgrounds (Berry-James et al., 2020), these statistics indicate that there is an unmet need for innovative programs that foster recruitment and retention of URMs and/or disabled students in the neuroscience workforce, in order to better reflect the broader population that neuroscience research seeks to benefit.

Advances in health care, education, technology, and other enhancements to our society that deeply touch our everyday lives will not come with a homogeneity of ideas, education, experience, and culture. The CEEd Core's in-depth interviews with community members confirm communities of color are distrustful of academic and health-centered institutions and their engagement practices. Not only does such disengagement prevent underrepresented youth from pursuing STEAM degrees and gaining economic earning power to contribute back to their community, but the lack of representation in healthcare and technology fields exacerbates URM communities' distrust of healthcare professionals. This is a significant issue in Minnesota as the URM population grows without a concomitant increase in the state's workforce (Flaherty, 2021; Khalid and Snyder, 2021). Consequently, the participation of URMs in STEAM is critical to address the growing health, education, and human service needs of our increasingly diverse population. To help close this gap, it is imperative to begin engaging with URM students in K-12, undergraduate, and graduate school, as well as their families, to increase STEAM participation and develop the next generation of URM scientists. In the **Supplementary Materials**, we describe four such programs including the Young Scientists (YS) Program, the Youth Engaged with Science (YES!) Program, NextGen Psych Scholars Program (NPSP), and the MN Leadership Education in Neurodevelopmental Disabilities (MN LEND) Program.

Discussion

The endemic issues of structural racism, ableism, sexism, and other inequities cannot be addressed by changes in policies and practices alone: change will require direct action and work in the trenches with our communities. To de-center the academic voice, we, the academic community, must move away from the authoritarian approach of creating, disseminating, and teaching knowledge. Although the efforts of MIDB are still in its early stages, the work continues to grow and shape itself through directly listening to community members, acting and reacting, and pursuing a mission of diversity and representation in programming, infrastructure, and staffing. Within MIDB and the work of the many partners listed in this article, options for potentially transformative research and practices are able to be explored to help address systemic concerns that continue to haunt institutions. Although beneficial, continuing to elevate diverse racial, ethnic, and linguistic communities, families, and youth through participation in STEAM fields will not clean or sterilize past atrocities. As we learn from our past to move forward, we must create solutions. Our various efforts are focused on increasing the presence of and support for a more diverse body of scholars and scholarship in science and other fields that continue to only have a sprinkling of diversity. Our efforts involve connecting with community members, families, schools, and scholars. These connections must be nurtured through relationships, trust, and the recognition of each other's humanity. Most importantly, nurturing and building trust takes time and must be supported by leadership to yield fruitful change. Only then can we walk in our truth of being with and for the community.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

AR is the first author and contributed heavily throughout this article. AHen contributed to writing and editing throughout. AM contributed to writing throughout the supplements of this publication. RS contributed to the writing and concept of this article. MD and MK contributed to writing throughout the supplements. JE contributed to writing throughout the introduction and conclusion, and editing. DF contributed to writing, editing, and conceptual support. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnint.2022.1060896/full#supplementary-material.

References

Berry-James, R. M., Gooden, S. T., and Johnson, R. G., III (2020). Civil Rights, social equity and census 2020. *Public Adm. Rev.* 80, 1100–1108. doi: 10.1111/puar.13285

Bertolero, M. A., Dworkin, J. D., David, S. U., Lloreda, C. L., Srivastava, P., Stiso, J., et al. (2020). Racial and ethnic imbalance in neuroscience reference lists and intersections with gender. *bioRxiv* [Preprint]. doi: 10.1101/2020.10.12.336230

Cole, E. R. (2020). Race at the top: historical insights on the college presidency and racial inequities. *Change Mag. Higher Learn.* 52, 17–21. doi: 10.1080/00091383.2020.1732754

Coley, B., and Holly, J. (2021). "Starting with the promises: moving from inspirational words to institutional action in addressing systemic racism," in *2021 IEEE Frontiers in Education Conference (FIE)*, 1–4. doi: 10.1109/FIE49875.2021.9637245

Flaherty, C. (2021). *The DEI Pathway to Promotion.* Inside Higher Ed. Available online at: https://www.insidehighered.com/news/2021/05/14/iupui-creates-path-promotion-and-tenure-based-dei-work.

Freund, K. M., Raj, A., Kaplan, S. E., Terrin, N., Breeze, J. L., Urech, T. H., et al. (2016). Inequities in academic compensation by gender: a follow-up to the national faculty survey cohort study. *Acad. Med.* 91, 1068–1073. doi: 10.1097/ACM.0000000000001250

Gilliam, C. A., Olszewski, A. E., McDade, J. E., Homer, P., Grow, H. M., McPhillips, H. A., et al. (2021). Grounded in justice: an equity framework for chief residents. *Acad. Med.* 96, 1638–1642. doi: 10.1097/ACM.0000000000004190

Heffner, G. G., Zandee, G. L., and Schwander, L. (2003). Listening to community voices: community-based research, a first step in partnership and outreach. *J. Higher Educ. Outreach Engagement* 8, 127–139. Available online at: https://openjournals.libs.uga.edu/jheoe/article/download/812/812.

Jones-London, M. (2020). NINDS strategies for enhancing the diversity of neuroscience researchers. *Neuron* 107, 212–214. doi: 10.1016/j.neuron.2020.06.033

Khalid, A., and Snyder, J. A. (2021). How to fix diversity and equity. *The Chronicle of Higher Education.* Available online at: https://www.chronicle.com/article/how-to-fix-diversity-and-equity.

Liu, H., Martinez Dy, A., Dar, S., and Brewis, D. (2021). Anti-racism in the age of white supremacy and backlash. *Equality Diversity Inclusion* 40, 105–113. doi: 10.1108/EDI-03-2021-339

López, M., Molnar, A., Johnson, R., Patterson, A., Ward, L., and Kumashiro, K. K. (2021). Understanding the attacks on critical race theory. *Natl. Educ. Policy* Available online at: https://files.eric.ed.gov/fulltext/ED616105.pdf.

Reingewertz, Y., and Lutmar, C. (2018). Academic in-group bias: an empirical examination of the link between author and journal affiliation. *J. Informetrics* 12, 74–86. doi: 10.1016/j.joi.2017.11.006

Society for Neuroscience (2017). Executive summary of report of neuroscience departments & programs survey. Academic year 2016-2017. Available online at: https://www.sfn.org/-/media/SfN/Documents/Survey-Reports/Final-SfN_2016-NDP-Survey-Executive-Summary.pdf.

Williams, C. (2019). Humility and community engagement: a stepwise approach to sustainability. *Acad. Med.* 94, 749–750. doi: 10.1097/ACM.0000000000002691

Yancy, G. (2018). *Backlash: What Happens When We Talk Honestly about Racism in America.* Lanham, MD: Rowman & Littlefield.

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Engaging the open science framework in quantifying and tracing scientists' research credits

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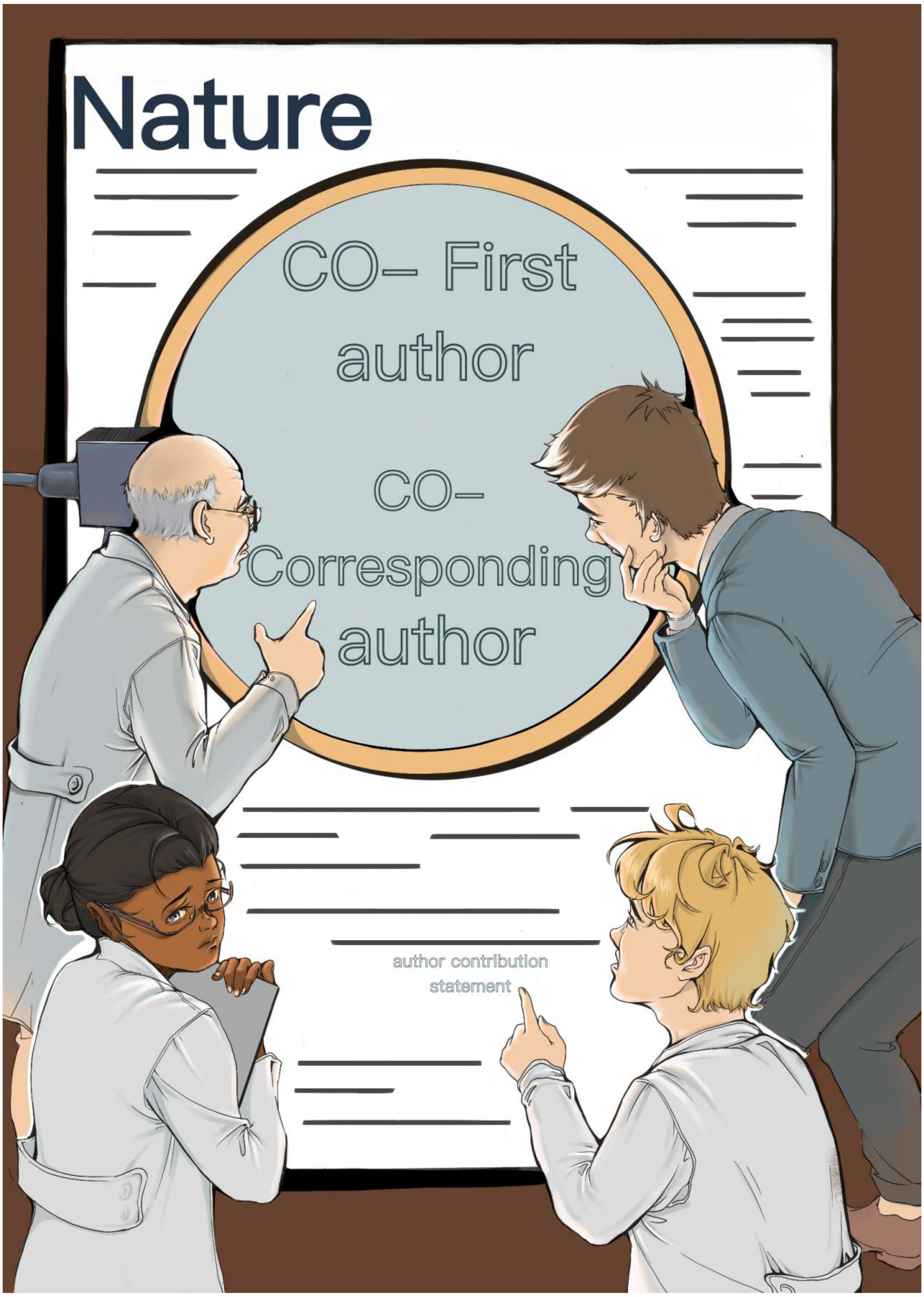
Introduction

Debates on how to determine positions in research authorship have not subsided. An institution funded by the United States National Institute of Environmental Health Sciences (NIEHS) provided reports for investigating authorship disputes from 6,700 researchers in the world. It found out that nearly half of the respondents had suffered from naming disagreement, and 38% of them believed that they had experienced unfair authorship ranking (Smith et al., 2020). What makes this trend worrisome is the fact that the matter of authorship unfolds sharp gender inequalities in the scientific community, where female authors are arranged with more co-first (rather than the first) authors relative to what is applicable to male authors (Fleming, 2021). Furthermore, the scrambling for privileged positions in authorship arrangements is increasingly forcing early career researchers to distance themselves from scientific works and big-science collaborations, especially neuroscientists (Yager, 2007; Coles et al., 2022). Under the current scientific incentive system, it is an intuition that the credits a study can deliver for an author can be likened to the commercial values of a building, with the front location (position) indicating a high price (credit).

Our efforts and challenges

It is no doubt that publishers have been aware of this circumstance and have made efforts to prioritize authors' credits above authorship arrangement. Scientific journals have long been firm and enthusiastic in asking authors to state and clarify what scientific roles they played in the actualization of a research study. The confirmation and clarification are usually made in a purpose-built section entitled, "Author Contribution Statement (ACS)" (Vasilevsky et al., 2021). Fortunately, this statement has been increasingly accepted by mainstream publishers such as *Nature Springer*, *Elsevier*, and *Cell Press* for fostering contributionship. However, the absence of standard measurement for this claim of scientific roles in the ACS makes it rather difficult to specifically evaluate and determine an author's deserved credits.

Furthermore, a machine-readable standardized statement called contributor roles taxonomy (CRediT) emerged to recognize scientific credits for authors based on the 15 categories, which have been broadly implemented thus far. That notwithstanding, another issue of concern in



GRAPHICAL ABSTRACT
Preface illustration. The "first-last-author-credit" hierarchy has long been dominated in the scientific incentive system despite intensive calling for contribution-based credits (author contribution statement). In the scientific communities, senior researchers would still make a decision to recommend one's promotion based on first and last positions in authorship rather than their contributions. Similarly, in the job market, institutions would acknowledge one's credit by positions in authorship in a study for faculty recruitment, while overlooking the author contribution statement at the end of studies. Thus, the current authorship system has brought on the risks underlying authorship disputes and race/gender inequalities in credit allocation heavily, especially for early career researchers and female scientists. In addition, this is one of the major barriers to extend teamwork and academic collaboration. On the contrary, scrambling for first and last positions leads to prominent credit inflation—that is to be observed—the number of co-first and co-corresponding authors has been increasing dramatically. Thus, we shall propose a new contributionship to acknowledge the author's credit for an open science and quantitative framework to tackle these issues. Credit: ZC and XRL.

the matter of ACS is the fact that CRediT is not available for all the fields of scholarship such as literature and library science. Recently, the contribution role ontology (CRO), a system, developed by the National Center for Data to Health (NCDH) recommended that CRediT be extended to include more statements (Ross-Hellauer, 2022). The inclusion should add 50 categories for covering almost all the fields of scholarly interest—the roles of community, coordination, and so on.

Despite the huge progress made so far, the scientific community still has challenges and difficulties accepting contributionship as a better alternative. In addition, institutions and job markets disapprove of faculty recruitment or promotion that is based on the ACS. One major reason for this aversion is the apparent stiff competition for faculty positions requiring institutions to make decisions rapidly and directly for the numerous researchers who are in their early career phase. This makes it less likely to deliberately evaluate authors' contributions claimed in studies one at a time. Moreover, another reason that could impede the spread of contributionship is the lack of quantifiable criteria for answering questions on how scientific credits that are based on authorship contributions could be evaluated. In addition, contributionship in the current tone is likely to expose an author's credit to a high risk of inflation, which may provide an "infinite credit resource" in evaluating one's contribution. The latter could make the scientific community fairly cautious in confronting such initiatives.

Open science and quantitative framework

Open Science Framework (OSF) typically advocates three principles in knowledge production, which are transparency, equity, and accountability (Madhur and Avci, 2022). In practice, OSF recommends authors to pre-register their research proposal in the accessible repository beforehand, so as to enable detailed, original sampling methods, analytic plans, and hypotheses.

The OSF is a powerful vehicle for facilitating and driving transparency through a deliberate reduction in the manipulation of model parameters and results. Meanwhile, equity and accountability, the values that the OSF pursues, emphasize the equal right of all the authors fully involved in scientific work. However, the authors are required to shoulder the same accountability for the weights they contribute to the work.

Using the percentage-of-contribution indicator (PCI) and author CRediT score (ACS), we have proposed the quantitative framework as an alternative for acknowledging authors' credits in authorship claims (Smith et al., 2018). Be that as it may, we reckon that two intrinsic pitfalls may occur in extending these quantitative systems. The first pitfall is the possibility of compounding impact factor (IF) in calculating authors' contributions. Authorship has, so far, been broadly certified to recognize and make sure the author who makes more scientific contributions to research gets due credit for the study. This may, however, not be adequate for acknowledging contributions or values that are judged by a journal's IF. Another flaw of the authorship system is the challenge of calculating the quantitative contributions of authors by absolute counts of categorical roles. In the process of estimating contribution—albeit it makes sense to consider the number of roles an author played in the CRediT category—it is usually unclear and difficult to determine the number of contributions that have been made for each role and how crucial each of the roles is for the study.

Open science and quantitative contributionship

We propose a new framework that integrates Open Science principles and quantitative rules for acknowledging scientists' credits in a study (see **Box 1**). More specifically, the framework recommends that authors pre-register and adopt the standardized authorship and contribution form (ACF) before the formal research procedure begins.[1] The ACF requires authors to self-estimate their contributions quantitatively ranging from 0 to 1.0 (contribution coefficient) by referring to either the CRediT or CRO statement. It also requires authors to provide details illustrating what parts would be handled in the corresponding categorical roles. Moreover, traceable modifications toward contributionship could be allowed on the ground of authors' consensus before pre-registering the ACF. In addition, the email addresses or any pathways accessible to each author should be given in the ACF. Once the work has been prepared for submission, the ACF should be designed to be in line with the pre-registration imperative in the online submission system. Any disparities compared with the pre-registration should be clearly stated in the ACS. Finally, the integrated ACF encompassing the authorship, contribution contexts/coefficients, and contacts would be generated automatically by the submission system and would be further printed at the head of the published study.

Discussion

Benefits and caveats

It is apparently rewarding to adopt the proposed authorship framework embracing the Open Science and quantitative contributionship systems. The framework could help drastically reduce authorship disputes by allocating credits to authors with the quantitative contribution method. The latter would be prominently beneficial for ensuring authoring equality in the increasing teamwork and academic collaboration system. The sequence determination authorship has been criticized for creating hurdles in academic collaborations as it assigns credits mostly by the first-and-last-author system (Hosseini, 2020). The more unfairly and unequally co-authors perceive they have been treated, the less motivation they have to concretize the teamwork they need. Thus, sharing credits with equal positions in this framework would be highly conducive to preventing scientific collaborations from suffering recurring authorship disputes.

Moreover, the tendencies for credit inflation may be controlled by quantitative contributionship. To tackle credit disputes in authorship, marking co-first and co-corresponding authors in one study is gradually becoming mainstream in the scientific community. Nevertheless, the trend appears to have been abused in the current

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[1] https://osf.io/3sjbc/

BOX 1 **Key steps for proposed contributionship framework.**

Step 1: Pre-registration

A standardized authorship and contribution form (ACF) requires the scientific communities to pre-register in repository or platform once research proposal is available:

-Authorship: *authors should be determined beforehand following the research proposal.*

-Contribution: *contributions should be described by contributor roles taxonomy (CRediT) or contribution role ontology (CRO) system in detail, including the illustration about which parts would be done in each category (e.g., drafting introduction at paragraph 1–3).*

-Contribution coefficients: *contribution coefficients should be provided grounded on actual contributions defined by CRediT or CRO system, but could be adjusted according to authors' consensus; the sum of coefficients for all the authors is equal to one; individual coefficient should be marked alongside with author's name.*

-Contacts: *authors should provide the accessible contact details alongside with contributions for the sake of facilitating correspondence and accountability.*

Step 2: Formal submission

Once the formal manuscript has been prepared, one author should be designated to submit it at online submission system:

-Online submission system: *author could upload the pre-registered ACF online submission system for automatic detection or fill ACF in system manually.*

-Author contribution statement (ACS) conflicts: *if any disparities emerged from the comparison to pre-registration, the reasons for modifying authors or contributions should be stated clearly in this section.*

Step 3: Publication and after publication

Once manuscript has been published at a journal, this ACF would be generated automatically to attach at the HEAD of final manuscript for acknowledging credits for each author:

-Publication: *ACF for final version should be attached at the first page of paper for detailing authorship/contributionship and history of modifying them; any disparities or modifications from pre-registration should be clearly claimed in ACF; individual coefficient should be marked alongside with author's name.*

-After publication: *contributions and corresponding credits could be evaluated by ACF with specific contexts and coefficients for authors in job markets; each author should be accountable for giving response for concerns and queries that readers raise aiming at his/her contributions in the paper as reported in ACF.*

form (Hornburg, 2018). We have reviewed studies published in Nature^{TM} within this decade (2010–2021) in order to scrutinize this trend. Nearly half of the studies therein marked the co-first authors or co-corresponding authors, especially in the domains of cell biology, genetics, medial research, and neuroscience (see **Figure 1**). Thus, claiming "equally contributed" for the co-first or co-last positions may be an artifice for credits. This quantitative framework is required to clearly and transparently state authors' contributions in authorship rather than some vague and unquantifiable mark, which facilitates the possible reduction of the guest-like co-first or co-corresponding authors. Furthermore, adding any additional co-authors would be at the expense of the decreasing average contribution coefficient, which propels the decision to mark co-authors prudently so as to limit credit inflation.

In addition, the transparency needed to determine authorship would be strengthened by the use of this framework. Pre-registration provides traceable and detectable access for observing the modification of authorship. It prevents honorary or guest authors from compromising the submission process. On the one hand, it seems to be a common configuration to add renowned researchers as honorary authors as a way of increasing the credits of the submitted articles and impressing the editors (Hornburg, 2018). On the other hand, the number of guest authors is sharply increasing in studies as an "interpersonal transaction" for extending the academic social network. Therefore, transparent reports on how authorship forms and the contributions of each author make this framework significant would be a promising way of cracking down on such naming misconducts.

It is worth highlighting that this framework makes accountability feasible for contributionship and, thus, maybe a blow to the widespread fake-paper factories and academic fraud systems. In Chinese Academy Science (CAS) institutions, the requisites for applying for tenured positions are at least eight studies that are published in high-profile journals (at least IF > 5.0) during a period of 3–6 years. The publications should have a varied outlook of independence and corresponding authorship. Even if doctors who are in their early career phase work in low-ranking institutions (e.g., level-2 local hospitals in China), their promotion will require at least three studies with authorship positions. Additional positions in

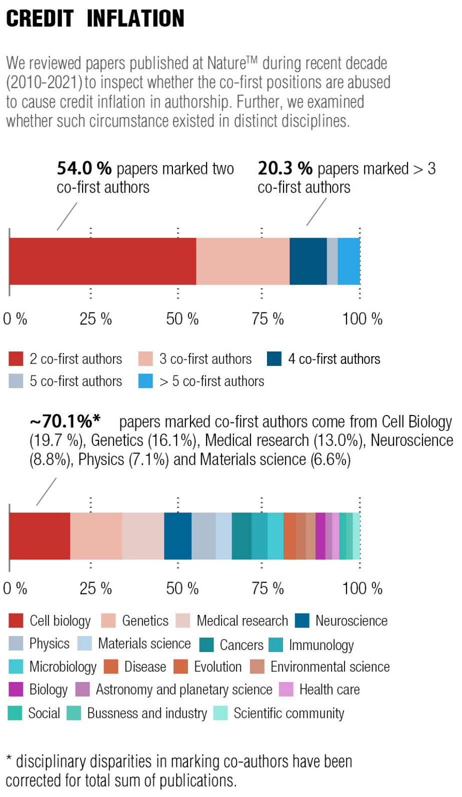

FIGURE 1
Credit inflation for co-first or co-corresponding positions in authorship. Data are acquired from Nature^{TM} (https://www.nature.com) by reviewing authorship for all the research articles published in Nature during the recent decade.

authorship hardly have any credits in the current scientific incentive system, at least in mainland China. Consequently, the serious career pressure often mounted on researchers to publish studies as either first or corresponding authors is one of the main reasons why young researchers indulge in academic fraud at the expense of an auspicious long-term career prospect. They settle for predatory journals or fake publishing firms.

The new framework provides transparent ways for authors to obtain credits they merit based on accountable and traceable contributions by quantitative metrics. A key advantage of this framework is that it discourages academic misconduct from authors. On the contrary, transparently reporting specific contributions of authors with contact information makes accountability feasible. It is also beneficial for investigative agencies that might want to examine specific authors who may have been reported for misconduct.

The caveats for implementing this contribution framework should be reiterated. Unexpected academic bullying may occur when the contribution coefficients are rated. Even if the extreme battles or disputes for authorship positions are significantly eased, it is hard to estimate the risk of what—bullying—junior researchers could suffer in the coefficient competition. There is less power for them to go against the senior researchers in allocating the coefficients. Another challenge is the high risk of abuse as stated in "Goodhart's Law" (Abualigah et al., 2021; Abualigah et al., 2022; Agushaka et al., 2022). Although each author receives credit fairly as expected, evaluating scientific credits for each of them may be abused when the coefficient is overly considered.

A framework beyond initiative

This is not a conceptual call for acknowledging each author's credits but aims to provide pragmatic ways to shift authorship from the "first-last-author-credit" hierarchy to a transparent, equal, and accountable contributionship. Compared to previous ones, this contributionship presents a quite mild and balanced scheme, neither in abolishing the "sequence-authorship-credit" hierarchy nor in overreaching absolutely objective index (Smith et al., 2018), which promises the acceleration to popularize this credit system.

Technically speaking, however, few hurdles would meet the implementation of this contributionship in the current technological framework. By mainstreaming the online submission system and ORCID with standardized machine-readable CRediT or CRO statements, all the processes that the contributionship requires could be easily supported. We have prepared a fictitious submission system for simulating how to submit an article by this contributionship.[2] Finally, attaching the ACF generated from an automatic system at the head of academic papers would make it less possible for a snub by institutions (Fleming, 2021). A snub could potentially increase the recognition of authors' credits more practically than their contribution statements.

Author's note

Contributionship has been pre-registered in Open Science Framework (OSF) at https://osf.io/3sjbc/ (10.17605/OSF.IO/3SJBC).

Author contributions

ZC: conceptualization, data curation, formal analysis, funding acquisition, methodology, and writing—original draft. XRL: conceptualization and validation. KM, XYL, and XZ: methodology and validation. ZF: funding acquisition. HC-P: conceptualization and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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[2] http://neurospider.cn/stimulatingsystem.html

References

Abualigah, L., Diabat, A., Sumari, P., and Gandomi, A. H. (2021). Applications, deployments, and Integration of Internet of Drones (IoD): A Review. *IEEE Sens. J.* 21, 25532–25546.

Abualigah, L., Elaziz, M. A., Sumari, P., Geem, Z., and Gandomi, A. (2022). Reptile Search Algorithm (RSA): A nature-inspired meta-heuristic optimizer. *Expert Syst. Appl.* 191:116158.

Agushaka, J., Ezugwu, A., and Abualigah, L. (2022). Dwarf mongoose optimization algorithm. *Comput. Methods Appl. Mech. Eng.* 391:114570.

Coles, N., Hamlin, J., Sullivan, L., Parker, T., and Altschul, D. (2022). Build up big-team science. *Nature* 601, 505–507. doi: 10.1038/d41586-022-00150-2

Fleming, N. (2021). The authorship rows that sour scientific collaborations. *Nature* 594, 459–462. doi: 10.1038/d41586-021-01574-y

Hornburg, D. (2018). Authorship position should not serve as a proxy metric. *Nature* 554, 423–424.

Hosseini, M. (2020). Equal co-authorship practices: Review and recommendations. *Sci. Eng. Ethics* 26, 1133–1148.

Madhur, M., and Avci, P. (2022). Author CRediT score (ACS): An order-independent measure of author contribution based on CRediT statement. *[Preprint]*. doi: 10.13140/RG.2.2.28310.68161

Ross-Hellauer, T. (2022). Open science, done wrong, will compound inequities. *Nature* 603, 363–363. doi: 10.1038/d41586-022-00724-0

Smith, E., Williams-Jones, B., Master, Z., Larivière, V., Sugimoto, C., Paul-Hus, A., et al. (2020). Misconduct and misbehavior related to authorship disagreements in collaborative science. *Sci. Eng. Ethics* 26, 1967–1993. doi: 10.1007/s11948-019-00112-4

Smith, G., Koehler, M., Girgis, H., Yan, D., Chen, Y., Chen, Y., et al. (2018). Optimized arylomycins are a new class of Gram-negative antibiotics. *Nature* 561, 189–194. doi: 10.1038/s41586-018-0483-6

Vasilevsky, N., Hosseini, M., Teplitzky, S., Ilik, V., Mohammadi, E., Schneider, J., et al. (2021). Is authorship sufficient for today's collaborative research? A call for contributor roles. *Account Res.* 28, 23–43. doi: 10.1080/08989621.2020.1779591

Yager, K. (2007). Each co-author should sign to reduce risk of fraud. *Nature* 450:610. doi: 10.1038/450610a

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A developmental approach to diversifying neuroscience through effective mentorship practices: perspectives on cross-identity mentorship and a critical call to action

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Many early-career neuroscientists with diverse identities may not have mentors who are more advanced in the neuroscience pipeline and have a congruent identity due to historic biases, laws, and policies impacting access to education. Cross-identity mentoring relationships pose challenges and power imbalances that impact the retention of diverse early career neuroscientists, but also hold the potential for a mutually enriching and collaborative relationship that fosters the mentee's success. Additionally, the barriers faced by diverse mentees and their

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Abbreviations: BRAINS, Broadening the Representation of Academic Investigators in NeuroScience; CNS, Community of Neuroscientists; GPA, Grade point average; GRE, Graduate Record Exam; NIH, National Institute of Health; NINDS, National Institute of Neurological Disorders and Stroke; PhD, Doctor of Philosophy; STEM, Science, technology, engineering, mathematics; URM, Underrepresented minority; US, United States.

mentorship needs may evolve with career progression and require developmental considerations. This article provides perspectives on factors that impact cross-identity mentorship from individuals participating in Diversifying the Community of Neuroscience (CNS)—a longitudinal, National Institute of Neurological Disorders and Stroke (NINDS) R25 neuroscience mentorship program developed to increase diversity in the neurosciences. Participants in Diversifying CNS were comprised of 14 graduate students, postdoctoral fellows, and early career faculty who completed an online qualitative survey on cross-identity mentorship practices that impact their experience in neuroscience fields. Qualitative survey data were analyzed using inductive thematic analysis and resulted in four themes across career levels: (1) approach to mentorship and interpersonal dynamics, (2) allyship and management of power imbalance, (3) academic sponsorship, and (4) institutional barriers impacting navigation of academia. These themes, along with identified mentorship needs by developmental stage, provide insights mentors can use to better support the success of their mentees with diverse intersectional identities. As highlighted in our discussion, a mentor's awareness of systemic barriers along with active allyship are foundational for their role.

KEYWORDS

perspective, mentorship and early career scientist challenges, neuroscience, diversity in science, cross identities, academic pipeline, qualitative survey

Introduction

The lack of diverse representation in neuroscience remains a significant problem reflecting the systemic inequities of the United States (U.S.) educational system and structural oppression that is deeply entrenched into the fabric of the country. Current data from the National Center for Education Statistics between the years of 1995–2015 show that non-Latinx, white neuroscience graduates represent the largest percentage of graduates across bachelor's (52.6–66.3%), Master's (52.6–60.8%), and doctoral (53.2%-66.5%) degree granting neuroscience programs (Ramos et al., 2017). While the number of neuroscientists entering the field is growing, the proportion of those from underrepresented backgrounds remains markedly lower than the U.S. census representation.

Historically, research efforts to characterize the demography of the academic landscape have focused on very narrow aspects of diversity (e.g., race, *or* gender, *or* disability). However, there is growing acknowledgment of the expansiveness of identity and its intersections. These intersecting identities shape access to power/privilege and, resultantly, one's experience navigating the world, including academia (Crenshaw, 1989; Cole, 2009). Transgender and nonbinary/gender expansive people, undocumented immigrants, people living with a disability, and religious minorities have been systematically excluded in the neurosciences, and initiatives to improve their representation in academic spaces are lacking (Corrington et al., 2020). The inclusion of diverse voices in the neurosciences is part of the necessary shift towards a more equitable society and directly contends with the discrimination and oppressive hegemony entrenched within the institution of education (Zhao, 2016; Bartz and Kritsonis, 2019). Additionally, diverse perspectives are the catalyst for innovation in the sciences (Graham et al., 2020; Daehn and Croxson, 2021) and contribute to more dynamic problem solving (Friedman et al., 2016).

Diverse identities should be reflected within all levels of the neuroscience pipeline, but representation appears poorest at higher ranking positions—that is, the further you advance along the academic pipeline, the "leakier" it becomes (Shaw et al., 2021). The attrition, or leaks, of diverse neuroscience talent tends to occur at critical transition junctures involving academic advancement (Shaw et al., 2021). A number of factors—likely interacting with one another—impact retention of diverse talent and contribute to leaks. While a comprehensive overview of factors contributing to attrition is beyond the scope of this article, we offer a few examples across different stages of training and career.

Among first-generation college students, some face unique challenges including disparities in access to resources and financial precarity impacting their ability to complete a degree. First generation and low income students are less likely to complete an application for financial aid (Bahr et al., 2018) and there is evidence that financial aid offer letters use inconsistent terminology and conflate different aid options (Burd et al., 2018), creating barriers to appropriate decision making to fund college education. Current data also show bias in graduate school admission processes including the discriminatory use of the standardized testing like the Graduate Record Exam (GRE) or other quantitative measures (e.g., GPA) as a predictor of academic success despite the GRE having low predictive validity (Moneta-Koehler et al., 2017). The GRE is a poor indicator of future research productivity (Woo et al., 2022) or graduate degree completion (Petersen et al., 2018) as it instead measures test taking ability and exam familiarity (Kruse, 2016). The continued use of the GRE by admissions committees contributes to pipeline leakiness as its incorrect use as an indicator of aptitude most often unfairly excludes women, racially and ethnically minoritized persons, and those from socioeconomic disadvantaged backgrounds from admission into graduate school programs (Miller and Stassun, 2014).

For historically excluded and marginalized graduate students, socialization to academia (i.e., the process whereby institutional values, skill sets and ways of engagement are learned and reinforced) can be in direct conflict with existing belief systems and often upholds dominant cultural norms (Weidman et al., 2001; Azizova, 2016), impacting feelings of belongingness and inclusivity both of which are predictors of retention and success in STEM PhD programs (Fisher et al., 2019). For women and birthing people, a critical transitional period along the academic pipeline postdoctoral phase where roles and responsibilities as a parent and scientist may collide with very little leeway and support. In fact, the decision of whether to start a family and when is a major predictor of attrition among postdoctoral fellows (Resmini, 2016; Ledford, 2017; Ysseldyk et al., 2019).

At the faculty level, funding rates are significantly lower for racially and ethnically minoritized groups and data show the Black scientists are less likely than their peers to receive an R01 grant from the NIH (National Institute of Health), reflective of a substantial funding gap impacting productivity and career progression on the tenure track (Ginther et al., 2011; Wilson et al., 2018). One study reported that applications from Black scientists were less likely to be discussed and received lower impact scores (Hoppe et al., 2019). In the study, greater than 20% of the funding gap was attributable to differences in choice of research topics by Black scientists compared to white counterparts. Topics more commonly identified as relevant to Black scientists, such as community-engaged research and population health, were awarded at lower rates, demonstrating bias and discrimination in funding priority as well as epistemic exclusion devaluing and delegitimizing the important work of racially minoritized scholars (Settles et al., 2021). The unfortunate truth of these data is that the Ivory Tower remains unattainable, unwelcoming, or housed with a glass ceiling that limits the upward mobility of many diverse neuroscientists [e.g., see Black in the Ivory (Davis, 2021) for overview].

While diversity is slowly increasing at the student level, those who hold high ranking faculty positions do not reflect the same diverse demographic and social identities. Often, cisgender, heterosexual, white men occupy senior neuroscience positions and serve as gatekeepers to academic advancement thereby limiting upward mobility. Not only does a power differential exist within the mentorship relationship based on career status, but the mentor's status within society's social hierarchy can influence the mentorship dynamic (Ragins, 1997; Thorne et al., 2021). As diverse neuroscience mentees ascend the academic ranks, it is likely that they will encounter incongruence between their identity and the social-demographic characteristics of a mentor. Admittedly, a number of thriving cross-identity mentoring relationships exist. In some instances, however, it may affect the mentor's ability to effectively respond to the systemic oppression, discrimination, and other challenges uniquely faced by the mentee.

Lack of effective mentorship has been regularly cited as a barrier to successful advancement in neuroscience (Singleton et al., 2021), and academia more broadly (Davis et al., 2021; Ocobock et al., 2021). Thus, it is incumbent on mentors to maintain awareness of approaches that are less helpful in mentorship dyads where identity incongruence is a factor, and to apply strategies and mentorship styles that facilitate retention and progression within neuroscience. For instance, in a study examining cross-racial mentoring of racially and ethnically minoritized faculty, the mentor's awareness of the mentee's cultural experience, the mentor's open-mindedness, and trust and comfort in the relationship shaped how race affected the relationship (Thorne et al., 2021). To date, there is limited research on mentorship practices that support diverse neuroscientists across training and career level. Identifying strategies that promote mentee retention and academic enrichment *across developmental stages* of education and career is central to building supportive, customized experiences unique to the mentee's needs at each transition juncture. Accordingly, our manuscript seeks to expand extant work by applying a developmental framework to examining cross-identity mentorship factors that: (1) hinder, (2) support, and (3) retain diverse neuroscientists in academia across varied developmental stages of training and career.

Methods

All study procedures were approved by the University of Minnesota Institutional Review Board and all participants provided written informed consent. Participants completed the survey on a voluntary basis and were offered co-authorship for their contribution.

Participants

Study participants are members of the first cohort of Diversifying the Community of Neuroscientists (Diversifying CNS) program (Diversifying the Community of Neuroscientists, 2022)—a National Institute of Neurological Disorders and Stroke (NINDS) R25 funded initiative. Demographic data are presented in **Table 1**. Out of the 19 program participants, 14 (73%) responded to the survey online. Of this subgroup, the majority of respondents were graduate students (8/14; 57%), followed by early career faculty (4/14; 29%), and postdoctoral fellows (2/14; 14%). All respondents were affiliated with an academic medical institution or university and identified as first-generation graduate students.

Survey procedure

The online survey was designed by coauthors (TH-J, RN) who participate in the Diversifying CNS Program. Survey questions were developed based on review of literature on mentorship and diversity in academia and the workforce. Based on the literature, TH-J and RJ first identified themes and concepts that were important to capture with the survey questions. Next, a list of potential questions were generated and piloted with a person outside of the Diversifying CNS program to ensure readability and adequate functionality of the online survey platform. The final survey consisted of 27 open-ended questions and 17 quantitative questions distributed for online completion using Qualtrics. Participants were asked to respond about their experiences at their current stage of training or career. Examples of open-ended questions included:

> What are your specific mentorship needs at this stage of your career?
>
> Have there been any barriers in identifying a mentor who shares some aspect of your social or demographic identity?
>
> What are the benefits to having a mentor whose identity differs from yours?

TABLE 1 Demographic characteristics of Diversifying CNS survey respondents (N = 14).

	n	%
Race		
White	3	21.4%
Black	6	42.9%
Asian	1	7.1%
American Indian or Alaska Native	1	7.1%
Multiracial	3	21.4%
Ethnicity		
Hispanic/Latino	4	28.6%
Gender identity		
Cisgender female	10	71.4%
Cisgender male	4	28.6%
Sexual orientation		
Heterosexual	9	64.3%
Bisexual	2	14.3%
Queer	1	7.1%
Panromantic, gray asexual	1	7.1%
No response	1	7.1%
Place of birth		
United States	10	71.4%
Latin America	2	14.3%
Jamaica	1	7.1%
Germany	1	7.1%
Professional background		
Molecular/cellular neuroscience	10	71.4%
Behavioral neuroscience	2	14.3%
Neuropsychology	2	14.3%
First generation American	3	21.4%
Person with a disability	3	21.4%
From economically disadvantaged background	7	50.0%
Primary language		
English	12	85.7%
Spanish	2	14.3%

Additionally, participants provided written examples of both a good and bad mentorship experience, barriers within the relationship, and suggestions for improvement. Lastly, respondents were provided with a menu of options of mentorship features they may seek (e.g., role model for work/life balance, sponsorship, one-on-one time, source of support) and ranked the list in order of importance.

Analysis

Narrative responses from the online survey were uploaded and organized in ATLAS.ti (Mac Version 22.1.0; ATLAS.ti, 2022). Responses were analyzed using an inductive thematic analysis (Braun and Clarke, 2006). This method is inductive, or data-driven, in nature and produces codes that directly reflect the data and are free of pre-existing theory. We were interested in understanding the lived experiences and meaning making of the group within a broader social and societal context and therefore prioritized the meanings derived from respondents' words. TH-J and RN separately read and completed open coding of responses. Codes were independently assigned by the level of meaning—that is, text segmentation was completed by meaning conveyed and not line, sentence, or paragraph—so long as the essence of the idea was preserved (DeCuir-Gunby et al., 2011). Coders met to discuss their codes and generate a code book with formal code definitions and coding criteria. They reviewed the text and reassigned codes according to these criteria. Text was allowed to have more than one code assigned. TH-J and RN then identified codes that had conceptual similarity; these were grouped into a theme with subordinate subthemes.

Quantitative and descriptive data were analyzed using IBM SPSS 28.0 (IBM Corp, 2021). Between-group comparisons of continuous data were made across education/career level using ANOVAs. Statistical significance was set at $p < 0.05$. All survey respondents were provided with a draft of the manuscript, and revised according to their suggestions, to ensure their words were accurately reflected and anonymity was upheld.

Results

Quantitative

Respondents were in their current academic role for approximately 3 (M = 3.08, SD = 1.21) years, and the amount of time did not differ by career level, $F_{(2,11)} = 2.27$, $p = 0.150$. Early career faculty reported having significantly less frequent beneficial mentoring relationships in their current academic stage (44.5% of relationships are beneficial) compared to postdoctoral fellows (90.0%) and graduate students (80.0%), $F_{(2,11)} = 9.22$, $p = 0.004$.

Qualitative

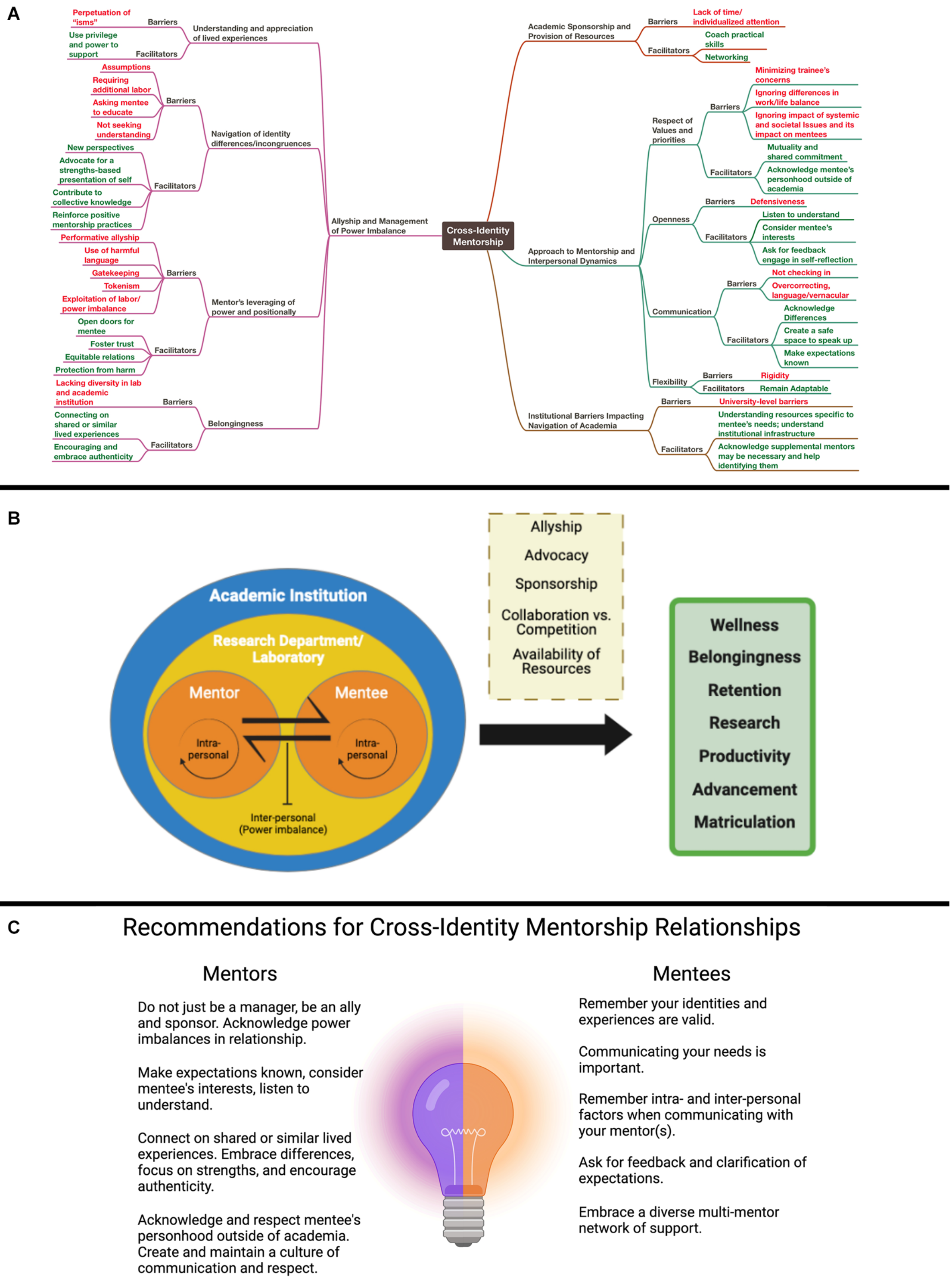
Factors impacting experience in neuroscience

Analysis of the narrative responses across the entire group revealed four themes that impact a mentee's experience in neuroscience regardless of developmental stage: (1) approach to mentorship and interpersonal dynamics, (2) allyship and management of power imbalance, (3) academic sponsorship, and (4) institutional barriers impacting navigation of academia. The **Supplementary Table** summarizes themes and subthemes, and offers illustrative quotes of barriers and supportive practices. **Figure 1A** provides a thematic map of the qualitative results.

Theme 1: approach to mentorship and interpersonal dynamics

For a majority of respondents, the mentor's approach to engaging was important and impacted their perception of the relationship.

Respect of values and priorities: Respondents emphasized the desire for mutual commitment and investment in the mentoring relationship, establishment of boundaries early on, and recognition of personhood outside of their role as an academic. Those from historically excluded and minoritized



Recommendations for Cross-Identity Mentorship Relationships

Mentors

Do not just be a manager, be an ally and sponsor. Acknowledge power imbalances in relationship.

Make expectations known, consider mentee's interests, listen to understand.

Connect on shared or similar lived experiences. Embrace differences, focus on strengths, and encourage authenticity.

Acknowledge and respect mentee's personhood outside of academia. Create and maintain a culture of communication and respect.

Mentees

Remember your identities and experiences are valid.

Communicating your needs is important.

Remember intra- and inter-personal factors when communicating with your mentor(s).

Ask for feedback and clarification of expectations.

Embrace a diverse multi-mentor network of support.

FIGURE 1
Factors related to cross-identity mentorship in the neurosciences. **(A)** A thematic map of barriers and facilitators in cross-identity mentor-mentee relationships. A full description with participant quotes is included in the Supplementary Table. **(B)** Factors impacting cross-identity mentor-mentee relationships depend on a number of layered structural, local, intra- and interpersonal factors, but are all important for the wellbeing, productivity, and success of mentees. **(C)** Recommendations for mentors and mentees that emerged from the early career neuroscientist survey.

backgrounds shared the importance of a mentor acknowledging the systemic and societal issues that not only impacts the mentee, but the family members with whom mentees may have close connections or responsibilities of caring for. For example, one respondent shared:

> . . .I have family members suffering at the hands of systemic racism (drug/alcohol/gambling addictions, suicide ideation, homelessness, extreme poverty, early death from health disparities etc). And this sadly can be the norm in minoritized communities

> due to colonialism and systemic racism. I recognize some people in my lab won't be able to understand, and I feel like I have only been able to connect with other [minoritized] students who may be in similar situations/understand this disparity in the USA. So the drawback is having to be able to do science and keep up while I know my community faces larger issues (sometimes science seems small to me).

Openness: Respondents noted the importance of a mentor listening to learn, asking about the mentee's interests/needs, soliciting feedback, and maintaining an open, curious outlook. This fosters a process of lifelong learning, critical reflection, and constant adjustment as stated by one participant:

> [The relationship] can be enhanced by staying committed to the process, asking for feedback from mentees, and continuing to learn throughout the entire process. No one expects a mentor to be perfect, and mentors from different backgrounds can have a positive impact on mentees, however, it just takes time. It involves speaking up on the inequities in academia and not avoiding the topic as if it doesn't affect the mentee. And it involves a lot of listening, learning, and reflecting.

Communication: Acknowledgment of differences that may create gaps in communication or understanding was preferred by respondents. These gaps may be more present for mentorship relationships where identity incongruence is a factor. The expectation that the mentee adapt their vernacular to match that of a mentor's dominant culture or to meet standards of "acceptability" was described as harmful. Respondents also shared the importance of discussing expectations up front. Communication was easiest when there is a safe space, including space for dissenting opinions; this dynamic contributed to comfort and authenticity within the relationship. In reflecting on a positive mentorship experience, one respondent shared:

> I was given the freedom to openly express myself and my feelings. Especially in regards to injustices I observe in the neuroscience and academic community. He supported my stance even when the larger majority in the community found me controversial.

Flexibility: Respondents desired a mentor who adapts to their evolving needs over time. A mentor lacking in flexibility was cited as a major barrier to academic development:

> My mentorship needs changed as I became more independent, but my advisor didn't adapt their style with those changes. The mentor was overbearing and wanted me to spend my time on their own projects that weren't my thesis work. This was very stressful, especially as a person for whom time is limited due to my disability.

Theme 2: allyship and management of power imbalance

This theme focuses on the mentor's status within academia, and society at large, and how the power afforded by the intersections of the mentor's identities can be used in ways that impact the mentee's experience in neuroscience.

Understanding and appreciation of lived experiences: Most respondents wanted mentors who seek to understand how multiple, interlocking systems of oppression impact their pursuit of a neuroscience career. One respondent shared the power of their mentor's support in a time of need:

> When you are having financial situations for a second and you can't seem to get out of it and it is stressing you and impacting your science and personal life. . .when someone says 'I can help' and they do mean it and take the time to understand why and how you got to that situation and offer to help is just amazing—you feel seen and taken care of and that's what I felt. I felt like I had an ally and someone that would never let me struggle.

Navigation of identity differences/incongruence: For respondents in cross-identity mentorship relationships, they shared that operating from a space of assumptions was detrimental to the relationship, for instance:

> [Mentor] doesn't understand what it's like being an underrepresented minority in a mainly white space. [Mentor] doesn't understand that sometimes me not being vocal isn't a lack of ideas but more just feeling uncomfortable. I am a first-generation college student.

Alternatively, many participants shared that, if navigated appropriately, the cross-identity relationship could serve as a space for new perspectives, collective knowledge, and advocacy.

When speaking on the positives that result from appropriate navigation of differences, one respondent considered how mentorship experiences in the present impact future mentorship and described it as:

> [An] opportunity to learn from someone of a different culture/identity. Positive experiences with being a cross-cultural mentee can lead to one being a better cross-cultural mentor in the future.

Mentor's leveraging of power and positionality: The onus of ensuring the relationship is equitable falls largely on the mentor, whose power can be used to improve conditions within the academy (via influencing institutional culture) or can be used to maintain the status quo or perpetuate harm. Respondents identified several forms of harm within cross-identity mentoring relationships including: gatekeeping, performative allyship, tokenism, and exploitation of labor. One respondent shared about their mentor:

> They were also way more advanced in their career and as a result served in a number of leadership roles and had power and influence at the institutional level. As a result of this, they wielded their power in harmful ways and sometimes impacted the upward mobility of me as a mentee via their positionality and status in academia. They were essentially an academic gatekeeper.

Central to a positive relationship is a sense of trust that the mentor will act with the mentee's best interest in mind. The mentor should be willing to use their power to advance the interests of the mentee and to disrupt oppression within the academy. For example, this may look like intervening when a mentee is asked to perform invisible, uncredited labor that is disproportionately assigned to historically marginalized persons (e.g., community outreach, mentoring other marginalized persons, recruitment of other marginalized persons into the department). Other examples include providing mentees professional opportunities to build skills or academic networks, amplifying their mentee's work on public platforms and in professional circles, and supporting or speaking up for their mentees in spaces where mentees may not be present (or invited).

Belongingness: Respondents shared the desire to be in community with people who value their existence and contributions. The ability to connect over shared experiences contributed to feelings of validation and being seen in spaces where they are the minority:

> My one mentor who is a Black woman in STEM greatly impacts me by providing me with advice on how to navigate academia being a Black woman. She is able to directly relate to problems I face and share her experiences and how she overcame them. She helps me feel validated and seen in ways that I cannot even begin to explain, so she has been very impactful in that realm.

Theme 3: academic sponsorship

Academic sponsorship was encapsulated by respondents' desire for resources to promote their advancement in neuroscience. Respondents wanted their mentor to leverage existing networks to help them build their own network. Respondents additionally desired to learn specific skills that will make them competitive in academia (e.g., grant writing, statistical analysis, publishing manuscripts) but also how to manage critical transitions, such as becoming the Principal Investigator of a research lab. One respondent desired mentorship on:

> Transitioning into a mentor/supervisor role: what to look for when hiring Research Assistants (RAs), navigating the transition from mentee to mentor, and becoming the "manager" of a lab group/small scientific team.

They also noted the importance of nomination for awards and introduction to new opportunities as a form of sponsorship.

Theme 4: institutional barriers impacting navigation of academia

This theme describes academia as an institution that upholds and recapitulates systems and practices of society at large, particularly those that thrive by the oppression and invisibility of minoritized and diverse beings. Respondents raise the need for specific resources (e.g., securing accommodations for a disability, funding for historically marginalized groups), but often having mentors who are unfamiliar with these options or how to support their mentee in securing them. One respondent recommended mentors:

> Get additional training in disability resources for mentees and how mentors can help trainees secure those resources.

Supplemental mentors who are more familiar with how to support their mentee in securing resources may be necessary; however, a number of respondents shared the challenges of having a mentor who is unwilling to acknowledge their shortcomings or unwilling to permit co-mentorship.

Mentorship needs by developmental stage

It is critical to emphasize that the needs of a mentee may change as they progress through the academic pipeline. Accordingly, mentorship styles should evolve and adapt as the mentee advances in their educational and professional career and increasingly gain greater independence in their research program. The following outlines mentorship needs identified by survey participants of varying training or early career stages.

Graduate students

When seeking mentorship, graduate students rated sponsorship as top priority. Provision of opportunities for financial supports (personal expenses or project-based needs), is particularly important given the limited funds offered by graduate student stipends:

> To their credit my mentor helped me secure a prestigious position and continued to nominateme for many awards/professional development opportunities. (I wrote my own recommendation letters for these awards/applications). They also helped me contact student financial services when I was considering dropping out due to family financial struggles and even offered to give me a small [dollar amount] loan to purchase groceries.

The second priority was having a mentor who is willing to consider their perspective and have open conversations about lived experiences. Responses highlighted how establishing mutual understanding did not require congruence across mentor and mentee identities alone, but necessitated appreciation of the complex ways identities intersect to create a power structure that differentially impacts access in academia. One graduate student acknowledged that having some shared aspect of identity with their mentor created an important common ground, but this did not always guarantee understanding:

> I felt initially comfortable that she was a queer woman but honestly that was almost a redherring. Just because you share an identity with someone doesn't mean that they have an intersectional understanding of accessibility and equity within academia.

Postdoctoral fellows

For postdoctoral fellows, most important was a mentor's willingness to consider their perspective and understand their lived experience. One respondent shared the importance of considering whether the mentee is a first-generation student and the financial burden of pursuing an academic career:

> Sometimes my mentor assumes I know things about the institution of academia that I don't because my first exposure to grad school/academia was when I started my PhD. My mentor (along with most of the other faculty) also went to school at a time where student loans weren't so predatory and overwhelming, so they don't necessarily understand how big a financial burden it can be.

Mentorship at this juncture may also focus on providing validation and encouragement to mentees with the goal of increasing their sense of self competency to build an independent program of research following fellowship. Given the brevity of many fellowship programs, open communication surrounding satisfaction with mentorship was identified as a tool to strengthen the relationship.

Early career

Junior faculty rated sponsorship as most important in what they seek from a mentor. Given early career scientists need to build an academic network and demonstrate high productivity in a relatively short probationary period, their inclusion in pertinent research and professional development opportunities (e.g., grants, collaborations, access to databases) is central to retention. One junior faculty shared:

> At my stage of career, I would value the personal connections that my mentor can provide (e.g., connecting me to potential collaborators), informing or sponsoring me in unique opportunities (e.g., co-investigator or collaborator on research projects/grants, editorial opportunities, etc.), and support in grant-writing.

Second in priority was having a mentor who provides coaching of career skills and individualized time and attention. Faculty who did not receive guidance on their science were forced to identify mentorship elsewhere.

Additional identity considerations

While the primary focus of analysis was mentorship experiences and needs across career phase, we considered other aspects of participants identities and the intersections of these identities, when appropriate, keeping in mind our limited sample size and a desire to maintain participant anonymity (which influenced the intersectional categories examined). We analyzed the existing themes and subthemes by intersectional categories to highlight some of the salient narratives from the data, but also acknowledge the need for a larger sample to offer a more comprehensive overview of lived experiences. Of particular importance is how a participant's social locus within society and the academy, based on the intersections of their identities, shapes their experience as neuroscientist mentee. Originating from Black feminist thought (Truth, 1951; Combahee River Collective, 1995), an intersectionality framework extends beyond analysis of a single aspect of a person's identity (e.g., race, class, gender), acknowledges the multidimensionality of their lived experience, and considers how this experience is influenced by societal power structures (Crenshaw, 1989; Collins, 2000).

Participants in our study living with a disability most frequently identified challenges around navigating identity differences with their mentor. Specifically, they described a culture of ableism that is especially prevalent within STEM fields, which makes advocating for their needs and resources to support their success in neuroscience a challenge and emotionally taxing. Respondents with a disability rarely encountered mentors in neuroscience who also have a disability. They shared that some senior neuroscientists may have non-visible disabilities but opt for nondisclosure due to the stigma and discrimination they may experience. This speaks to how the culture of academia (known to reward high productivity/output, competition, and perfectionism) is not conducive to the psychological safety or vulnerability necessary for this type of personal disclosure. Consequently, this may limit rich opportunities for mentees to connect over shared experiences with a more senior neuroscientist living with a disability. Respondents also shared that cross-identity differences within mentoring relationships can be leveraged in a way that are supportive and introduce new ways of being. For example, one woman living with a disability credited her advisor with helping her to present herself in strongest light possible in an application, countering the social norms and socialization of women to be modest and not self-promote or share accomplishments (Diekman et al., 2010; Smith and Huntoon, 2014).

There was qualitative evidence that racially and ethnically minoritized women in the sample were more likely to discuss an aspect of their identity in relation to their family (e.g., one participant described themselves as a daughter and provider to their mother), to share the challenges of navigating work-family life as an academic, and to disclose some of their personal values about family that may conflict with their mentor's and the academy at large. For example, academia reinforces values that align with the dominant white male majority and reward academics who adhere to these values and uphold social norms within the academy (Brauer et al., 2022). Greater appreciation is needed of the differences in family structure and caregiving responsibilities, the double duty of motherhood while working as an academic, and the unequal distribution of academic labor—many times invisible—that disproportionately impact racially and ethnically minoritized women (Moore, 2017; Social Sciences Feminist Network Research Interest Group, 2017).

Discussion

The results of the present study amplify and extend numerous efforts within the neuroscientific community aimed at identifying and dismantling oppressive structures and processes that lead to the systemic exclusion and marginalization of diverse people in neuroscience. We stand in solidarity with organizations, such as (Singleton et al., 2021; Black in Neuro, 2022; SPARK Society, 2022), and the BRAINS program (Brains, 2022) which create visibility for the invisible and/or erased neuroscientists, and uplift perspectives that deviate from the mainstream. Our findings resonate with many other accounts that highlight how race and ethnic identity are reified and reinforced in dynamic ways that feed into the preservation of whiteness, power, and dominance of the majority. Additionally, findings provide rich context and situate the intersectional experiences of neuroscientist mentees from other marginalized and historically excluded backgrounds (e.g., sexually minoritized, disabled, economically disadvantaged, immigrant). **Figure 1B** provides a conceptual model that illustrates the layered, complex dynamic of a mentor-mentee relationship within academia.

We specifically seek to highlight the individual-level factors that both the mentor and mentee separately bring to the relationship, as well as the clear power differential that is inherent to the interpersonal dynamic. This relationship offers a set of experiences that are nested within a larger ecosystem of the academic institution as well as society and social values (Sambunjak, 2015; Vargas et al., 2021). Both participants of the mentorship dyad bring their own set of worldviews, lived experiences, and biases which influence the discourse and behaviors within the mentorship relationship (DiAngelo, 2018). Interpersonal factors such as degree of individualism vs. collectivism, expectations for the relationship, and social justice orientation (Clutterbuck, 2007; Vargas et al., 2021) vary across culture and other aspects of identity but are important factors that influence the nature of engagement particularly when there is identity incongruence. For mentors, their past experiences as a former mentee, current encounters within the system of academia, willingness to acknowledge their power and privilege, and general openness to identity differences may shape their approach to mentorship (Vargas et al., 2021). For historically marginalized mentees, feelings of imposter syndrome, social isolation, and experiences of discrimination or identity-based stress may impact help-seeking within the relationship (Williams et al., 2018; Muradoglu et al., 2022). Full appreciation of the mentorship dynamic requires careful consideration of individual attributes and experiences within the dyad as well as contextualization within a broader macrosystem of and will likely, at points, require participating in difficult dialogues as a means of engagement in equitable mentoring relations (Madore and Byrd, 2022).

Many of the academic barriers identified by our group are by design in that they recapitulate social hierarchy within the academy and have unfortunately led to a mass exodus of some of the most talented minds (see Flaherty, 2021; Matias et al., 2021 for examples). We acknowledge "the master's tools will never dismantle the master's house" (Lorde, 1984) as the foundations of academia are deeply flawed and designed to maintain these inequities. True institutional change will require a multi-tiered approach including implementing change at the policy level. However, engaging in effective mentorship practices offers the opportunity to deconstruct oppressive systems via investing in the mentee's success, nominating them for leadership roles, creating a sincere environment of inclusion and belongingness, and intentionally changing the demographic landscape of neuroscience even if primarily at the local (laboratory) level. As a mentor, embarking on the ongoing, life-long process of critical self-reflection and education (e.g., developing language to discuss inequities, recognizing one's role in maintaining and/or perpetuating inequities within academia, naming and calling out epistemic exclusion)–is a crucial first step. Additionally, culturally-responsive mentorship education should be a component of faculty onboarding, and training should be routinely required throughout one's career in the academy. Mentorship training that is process oriented and moves beyond the theory or strategy of mentorship and delves into personal mentorship experiences, reflections, and application would be especially beneficial (Balmer and Richards, 2012).

The themes in our study underscore the importance of a mentor's awareness of their status within the larger social hierarchy, acknowledgment of the structural factors that impact diverse mentees (i.e., structural racism and power), and engagement in active allyship, emphasizing elements of academia that extend beyond those that put the onus on diverse mentees. Inaction to address these bare minimums in the face of persisting structural barriers implies complicit endorsement of the processes that cause harm to minoritized people. We offer a list of recommendations for cross-identity mentorship relationships in **Figure 1C** based on the collective knowledge gleaned from our group survey.

Our qualitative investigation, conducted by diverse neuroscientists about diverse neuroscientists, challenges research epistemology that prioritizes Eurocentric approaches to the production of knowledge, while highlighting the artificial distinction between the "researcher and the researched" (Probst, 2016; Holmes, 2020). We hope this examination of cross-identity mentorship in diverse early-career neuroscientists will inspire future efforts that elevate the diverse voices of those experiencing the effects of structural oppression, as those perspectives hold the transformative and radical insights needed for change.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary materials**, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving human participants were reviewed and approved by University of Minnesota Institutional Review Board. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TH-J wrote the first draft of this manuscript, designed the survey, and completed data analysis. RN designed the survey, completed data analysis, and contributed to writing the methods. CC-I contributed to writing the discussion and created the figure. JA contributed to writing the abstract. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnint.2023.1052418/full#supplementary-material.

References

ATLAS.ti (2022). *Scientific Software Development GmbH [ATLAS.ti 22.1.0 Mac]*. Available online at: https://atlasti.com.

Azizova, Z. T. (2016). Complexity of academic socialization of historically underrepresented doctoral students: de-privileging distinctions between macro- and micro-theoretical approaches. *J. Committed Soc. Change Race Ethnicity (JCSCORE)* 2, 2–39. doi: 10.15763/issn.2642-2387.2016.2.2.1-39

Bahr, S., Sparks, D., and Hoyer, K. M. (2018). Why didn't students complete a free application for federal student aid (FAFSA)? A detailed look. National Center for Education Statistics. Available online at: https://files.eric.ed.gov/fulltext/ED590789.pdf.

Balmer, D. F., and Richards, B. F. (2012). Faculty development as transformation: lessons learned from a process-oriented program. *Teach. Learn. Med.* 24, 242–247. doi: 10.1080/10401334.2012.692275

Bartz, D. E., and Kritsonis, W. A. (2019). Racism, the white power structure and the tragic history of the education of African American children in the United States. *Schooling* 10, 1–9.

Black in Neuro (2022). *Our Story*. Available online at: https://blackinneuro.com/about.

Brains (2022). *About*. Available online at: https://brains.uw.edu/about.

Brauer, D. D., Mizuno, H., Stachl, C. N., Gleason, J. M., Bumann, S., Yates, B., et al. (2022). Mismatch in perceptions of success: investigating academic values among faculty and doctoral students. *J. Chem. Educ.* 99, 338–345. doi: 10.1021/acs.jchemed.1c00429

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Burd, S., Fishman, K. L., and Habbert, J. (2018). "Decoding the cost of college: the case for transparent financial aid award letters," in *New America*. Available online at: https://d1y8sb8igg2f8e.cloudfront.net/documents/Decoding_the_Cost_of_College_Final_6218.pdf.

Clutterbuck, D. (2007). "An international perspective on mentoring," in *The Handbook of Mentoring at Work: Theory, Research and Practice*, eds B. R. Ragins, and K. E. Kram (Thousand Oaks, CA: Sage), 633–656.

Cole, E. R. (2009). Intersectionality and research in psychology. *Am. Psychol.* 64, 170–180. doi: 10.1037/a0014564

Collins, P. H. (2000). *Black Feminist Thought: Knowledge, Power and the Politics of Empowerment*. New York, NY: Routledge.

Combahee River Collective (1995). "Combahee river collective statement," in *Words of Fire: An Anthology of African American Feminist Thought*, ed B. Guy-Sheftall (New York, NY: New Press), 232–240. Original work published 1977.

Corrington, A., Hebl, M., Stewart, D., Madera, J., Ng, L., and Williams, J. (2020). Diversity and inclusion of understudied populations: a call to practitioners and researchers. *Consult. Psychol. J. Pract. Res.* 72, 303–323. doi: 10.1037/cpb0000188

Crenshaw, K. (1989). Demarginalizing the intersection of race and sex: a black feminist critique of antidiscrimination doctrine, feminist theory and antiracist politics. *Univ. Chicago Legal Forum* 1, 139–167. Available online at: https://chicagounbound.uchicago.edu/uclf/vol1989/iss1/8.

Daehn, I. S., and Croxson, P. L. (2021). Disability innovation strengthens STEM. *Science* 373, 1097–1099. doi: 10.1126/science.abk2631

Davis, S. M. (2021). *Black in the Ivory*. Available online at: https://blackintheivory.net.

Davis, T. M., Jones, M. K., Settles, I. H., and Russell, P. G. (2021). Barriers to the successful mentoring of faculty of color. *J. Career Dev.* 49, 1–19. doi: 10.1177/0894845321101337

DeCuir-Gunby, J. T., Marshall, P., and McCulloch, A. W. (2011). Developing and using a codebook for the analysis of interview data: an example from a professional development research project. *Field Methods* 23, 136–155. doi: 10.1177/1525822x10388468

DiAngelo, R. (2018). *White Fragility: Why it's So Hard for White People to Talk About Racism*. Boston, MA: Beacon Press.

Diekman, A. B., Brown, E. R., Johnston, A. M., and Clark, E. K. (2010). Seeking congruity between goals and roles: a new look at why women opt out of science, technology, engineering and mathematics careers. *Psychol. Sci.* 21, 1051–1057. doi: 10.1177/0956797610377342

Diversifying the Community of Neuroscientists (2022). *University of Minnesota*. Available online at: https://diversifyingcns.umn.edu/.

Fisher, A. J., Mendoza-Denton, R., Patt, C., Young, I., Eppig, A., Garrell, R. L., et al. (2019). Structure and belonging: pathways to success for underrepresented minority and women PhD students in STEM fields. *PLoS One* 14:e0209279. doi: 10.1371/journal.pone.0209279

Flaherty, C. (2021). Why They Left. *Inside Higher Ed*. Available online at: https://www.insidehighered.com/news/2021/05/03/multiple-black-professors-have-resigned-recent-years-over-racism.

Friedman, H. H., Friedman, L. W., and Leverton, C. (2016). Increase diversity to boost creativity and enhance problem solving. *Psychosoc. Issues Hum. Res. Manage.* 4:7. doi: 10.22381/pihrm4220161

Ginther, D. K., Schaffer, W. T., Schnell, J., Masimore, B., Liu, F., Haak, L. L., et al. (2011). Race, ethnicity and NIH research awards. *Science* 333, 1015–1019. doi: 10.1126/science.1196783

Graham, J., Chirino Chase, B., and Wright, J. (2020). Cultural diversity drives innovation: empowering teams for success. *Int. J. Innovat. Sci.* 12, 323–342. doi: 10.1108/ijis-04-2020-0042

Holmes, A. (2020). Researcher positionality - a consideration of its Influence and place in qualitative research - a new researcher guide. *Shanlax Int. J. Educ.* 8, 1–10. doi: 10.34293/education.v8i4.3232

Hoppe, T. A., Litovitz, A., Willis, K. A., Meseroll, R. A., Perkins, M. J., Hutchins, B. I., et al. (2019). Topic choice contributes to the lower rate of NIH awards to african-american/black scientists. *Sci. Adv.* 5:eaaw7238. doi: 10.1126/sciadv.aaw7238

IBM Corp (2021). *IBM SPSS Statistics for Macintosh*, Version 28.0. Armonk, NY: IBM Corp

Kruse, A. J. (2016). Cultural bias in testing: a review of literature and implications for music education. *Update Appl. Res. Music Educ.* 35, 23–31. doi: 10.1177/875512331557621

Ledford, H. (2017). US postdocs face steep challenges when starting families. *Nature* doi: 10.1038/nature.2017.22200

Lorde, A. (1984). 'The master's tools will never dismantle the master's house (Comments at the "The personal and the political panel," in *Second Sex Conference* (New York, September 29, 1979).

Madore, M. R., and Byrd, D. (2022). Optimizing mentoring relationships with persons from historically marginalized communities through the use of difficult dialogues. *J. Clin. Exp. Neuropsychol.* 44, 441–449. doi: 10.1080/13803395.2022.2108770

Matias, J. N., Lewis, N. Jr., and Hope, E. (2021). Universities Say They Want More Diverse Faculties. So Why Is Academia Still So White?. *FiveThirtyEight*. Available online at: https://fivethirtyeight.com/features/universities-say-they-want-more-diverse-faculties-so-why-is-academia-still-so-white/.

Miller, C., and Stassun, K. (2014). A test that fails. *Nature* 510, 303–304. https://doi.org/10.1038/nj7504-303a

Moneta-Koehler, L., Brown, A. M., Petrie, K. A., Evans, B. J., and Chalkley, R. (2017). The limitations of the GRE in predicting success in biomedical graduate school. *PLoS One* 12:e0166742. doi: 10.1371/journal.pone.0166742

Moore, M. R. (2017). Women of color in the academy: navigating multiple intersections and multiple hierarchies. *Soc. Prob.* 64, 200–205. doi: 10.1093/socpro/spx009

Muradoglu, M., Horne, Z., Hammond, M. D., Leslie, S.-J., and Cimpian, A. (2022). Women—particularly underrepresented minority women—and early-career academics feel like impostors in fields that value brilliance. *J. Educ. Psychol.* 114, 1086–1100. doi: 10.1037/edu0000669

Ocobock, C., Niclou, A., Loewen, T., Arslanian, K., Gibson, R., and Valeggia, C. (2021). "Demystifying mentorship: tips for successfully navigating the mentor-mentee journey". *Am. J. Hum. Biol.* 34:e23690. doi: 10.1002/ajhb.23690

Petersen, S. L., Erenrich, E. S., Levine, D. L., Vigoreaux, J., and Gile, K. (2018). Multi-institutional study of GRE scores as predictors of STEM PhD degree completion: GRE gets a low mark. *PLoS One* 13:e0206570. doi: 10.1371/journal.pone.0206570

Probst, B. (2016). Both/and: researcher as participant in qualitative inquiry. *Qual. Res. J.* 16, 85–102. doi: 10.1108/qrj-06-2015-0038

Ragins, B. R. (1997). Diversified mentoring relationships in organizations: a power perspective. *Acad. Manage. Rev.* 22, 482–521. doi: 10.5465/amr.1997.9707154067

Ramos, R. L., Alviña, K., and Martinez, L. R. (2017). Diversity of graduates from Bachelor's, Master's and Doctoral Degree Neuroscience Programs in the United States. *J. Undergraduate Neurosci. Educ.* 16, A6–A13.

Resmini, M. (2016). The 'leaky pipeline'. *Chemistry* 22, 3533–3534. doi: 10.1002/chem.201600292

Sambunjak, D. (2015). Understanding wider environmental influences on mentoring: towards an ecological model of mentoring in academic medicine. *Acta Med. Acad.* 44, 47–57. doi: 10.5644/ama2006-124.126

Settles, I. H., Jones, M. K., Buchanan, N. T., and Dotson, K. (2021). Epistemic exclusion: scholar(ly) devaluation that marginalizes faculty of color. *J. Divers. Higher Educ.* 14, 493–507. doi: 10.1037/dhe0000174

Shaw, A. K., Accolla, C., Chacón, J. M., Mueller, T. L., Vaugeois, M., Yang, Y., et al. (2021). Differential retention contributes to racial/ethnic disparity in US academia. *PLoS One* 16:e0259710. doi: 10.1371/journal.pone.0259710

Singleton, K. S., Tesfaye, R., Dominguez, E. N., and Dukes, A. J. (2021). An open letter to past, current and future mentors of black neuroscientists. *Nat. Rev. Neurosci.* 22, 71–72. doi: 10.1038/s41583-020-00421-9

Smith, J. L., and Huntoon, M. (2014). Women's bragging rights: overcoming modesty norms to facilitate women's self-promotion. *Psychol. Women Quart.* 38, 447–459. https://doi.org/10.1177/0361684313515840

Social Sciences Feminist Network Research Interest Group (2017). The burden of invisible work in academia: social inequalities and time use in five university departments. *Humboldt J. Soc. Relations* 39, 228–245. Available online at: http://www.jstor.org/stable/90007882.

SPARK Society (2022). *Our Mission: Empower*. Available online at: https://www.sparksociety.org/.

Thorne, K. M., Jones, M. K., Davis, T. M., and Settles, I. H. (2021). The significance of race in cross-racial mentoring of faculty of color. *Transl. Issues Psychol. Sci.* 51, 462–472. doi: 10.1037/tps0000286

Truth, S. (1951). "The Ain't I A Woman Speech," in *Women's Rights Convention* (Akron, Ohio), 21 June 1851. Retrieved Nov 1, 2022.

Vargas, J. H., Saetermoe, C. L., and Chavira, G. (2021). Using critical race theory to reframe mentor training: theoretical considerations regarding the ecological systems of mentorship. *Higher Educ.* 81, 1043–1062. doi: 10.1007/s10734-020-00598-z

Weidman, J. C., Twale, D. J., and Stein, E. L. (2001). "Socialization of graduate and professional students in higher education: a perilous passage," in *ASHE-ERIC Higher Education Report. Jossey-Bass Higher and Adult Education Series* (San Francisco, CA: ERIC).

Williams, M. S., Brown Burnett, T. J., Carroll, T. K., and Harris, C. J. (2018). Mentoring, managing and helping: a critical race analysis of socialization in doctoral education. *J. College Student Retention Res. Theory Pract.* 20, 253–278. doi: 10.1177/1521025116657834

Wilson, M. A., DePass, A., and Bean, A. J. (2018). Institutional interventions that remove barriers to recruit and retain diverse biomedical PhD students. *CBE Life Sci. Educ.* 17:ar27. doi: 10.1187/cbe.17-09-0210

Woo, S. E., LeBreton, J. M., Keith, M. G., and Tay, L. (2022). Bias, fairness and validity in graduate-school admissions: a psychometric perspective. *Perspect. Psychol. Sci.* doi: 10.1177/17456916211055374. [Online ahead of print].

Ysseldyk, R., Greenaway, K. H., Hassinger, E., Zutrauen, S., Lintz, J., Bhatia, M. P., et al. (2019). A leak in the academic pipeline: identity and health among postdoctoral women. *Front. Psychol.* 10:1297. doi: 10.3389/fpsyg.2019.01297

Zhao, Y. (2016). From deficiency to strength: shifting the mindset about education inequality. *J. Soc. Issues* 72, 720–739. doi: 10.1111/josi.12191

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Gender diversity associated with patterns of brain activation seen in populations that experience childhood stress

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Introduction: Stressful childhood experiences are associated with unique brain activity patterns during emotional processing. Specifically, pediatric stress is linked to activation in the insulae, superior temporal and parahippocampal gyri, and the amygdalae, as well as differential activation in the dorsal anterior cingulate cortex when viewing emotional faces. Gender diversity is broadly associated with higher victimization and mental health disparities in children aged 9/10, but whether it is associated with stress-like alterations in brain function (BOLD signal during task-based fMRI) remains unknown. We investigate the functional brain correlates of this relationship to determine if gender-diverse youth show patterns of functional activity during an emotional task consistent with those of other populations that experience heightened stress.

Methods: We used data from the Adolescent Brain Cognitive Development (ABCD)® study. First, we identified a subset of 4,385 participants aged 10/11 years with gender diversity data and quality-controlled fMRI data from the EN-Back (emotional *n*-back) task. The EN-Back is a working memory task that presents emotion faces as well as pictures of places as control stimuli. We regressed BOLD signal associated with emotion faces (faces minus places contrast) on gender diversity. Next, we tested if parental acceptance or youth perceptions of their school environment moderated the relationship between gender diversity and activation in the insulae or fusiform gyrus. Finally, we used structural equation modeling to investigate gender diversity's association with parental acceptance, perceptions of school environments, internalizing and externalizing problems.

Results: Gender diversity was associated with widespread increases in BOLD signal during the faces condition of the EN-Back task. Youth's report of parental acceptance and school environment did not moderate the relationship between gender diversity and BOLD signal in the insula or fusiform gyrus. Gender diversity was related to greater parent and school-related stress, which was associated with elevated mental health problems.

Conclusion: Patterns of functional activity were consistent with those reported in prior literature on childhood stress. Gender diversity was associated with increased emotional and behavioral problems, as well as parent and school-related stress. These findings indicate the importance of the home and school environments for supporting the wellbeing of gender diverse youth.

KEYWORDS

fMRI, BOLD (blood oxygenation level dependent) signal, gender diversity, stress, ABCD

1. Introduction

Gender is multifaceted and includes how someone identifies, expresses, and feels about their gender. Gender is not just a categorical identity (e.g., cisgender/transgender or boy/girl/non-binary/agender etc.), but rather a constellation of dimensional constructs (see **Table 1** for definitions). Internal dimensions of gender include felt-gender, which describes the extent to which someone feels gender, and contentedness, the degree to which someone is content with their gender. External dimensions of gender include expression, behavior, clothing, or mannerisms aligned (or not) with cultural expectations of femininity or masculinity. All facets of gender are relevant for all people. The degree to which an individual does or doesn't align with societal expectations based on their sex assigned at birth—gender diversity—can vary independently along each construct. For instance, a person may describe themselves as feeling somewhat like the gender that aligns with their sex assigned at birth (felt gender) while mostly dressing, acting, or choosing activities similar to the gender associated with the opposite sex (gender non-conformity). Gender diverse refers to youth who experience some aspect of gender that does not match society's stereotypes regarding their sex assigned at birth (American Psychological Association Division 16 and 44, 2015).

Gender minority youth (youth with transgender and/or non-binary identities) face overwhelming rates of discriminatory and harmful legislation, institutional discrimination in schools, the justice system, health systems, and public accommodations (e.g., Greytak et al., 2016; Bortz and Safer, 2018; Kosciw et al., 2020), as well as higher rates of peer and family rejection and victimization (e.g., Landolt et al., 2004; Roberts et al., 2012; Gordon et al., 2018). Subsequently, gender minority youth have elevated mental health problems compared to their peers (e.g., Spivey and Prinstein, 2019; Potter et al., 2021). In fact, over 50% of gender minority youth in a 2021 national survey reported considering suicide (Paley, 2021).

Although recent estimates suggest gender minority youth represent approximately 1.8% of the population (Johns et al., 2019), gender diversity is common. One study found that 27% of adolescents in the California school system reported that their peers would describe their gender expression as non-conforming (Wilson et al., 2017). Potter et al. (2021) found that in the Adolescent Brain Cognitive Development (ABCD) study, 33.2% of youth ages 10–11 (approximately 1/3 of a sample of 4,935 participants across 21 sites in the United States) endorse some gender ratings that are not fully aligned with assigned sex. Further, this dimensional gender diversity in this community sample was associated with increased mental health symptoms. Suggesting that level of gender diversity, regardless of minority identity status, is associated with disproportionate negative health outcomes as early as 10 years of age. Higher levels of distress among gender diverse youth continues through high school. Findings from a study conducted by Lowry et al. (2018), suggest that one dimension of gender diversity, gender non-conformity, was associated with greater feelings of sadness and hopelessness among a group of high school students.

While gender diversity is not the same as a gender minority identity, intersocial stressors from non-conformity with dominant culture can significantly impact health and wellbeing. Indeed, previous literature has shown that youth who do not conform to gender conventions are at higher risk of peer victimization and rejection (e.g., Aspenlieder et al., 2009; Toomey et al., 2012). Utilizing data from the ABCD study, our recent research has found that gender non-conformity was associated with increased family conflict and poorer perceptions of school environment such that greater gender non-conformity was associated with elevated total behavioral and emotional health symptoms, increased family conflict and poorer perceptions of the school environment (Loso et al., 2023). Further, family and school stress significantly mediated the relationship between gender non-conformity and mental health problems. Taken together, emerging literature demonstrates that youth who, even slightly, violate cultural expectations regarding gender, experience more mental health problems, and that positive school and family environments can buffer this relationship.

Heightened distress associated with victimization and discrimination among gender diverse youth can be conceptualized with the minority stress model. The minority stress model was first coined by Ilan Meyer (Meyer, 1995, 2003; Meyer and Dean, 1998) to describe the experiences of individuals in the gay, lesbian and bisexual community and was later adapted for application to transgender and gender non-conforming individuals (Hendricks and Testa, 2012). Meyer defines minority stress as the stress that arises when the experience of an individual in a minority group is in contradiction to the majority culture. Minority stress operates through three major processes to create negative health outcomes. (1) Distal stressors are larger, objective, institutionalized discriminations that do not rely on a person's perceptions of their oppression, whereas proximal stressors are subjective, individual stressors that are based on how an individual appraises a stressful event. Meyer proposed two distinct forms of proximal stress: (2) expecting to experience victimization or discrimination and (3) internalizing negative societal attitudes related to one's minority status. Proximal and distal stressors are inextricably linked. For instance, if a gender non-conforming child is bullied at school for the way that they dress and the school does not address the

TABLE 1 Definitions of terms used in this manuscript.

Term	Definition
Gender diverse	Any degree of variation from societally defined expectations or stereotypes regarding male or female gender norms
Gender identity	An individual's internal definition of their gender
Gender non-conformity	Dressing or acting in a way that does not completely conform to the traditional gender stereotypes that society has ascribed to the individual's sex assigned at birth
Felt gender	The extent to which one feels like the gender aligned with their sex assigned at birth and like the gender not aligned with their sex assigned at birth
Gender non-contentedness	Not feeling content with the gender aligned with one's sex assigned at birth
Transgender	An umbrella term that describes someone whose gender identity does not align with their sex assigned at birth
Cisgender	This term describes an individual whose gender identity is wholly aligned with the gender society associates with their sex assigned at birth

harassment (distal stressors) they may become anxious to go to school due to anticipation (proximal stress) that they will be bullied and victimized by their peers and that school personnel will not protect them. Although the expectation of being bullied is a subjective experience, it is in reaction to a real, external threat and may be an accurate expectation. Although minority stress is defined as stress related to having a minority identity (e.g., transgender, non-binary), a minority stress framework can still inform heightened distress experienced by youth who endorse some level of gender diversity.

Research suggests that minority stress gets "under the skin" and is associated with inflammatory biomarkers and poor physical health outcomes (e.g., McQuillan et al., 2021). A single study comparing clinic-referred transgender adults to a cisgender group found altered amygdala processing that was associated with levels of choline (measured with magnetic resonance spectroscopy; Kiyar et al., 2022). While research on the neurobiology of gender diversity-based minority stress is relatively new, hasn't yet extended to younger samples, and has only been conducted with individuals with a minority identity (as opposed to some level of gender diversity), there is a deep literature on other forms of childhood stress (e.g., maltreatment, poverty, anxiety disorders). For example, a meta-analysis found that maltreated youth have greater activation in the insulae, superior temporal and parahippocampal gyri when viewing emotional faces compared to non-maltreated peers (Hein and Monk, 2017). Other studies of children who experience stress have shown increased activation in the amygdalae when viewing emotional faces (Etkin and Wager, 2007; Hein and Monk, 2017; Miller et al., 2020). Studies have found a relationship between elevated stress and alterations in the dorsal anterior cingulate cortex (Keding and Herringa, 2016; Weissman et al., 2020), however the direction of these effects are mixed. Taken together, pediatric stress may be detectable in brain regions associated with social perception and cognition (superior temporal gyrus); processing subjective feelings and uncertainty (insula); and processing emotion (amygdalae, OFC).

To our knowledge, previous studies have not examined the relationship between gender diversity, environmental stressors, neurobiology, and mental health in a community sample of younger children. To fill this gap in the literature, we first aimed to investigate if levels of gender diversity among a community sample of early adolescents were associated with patterns of functional brain activation consistent with childhood stress. Based on existing literature and our previous behavioral work, we hypothesized that gender diversity would be associated with greater activation in the insula, superior temporal and parahippocampal gyri, and the amygdalae as well as differential activation in the dorsal anterior cingulate cortex when viewing emotional faces compared to when viewing places. Our second aim was to determine if distal factors (parental acceptance and school environment) act to moderate the relationship between gender diversity and neural correlates of stress (the insula and fusiform gyrus). We hypothesized that these relationships would be weaker with higher parental acceptance and positive perceptions of school environment, and thus be targets for intervention. Finally, we aimed to examine the relationship between gender diversity, parental acceptance, perceptions of school and emotional and behavioral health concerns. We hypothesized that gender diversity would be associated with lower parental acceptance, poorer perceptions of school environment, and elevated mental health problems.

2. Materials and methods

2.1. Participants

Data from the Adolescent Brain Cognitive Development Study (ABCD)® study, obtained from the National Institute of Mental Health (NIMH) data archive (release 4.0) was used for this project. ABCD is a large, longitudinal study of 11,875 adolescents enrolled at ages 9–10 across the United States. Parent and child participants were primarily recruited through schools, with minimal exclusion criteria (Garavan et al., 2018). All participants provided consent/assent and the University of California San Diego's Institutional Review Board approved the study protocol. The demographics of the ABCD study participants approximate the demographics of 9–10-year-old youth from the 2015 American Community Survey. ABCD's inclusion/exclusion flag was utilized to remove subjects who did not pass imaging quality control (Hagler et al., 2019 for more information on ABCD fMRI processing and quality control). To better balance the sample (many participants did not endorse gender diversity), maximize variability associated with gender diversity, and attempt to eliminate confounding that may impact neurobiology, a 1:1 nearest neighbor propensity score without replacement case matching technique was used. This technique used a propensity score estimated utilizing logistic regression of the group (participants that endorsed gender diversity n = 2,196 vs. participants that did not endorse any gender diversity; total sample = 4,392) on the covariates which included scanner, age, race, puberty, sex, and highest household education (HHE). See **Figure 1** for inclusion criteria and the number of participants remaining after each exclusion.

2.2. Behavioral measures

2.2.1. Gender diversity

Gender diversity was measured using four-items (each on a 5-pt scale) that assess felt-gender, contentedness with sex assigned at birth, and gender expression (see **Table 2** for gender questions; Potter et al., 2021). A sum score (range 4–20) of the addition of all four items was recoded with higher scores indicating greater gender diversity. Therefore, participants with a score of four endorsed no gender diversity and those who endorsed some amount of gender diversity had scores ranging from 5 to 20. Participants were excluded if they were missing more than two items, for participants missing one to two items, other items were averaged and then used as the value for the missing item(s). Given that many children at this developmental age do not have a clearly defined gender identity or expression, a summary score was used (as opposed to examining the dimensions separately) in order to maximize the variability of the data. Additionally, the items that assess contentedness, gender expression and felt-gender are highly correlated with each other.

2.2.2. Stress-school

The School Environment subscale from the PhenX School Risk and Protective Factors protocol originally derived from the Communities That Care Youth Survey (Arthur et al., 2007) examines youth's perceptions of their school climate and school engagement. Statements are endorsed on a scale from 1 (*definitely not true)* to 4 (*definitely true).* The items "I feel safe at my school," "I get along with my teachers," and "The school lets my parents know when I have done something well" were used in the behavioral analysis as indicators for a latent factor with higher scores indicating more positive perceptions of school environment. The school environment subscale was used as a moderator in the moderation analysis.

2.2.3. Stress-family

The Child Report of Behavior Inventory (CRPBI; Schaefer, 1965; Barber, 1997) is a measure of youth's perceptions of caregiver acceptance. Higher scores indicate greater warmth/acceptance. Participants report on both the parent or caregiver who is participating in the study (most often biological mothers) and a second caregiver (e.g., grandfather, other mother, father). Mean scores for each caregiver were used in the behavioral analysis as indicators of a latent factor with higher scores indicating greater acceptance. For the moderation analysis, mean scores for each caregiver were averaged and used as a moderator.

2.2.4. Mental health problems

2.2.4.1. Child behavior checklist (CBCL)

The Child Behavioral Checklist (CBCL) is an empirically driven, standardized, dimensional parent-report measure that examines emotional and behavioral problem items (Achenbach and Rescorla, 2001). In the current study, we used raw scores from the broadband Internalizing and Externalizing scales as indicator variables for a latent factor that we labeled mental health problems. Higher scores indicate more problems.

2.2.4.2. Brief problem monitor-youth form (BPM-Y) for ages 11–18

The Brief Problem Monitor-Youth (BPM-Y) is a short-form based on the Youth Self-Report Form, a complement to the CBCL (YSR; Achenbach et al., 2011). The BPM-Y Internalizing and Externalizing raw problem scores were used as indicators for latent mental health problems, with higher scores indicating more problems.

2.3. Covariates

Covariates used in this study were used to account for factors associated with gender diversity; neuroimaging signal; and stress. Age in months, pubertal status, and sex assigned at birth have been previously associated with gender diversity in the ABCD study (Potter et al., 2021). Race and highest household education were included to account for effects of systemic racism and discrimination related to income level. Scanner number accounted for differences between scanners across sites. Finally, family ID nested within site was used to account for the sibling relationships in ABCD. All covariates except scanner ID and puberty were reported through the parent-reported demographics survey (Barch et al., 2018). Parent-reported pubertal status was collected with the Pubertal Development Scale (Petersen et al., 1988) which yields five categories (1 = pre-pubertal, 2 = early pubertal, 3 = mid-pubertal, 4 = late-pubertal, and 5 = late-pubertal).

2.4. Functional MRI acquisition

The ABCD scanning protocol is harmonized for use across three 3T scanner platforms [Siemens Prisma, General Electric (750) and Phillips] and uses multi-band imaging across 21 sites. The ABCD scan protocol includes collection of structural, diffusion and functional MRI (fMRI; both resting state and task-based fMRI) images. The fMRI acquisitions (2.4 mm isotropic, TR = 800 ms) utilize multiband EPI with slice acceleration factor six. The T1w acquisition (1 mm isotropic) is a 3D T1w inversion prepared RF-spoiled gradient echo scan that uses prospective motion correction (currently only on Siemens and GE scanners). The T2w acquisition (1 mm isotropic) is a 3D T2w variable flip angle fast spin echo scan. The T2w also uses prospective motion correction (but only on Siemens and GE scanners). For further details on the ABCD imaging protocol see Casey et al. (2018) and Hagler et al. (2019).

2.5. EN-Back task

The EN-Back task is a working memory task with a block design consisting of two working memory conditions (0-back and 2-back); and two stimuli conditions (emotion faces and places). The task is administered in two runs each containing eight blocks of trials and four 15-s periods containing a fixation cross. There are 160

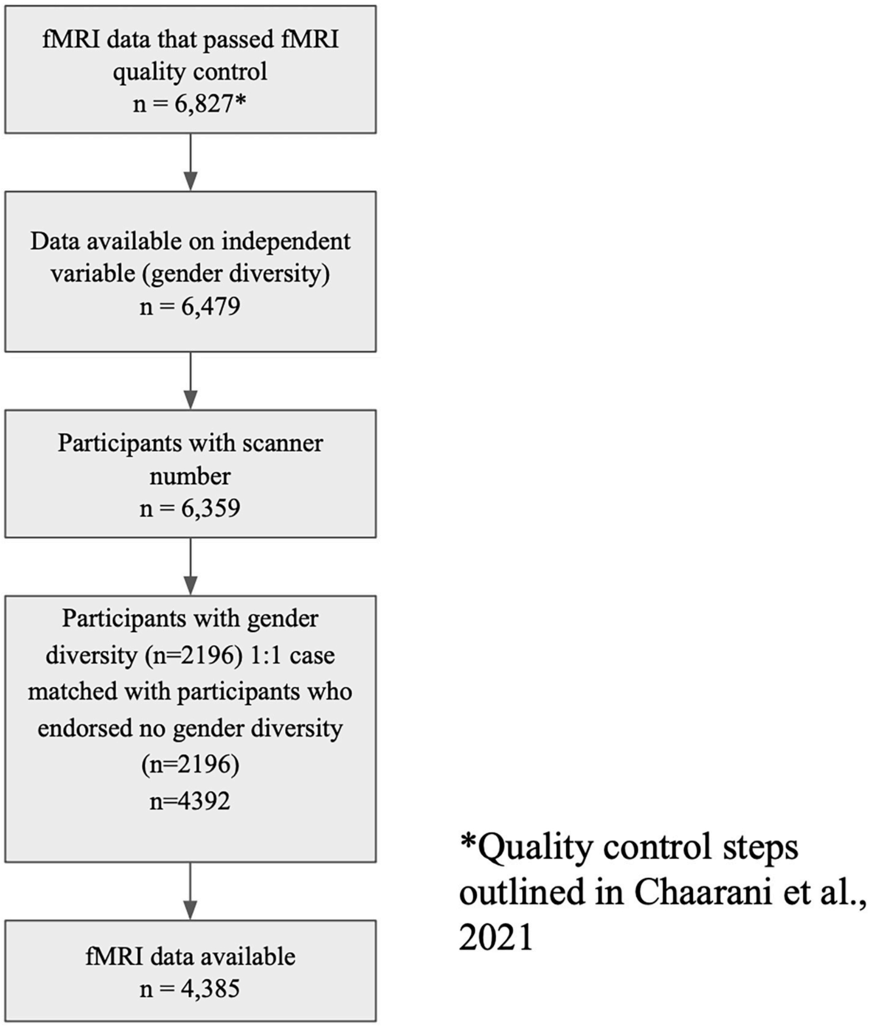


FIGURE 1
Inclusion criteria and number of participants remaining after each step of exclusion. *Quality control steps outlined Chaarani et al. (2021).

TABLE 2 Multi-dimensional assessment of gender.

How much do you feel like a < boy/girl >?
How much do you feel like a < girl/boy >?
How much have you had the wish to be a < girl/boy >?
How much have you dressed or acted as a < girl/boy > during play?

trials in total with 96 unique stimuli of four types (happy faces, fearful faces, neutral faces, and places). Participants completed the EN-Back in a high spatial and temporal resolution simultaneous multi-slice/multiband echo-planar imaging (EPI) scanner with fast integrated distortion correction. Further information on fMRI quality control and processing pipelines have been previously described by Casey et al. (2018) and Hagler et al. (2019). EN-Back data used in these analyses included individual subject level GLM beta coefficients and s.e.m. (calculated from the ratio of the beta and *t*-statistic) calculated for each voxel and vertex. The faces vs. places contrast (collapsed across working memory conditions) from the baseline neuroimaging session (when youth were ages 9–10) were analyzed. The faces vs. places contrast is activation when viewing emotional faces (happy faces, fearful faces, and neutral faces) minus activation when viewing places stimuli.

2.6. Analytic strategy of aim 1—Characterize the association between patterns of brain activation during emotional face stimuli and gender diversity

The first aim of this study was to examine the relationship between gender diversity (collected at the year 1 time point, Mage = 10.93) and patterns of activation (collected at ages 9–10 at the baseline timepoint, Mage = 9.93) while participants were viewing emotion faces (minus activation when viewing places) to investigate if gender diverse youth have patterns of activation similar to other populations that experience stress. Freesurfer's Permutation Analysis of Linear Models' (PALM; Winkler et al., 2014). General Linear Model (GLM) was used to generate a cortical and subcortical map that regressed gender diversity (sum score) on the faces minus places contrast (collapsed across working memory load). Permutation testing was utilized to improve reproducibility and robustness of findings. To better balance the sample (many participants did not endorse any gender diversity), maximize variability associated with gender diversity, and attempt to eliminate confounding that may impact neurobiology, we used a 1:1 nearest neighbor propensity score without replacement case matching technique using the MatchIt package (Ho et al., 2011). This technique used a propensity score estimated utilizing logistic regression of the group (participants that endorsed gender diversity $n = 2{,}196$ vs. participants that did not endorse any gender diversity; total sample = 4,392) on the covariates which included scanner, age, race, puberty, sex, and highest household education (HHE). Covariates used in the fMRI model were from the baseline timepoint. Case matching yielded good balance as evidenced by all the standardized mean differences for the covariates being below 1. Seven participants in the sample were missing data on highest household education (0.1% of the sample prior to case-matching) and 149 (2.3%) were missing parent reported pubertal status. Prior to case matching, missing values for these participants were median imputed based on the participant's sex and site. Seven more participants were excluded due to not having available fMRI data (final sample = 4,385). Because pubertal status and sex assigned at birth are inextricably linked to the independent variable (gender diversity), and the dependent variable (fMRI activation) these variables were case-matched, but not included as covariates. Although case matching yielded good balance, the standardized mean difference for race and household education were greater than the standardized mean difference of puberty and sex assigned at birth. Further, race and household education do not have a biological basis and are ways in which to categorize how individuals are differentially impacted by social institutions and systems that enact harm due to racism and classism. Thus, race and household education were included as covariates in the model (Buchanan et al., 2021). Scanner number was included as a dummy coded covariate to account for the effects of different scanners on the neuroimaging results. To account for statistical dependency of family structure of participants in the study, PALM's exchangeability blocks were used, which allows for modeling of the dependence of siblings in the requested 1,000 permutations (Winkler et al., 2015). Gender diversity and all the covariates were mean centered, consistent with PALM program requirements and previous methods (Chaarani et al., 2021). FDR corrected p-value maps thresholded at <0.05 were used to determine statistically significant areas of activation.

2.7. Aim 2—Examine if stress factors, parental acceptance and school environment, moderate the relationship between gender diversity and heightened activation in the insula and fusiform regions

Four regions of interest were extracted from the task activation map: the fusiform (left and right hemisphere) and the insula (left and right hemisphere) and the ROIs were averaged across hemispheres. Next, four moderation models were run. For the first analysis, youth's report of their parent's acceptance and their caregiver's acceptance were averaged. The average score was used as a moderator to determine if overall parental acceptance moderated the relationship between gender diversity and insula activation. This analysis was repeated but with fusiform activation (averaged across hemispheres) as the dependent variable. In addition to examining the moderating role of parental acceptance, we also investigated if perceptions of school environment moderated the relationship between gender diversity and insula activation. The analysis was then repeated but with the fusiform ROI as the dependent variable. See proposed models in **Figure 2**.

2.8. Strategy of aim 3—Examine the relationship between parental acceptance, perceptions of school environment, gender diversity and mental health symptoms

We examined the relationship between gender diversity and mental health problems using a structural equation modeling framework (see **Table 3** for proposed stress and mental health indicators and **Figure 3** for proposed SEM model). All variables used in the behavioral model were collected at the year 1 time point (Mage = 10.93). Participants used in the fMRI analyses were used in the behavioral analyses. Data were used from the year 1 timepoint when children were ages 10–11 (the participants' second in-person visit; $n = 4{,}385$). All behavioral analyses were conducted in R version 4.0.0 (RStudio Team, 2020) using the lavaan package (Rosseel, 2012). Prior to analyzing the path models, measurement models were conducted to determine if better model fit would be achieved through modeling stress as one or two factors (parent-related and school-related stress). To scale the latent factors, the first indicator of each latent factor was fixed to one. To account for the statistical dependency of family, cluster robust standard errors were utilized. To account for missing data and positive skew of some of the indicator variables, Maximum Likelihood Robust estimation was used which allowed for the entire sample of 4,385 to be analyzed. For the SEM model, covariates (sex assigned at birth, race, age in months, and highest household education) were included as exogenous predictors with one-headed paths to each variable in the model.

3. Results

3.1. Participants

See **Table 4** for demographics of participants.

3.2. Results—Aim 1

Cortical and subcortical p-value maps were generated to model activation patterns of recoded gender diversity on emotional faces (activation when viewing faces—neutral, happy, and fearful, minus activation when viewing places, collapsed across working memory load) and are displayed in **Figure 4**. On the cortical

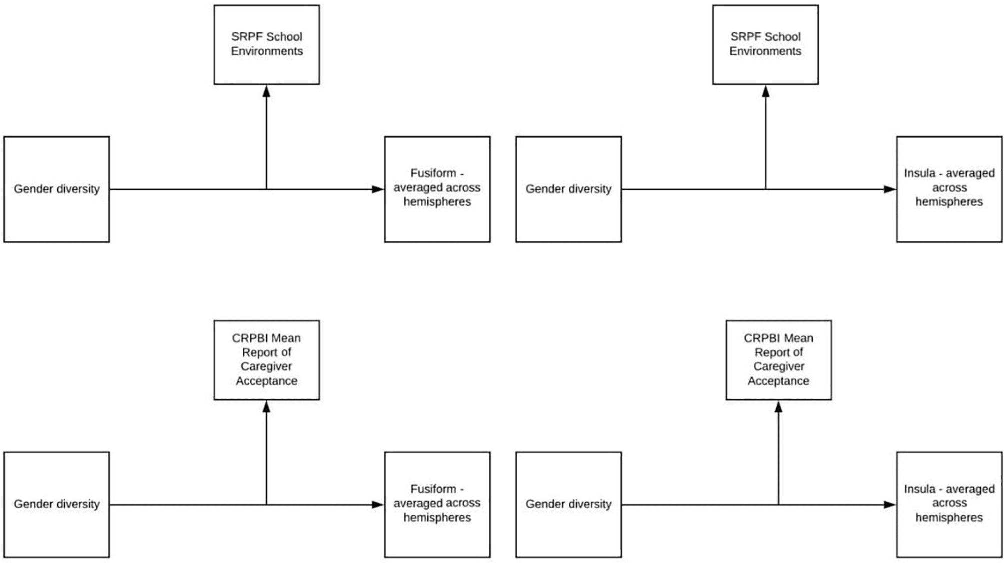


FIGURE 2
Moderation models.

TABLE 3 Latent construct and indicators.

Latent construct	Items/Scale	Measure
School-related stress	Item 3 "I get along with my teachers" Item 6 "I feel safe at my school"	School risk and protective factors Arthur et al. (2007)
	Item 7 "The school lets my parents know when i have done something well"	
Parent-related stress	Mean report of parent by youth	Child report of parent behavior inventory (CRPBI; Schaefer, 1965; Barber, 1997)
	Mean report of secondary caregiver by youth	
Mental health	Parent-reported total externalizing problems	Child behavior checklist total problems Achenbach and Rescorla (2001)
	Parent-reported total internalizing problems	
	Youth-reported total externalizing problems	Brief problem monitor (BPM) total problems Achenbach et al. (2011)
	Youth-reported total internalizing problems	

map, gender diversity was associated with wide-spread greater bilateral activation in task-related areas. Specifically, the fusiform, orbitofrontal (lateral and medial) areas, rostral middle frontal region, occipital and parietal regions. Consistent with our hypothesis, the cortical map showed greater activation of bilateral insula, superior temporal gyrus, and parahippocampal gyrus with more gender diversity when viewing emotional faces compared to places ($p < 0.05$, FDR-corrected). The subcortical map suggested gender diversity associated with right amygdala, as predicted by the stress literature, as well as activation in the right putamen. No differential activation was detected in the dorsal anterior cingulate cortex in either map.

3.3. Results—Aim 2

Results from the four moderation models were not significant. Perceptions of the school environment did not moderate the relationship between gender diversity and heightened insula or fusiform activation. Similarly, parental acceptance did not significantly moderate these relationships.

3.4. Results—Aim 3

See **Table 5** for descriptive statistics and bivariate correlations of the indicators used in aim 2.

3.4.1. Confirmatory factor analyses

We first examined the fit of a model with one latent stress factor. The overall goodness of fit statistics (as recommended by Hu and Bentler, 1999) for the one factor model indicated poor model fit, $\chi 2$ (26) = 1,678.69, $p < 0.001$, RMSEA = 0.13 (90% CI = 0.12, 0.14), SRMR = 0.07, TLI = 0.61, CFI = 0.72. Examination of the factor loadings revealed that parent-reported Internalizing and Externalizing Problems from the Child Behavior Checklist

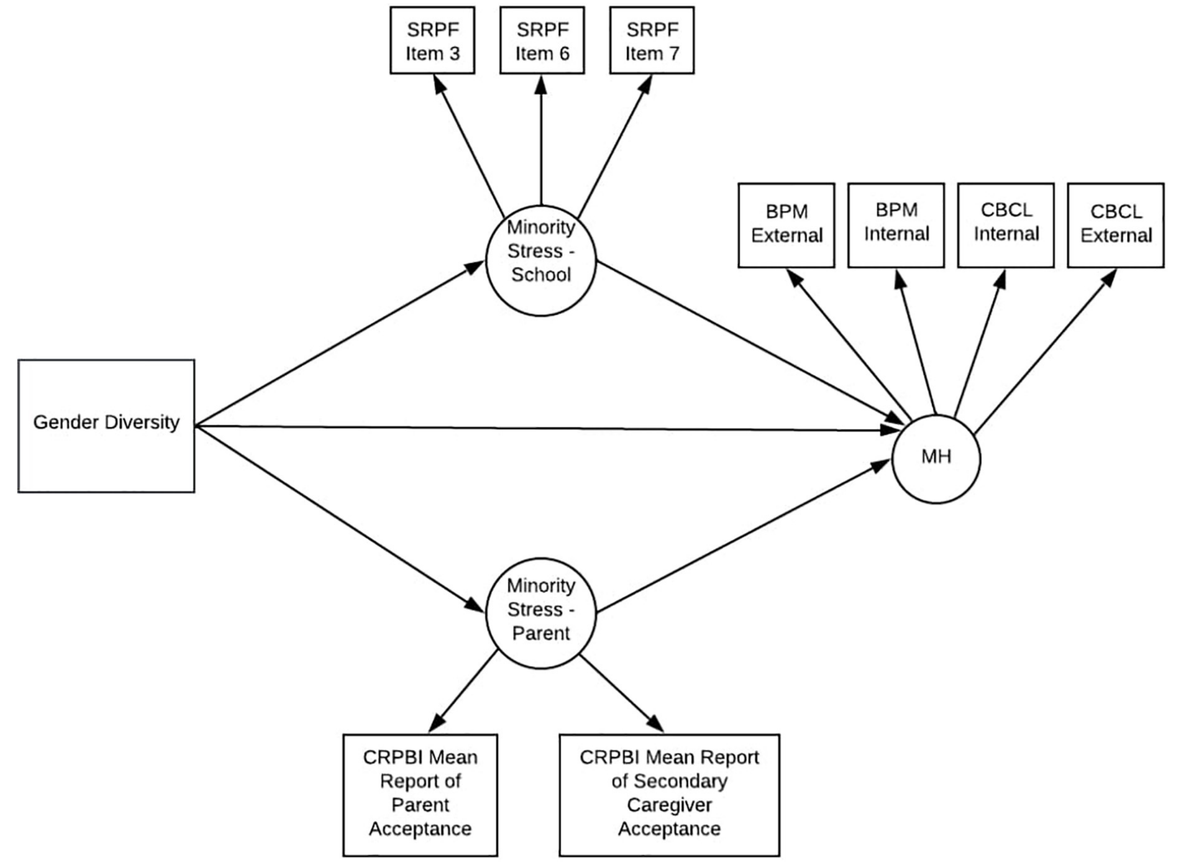


FIGURE 3
Proposed behavioral model. SRPF, school risk and protective factors; Item 3 = "I get along with my teachers"; Item 6 = "I feel safe at my school"; Item 7 = "The school lets my parents know when I've done something well"; BPM, brief problem monitor (ASEBA brief problem monitor—youth form for ages 11–18); CBCL, child behavior checklist [child behavior checklist for ages 6–18 (CBCL/6–18)]; CRPBI, children's report of parent behavior inventory.

loaded poorly onto the mental health latent factor compared to youth Externalizing and Internalizing Problems ($R = 0.49$; $R = 0.44$, respectively). Dropping the parent-reported indicators from the one factor model improved model fit, χ^2 (13) = 265.55, $p < 0.001$, RMSEA = 0.07 (90% CI = 0.06, 0.08), SRMR = 0.03, TLI = 0.93, CFI = 0.89.

Next, the fit of a two-factor model (labeled parent- and school-related stress) was analyzed using confirmatory factor analysis. Goodness of fit indices indicated that the two-factor solution provided good fit to the data, χ^2 (11) = 122.43, $p < 0.001$, RMSEA = 0.05 (90% CI = 0.04, 0.06), SRMR = 0.02, TLI = 0.95, CFI = 0.97. Thus, the two-factor solution was used for the structural equation model.

3.4.2. Structural equation model

Figure 5 shows the model predicting the factor labeled mental health. Fit indices suggest that the model was a good fit to the data χ^2 (47) = 223.77, $p < 0.001$, RMSEA = 0.03 (90% CI = 0.03, 0.04), SRMR = 0.02, TLI = 0.93, CFI = 0.96. All factor loadings were statistically significant ($p < 0.001$) and ranged from 0.44 to 0.59 for school-stress, were 0.70 and 0.56 for primary and secondary caregiver parental acceptance (respectively), and 0.62 to 0.70 for mental health problems. Examination of the structural model revealed that gender diversity was associated with poorer perceptions of school environment, lower reports of parental acceptance and increased mental health problems. Positive perceptions of school environment and higher parental warmth were associated with reduced mental health problems. To determine if school environment and parental acceptance exert an equal effect on mental health problems, we constrained the paths from school environment to mental health and parental acceptance to mental health. A chi square difference test was significant, $\chi 2$ (48) = 187.98, $p < 0.001$, suggesting that the model fit benefits from having separate paths from school environment to mental health problems and parental acceptance to mental health problems.

4. Discussion

4.1. Conclusion and implications

The current study found that greater gender diversity in a community sample of youth is associated with increased BOLD signal in task-related brain regions. Specifically, the fusiform, orbitofrontal (lateral and medial) areas, rostral middle frontal region, occipital and parietal regions known to be active during recognition, visual/sensory perception, emotion, and memory.

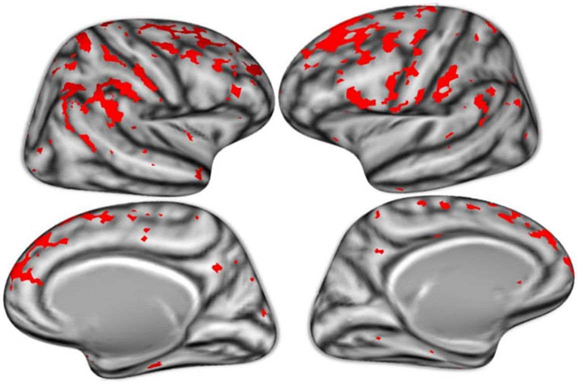
TABLE 4 Demographics of participants used in analyses.

Baseline visit demographics			Demographics second in-Person visit (year 1)		
Variable	Number	Percentage	Variable	Number	Percentage
Sex assigned at birth			N/A sex and race remain constant		
Female	2,896	66			
Male	1,489	34			
Race/ethnicity					
White	2,588	59			
Black	470	10.7			
Latino/latine/latinX	818	18.7			
Asian	96	2.2			
Other	413	9.4			
Highest household education			Highest household education		
<High school diploma	143	3.3	<High school diploma	147	3.4
High school diploma/GED	282	6.4	High school diploma/GED	266	6.1
Some college	976	22.3	Some college	1,002	22.9
Bachelors degree	1,206	27.5	Bachelors degree	1,194	27.2
Post graduate degree	1,757	40.1	Post graduate degree	1,767	40.3
Not answered/Declined to answer/Do not know	21	0.4	Not answered/Declined to answer/Do not know	9	0.2
Combined income			Combined income		
<50 K	965	22	<50 K	902	20.6
50–100 K	1,176	26.8	50–100 K	1,127	25.7
>100 K	1,949	44.4	>100 K	2,090	47.7
Not answered/Declined to answer/Do not know	295	6.7	Not answered/Declined to answer/Do not know	266	6.1

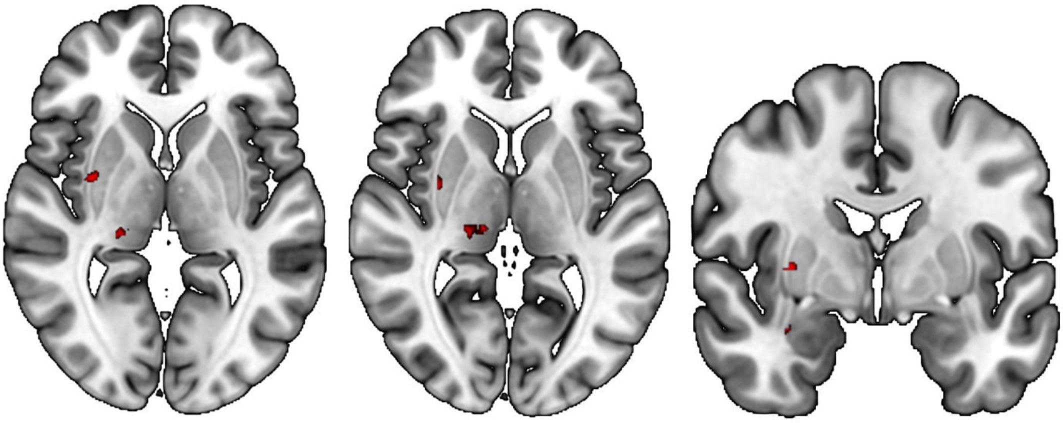
Consistent with our hypothesis, gender diversity was also associated with areas commonly activated in populations that experience stress such as the superior temporal gyrus (e.g., De Bellis et al., 2002; Hein and Monk, 2017), parahippocampal gyrus, amygdala and insula (e.g., Hein and Monk, 2017). Inconsistent with our hypothesis, gender diversity was not associated with activation in the dorsal anterior cingulate cortex. This may suggest that the dorsal anterior cingulate cortex is not associated with stress related to gender diversity. An additional reason we may not have found significant findings in the dorsal anterior cingulate is because gender diversity and fMRI imaging data were collected at different time points. The effect may have been stronger had gender diversity and brain imaging been collected at the same time. Our results support our hypothesis that gender diversity is associated with brain activation patterns that are consistent with other types of childhood stress (e.g., Etkin and Wager, 2007; Hein and Monk, 2017; Miller et al., 2020).

Parental acceptance nor youth perceptions of their school environments moderated the relationship between gender diversity and elevated activation in the insula or fusiform. This may be due to several factors. The first is that the school environment and parental acceptance measures ask youth about parental acceptance and their experience at school generally, and not in relation to their gender diversity. It will be important for future studies to replicate this study using measures that specifically assess parental acceptance and school environment as it relates to youth's gender diversity. Another potential reason that school environment and parental acceptance did not moderate the relationship between gender diversity and elevated activation is that fMRI activation while viewing emotional faces may have been more related to expectation or fear of rejection (a proximal minority stressor) as opposed to more distal stressors like parental acceptance or school environment. Finally, it is possible that the stress factors did not moderate the relationship between gender diversity and task activation due to the developmental age of the participants. Further cumulative experiences of stressful home and school environments may strengthen their modifying effects.

Finally, we found that in a sample with mostly minor levels of gender diversity, this variability is associated with decreased parental acceptance, poorer perceptions of school environment and elevated mental health problems such that the more gender diverse a child is the less parental acceptance they experience, the poorer their perception of school and the more elevated their behavioral and emotional symptoms. Positive perceptions of school environment and higher parental acceptance were associated with fewer behavioral and emotional health problems; and school environment and parental acceptance were found to be separate contributors to behavioral and emotional health problems. This suggests that the more supportive and positive a child's school environment, the more protective these factors are against the emergence of mental health problems. It is important to note that gender diversity in this study was measured dimensionally



Cortical Activation Map – Cortical fMRI Activation Significantly Associated with Gender Diversity (p<.05)



Subcortical Activation Map – Subcortical fMRI Activation Significantly Associated with Gender Diversity (p<.05)

FIGURE 4
FDR corrected *P*-value maps.

and that most participants in the sample do not have a gender minority identity.

The findings of our study are important as they suggest that even minor levels of gender diversity in community youth are associated with markers of stress in the brain. Our behavioral findings provide further support for stress experienced by gender diverse youth by demonstrating the relationship between gender diversity and lower parental acceptance as well as poorer perceptions of the school environment. Our study underscores the importance of policies and legislation to ensure that school environments protect and celebrate gender diverse youth and highlights the importance of funding to provide support to families of gender diverse youth. It is also significant that school and family environments contribute uniquely to outcomes, suggesting multiple gateways for improving outcomes for youth. Promoting acceptance and protection of gender diversity within school and family environments may have important preventative effects. Extant literature suggests a relationship between minority stressors such as gender-based victimization, bullying, lack of parental or familial support, and suicidal behaviors (e.g., Bochicchio et al., 2021). Further, minority stress is associated with behavioral dysregulation, an important mediator of the relationship between minority stress and elevated suicidal ideation (e.g., Drescher et al., 2023). Although these studies were conducted with youth and adults with a gender minority status, our findings suggest a broader, generalizable relationship that extends to youth who endorse some level of gender diversity.

4.2. Limitations and future directions

4.2.1. Measurement considerations

It is important to consider the limitations of this study when interpreting the results. A notable limitation of the current study is that the brain analyses and gender diversity data were collected at different time points. This is due to the ABCD study design as gender diversity was not measured at the study baseline visit (Potter et al., 2021). However, we believe, if anything, that this

TABLE 5 Bivariate correlations and descriptive statistics for aim 2.

Indicator variables	Mean (SD)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. SRPF item 3	3.67 (0.55)	1																	
2. SRPF item 6	3.71 (0.56)	0.34**	1																
3. SRPF item 7	3.20 (0.84)	0.24**	0.26**	1															
4. Gender diversity	18.8 (1.94)	−0.10**	−0.13**	−0.06**	1														
5. Highest household Ed.	3.96 (1.08)	0.06**	0.09**	−0.02*	−0.05**	1													
6. Sex assigned at birth	0.66 (0.47)	0.12**	0.06**	0.07**	0.10**	−0.03	1												
7. Black	0.11 (0.31)	−0.10**	−0.08**	−0.01	0.06*	−0.23**	0.07**	1											
8. Latine/LatinX/Latino	0.19 (0.39)	−0.01	−0.04*	0.01	0.01	−0.31**	0	−0.15**	1										
9. Asian	0.02 (0.14)	0	0.01	0	−0.03	0.09**	0.01	−0.05**	−0.07**	1									
10. Other Race	0.09 (0.29)	−0.03*	−0.04*	−0.01	0.02*	0.02**	0.01	−0.10**	−0.15**	−0.05*	1								
11. Puberty score	2.27 (1)	−0.01	−0.04*	−0.01	0.10**	−0.14**	0.56**	0.19**	0.08**	−0.02	0.01	1							
12. Age in months	131.2 (7.74)	−0.08**	−0.06**	−0.04*	−0.03*	0.01	0.02	0	−0.02*	−0.01	0.02	0.29**	1						
13. BPM-youth externalizing	1.89 (1.92)	−0.30**	−0.21**	−0.19**	0.23**	−0.10**	−0.11**	0.06**	0.02	−0.03*	0.03*	0.01	0.05*	1					
14. BPM-youth internalizing	1.75 (2.08)	−0.18**	−0.28**	−0.17**	0.24**	−0.08**	−0.03*	0.02	0.05*	−0.02*	0.03*	0.06**	0.04*	0.43**	1				
15. CBCL externalizing	3.62 (5.03)	−0.16**	−0.11**	−0.06**	0.06**	−0.09**	−0.11**	0.04*	0.01	−0.06**	0.01	0	0	0.30**	0.14**	1			
16. CBCL internalizing	5.03 (5.40)	−0.10**	−0.10**	−0.04**	0.08**	−0.03	0.01	−0.04**	0.01	−0.05*	0.04*	0.06**	0.02	0.15**	0.27**	0.56**	1		
17. Caregiver acceptance	2.77 (0.31)	0.21**	0.18**	0.22**	−0.13**	0.05*	0.07**	−0.01	−0.04	−0.01	−0.04*	−0.01	0.03*	−0.23**	−0.20**	−0.09**	−0.08**	1	
18. Parental acceptance	2.81 (0.28)	0.26**	0.25**	0.23**	−0.12**	0.09**	0.05**	−0.07**	−0.04*	−0.01	−0.04*	−0.02	0.04	−0.31**	−0.26**	−0.15**	−0.07**	0.39**	1

*$p < 0.05$, **$p < 0.001$.

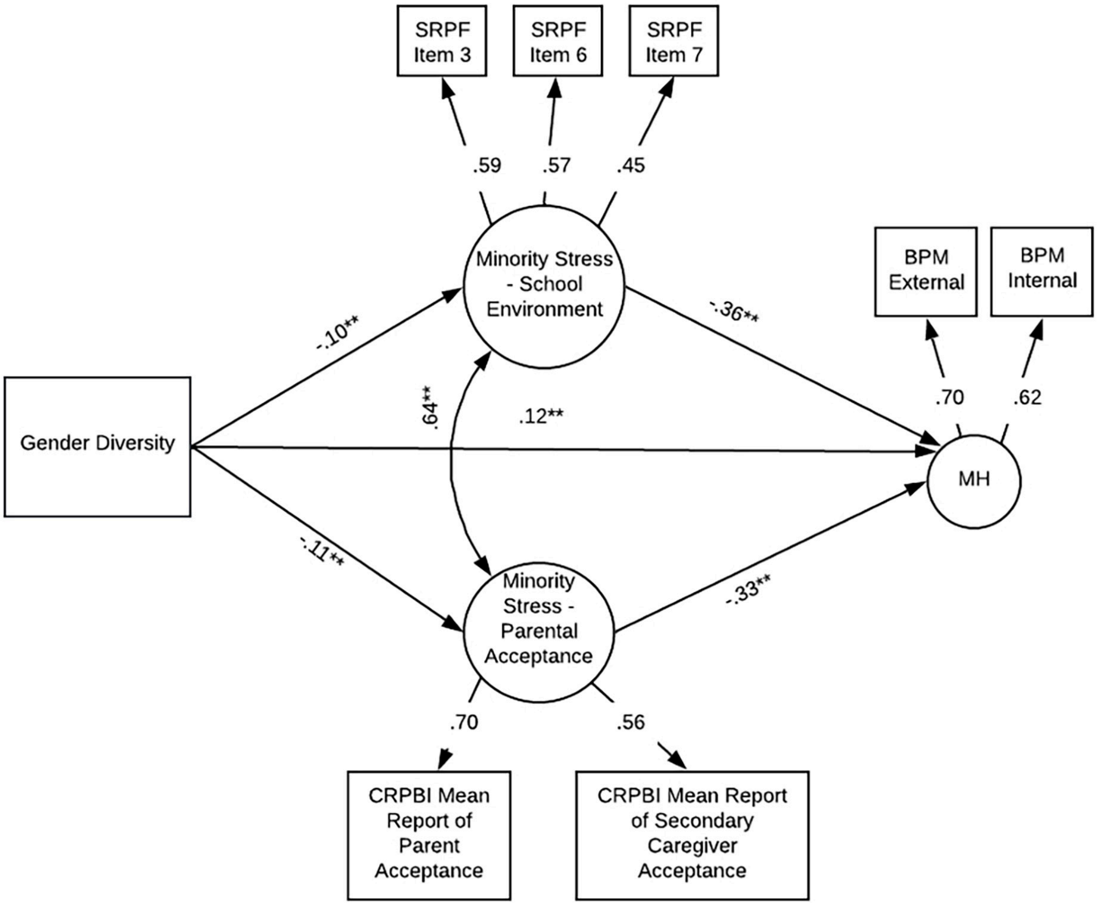


FIGURE 5
Final model. SRPF, school risk and protective factors; Item 3 = "I get along with my teachers"; Item 6 = "I feel safe at my school"; Item 7 = "The school lets my parents know when I've done something well"; BPM, brief problem monitor (ASEBA brief problem monitor—youth form for ages 11–18); CRPBI, children's report of parent behavior inventory; MH, mental health. **$p < 0.001$.

underestimates the relationships we report. Stress related to gender diversity-based bullying or victimization is likely not as prevalent at ages 9 and 10. Existing developmental literature suggests that teasing and victimization related to gender diversity emerges in early adolescence. Early adolescence is a time of "gender intensification" where peers exert pressure to conform to gender stereotypes (Hill and Lynch, 1983) and children who do not follow gender norms are more likely to be rejected or teased (e.g., Thorne, 1993; Martin and Ruble, 2010). Nevertheless, due to the reverse temporality of gender diversity, results of the study should be interpreted cautiously. Despite the limitation of the temporality of the measures, gender diversity within the sample appears to be stable across time. For instance, 77.8% of youth with data at year 1 (when gender diversity data was first collected) and year 2 either became more gender diverse or maintained the same level of gender diversity. While this was a cross-sectional study that used data from two time points, it is noteworthy that the data used is part of an ongoing study that will allow for future longitudinal assessment. It will be important for future studies to examine longitudinal associations between gender diversity, stress and fMRI activation during an emotion faces task.

Another important limitation is that the stressors in our behavioral model were not specifically assessing parental acceptance and perceptions of school environment as they relate to gender diversity. Although our findings suggest that there is a relationship between gender diversity, mental health, school perceptions, and parental acceptance in the behavioral model, our findings do not indicate that these outcomes are caused by youth gender diversity. Further studies should examine the relationship between school perceptions and parental acceptance related to gender diversity and mental health outcomes.

4.2.2. Intersectionality

Our study did not examine intersecting identities such as race, income, or ability. Intersecting bias and prejudice toward gender diverse youth may confer additional or unique risk and protective factors. Future research should examine how gender diversity-related stress uniquely impacts the neurobiology and mental health of youth with intersecting identities. Another notable limitation is that we did not examine sex differences in this study. There is some research that suggests males assigned at birth are more heavily penalized for gender diversity, specifically gender non-conformity, compared to females (e.g., van Beusekom et al., 2020). Future research should examine sex differences in gender diversity-related stress using both behavioral and fMRI methods.

5. Conclusion

Despite the above limitations, our study has important implications for our understanding of the relationship between parental acceptance, perceptions of school environment, brain function, and mental health among youth who endorse some level of gender diversity. This is the first study to examine the neural underpinnings of gender diversity and stress in a community sample of children. Our results suggest that gender diversity is associated with patterns of brain activity that are consistent with other populations who experience stress—a finding that may help to understand the consequences of expecting discrimination and/or peer victimization related to gender. While parental and school stressors did not moderate heightened fMRI activation, the current study contextualized the heightened fMRI activation by demonstrating a relationship between gender diversity, peer and family related stress, and elevated behavioral and emotional problems. Further, our findings suggest a relationship between gender diversity, family and school stressors, neurobiology and mental health even among youth who are not non-binary or transgender. Our fMRI and behavioral findings suggest that there are mental health consequences and neural underpinnings of external stress factors experienced by gender diverse youth. Our findings underscore the importance of creating school and family environments that serve as a buffer against gender diversity-related stress.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: doi: 10.15154/1523041.

Ethics statement

This study involves human participants and was reviewed and approved by the Appropriate Institutional Review Boards. Written informed consent to participate in this study was provided by the participants' legal guardian and youth provided written assent.

Author contributions

HL performed the statistical analysis and wrote the first draft of the manuscript. MA provided mentorship and technical support in the creation of the figures. BC provided technical support and mentorship of the fMRI statistical analyses. AP and SD contributed to the conception and design of the study and wrote sections of the manuscript. AP was the senior mentor on the project. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Achenbach, T. M., and Rescorla, L. (2001). *Manual for the ASEBA school-age forms & profiles: An integrated system of multi-informant assessment*. Burlington, VT: University of Vermont.

Achenbach, T. M., McConaughy, S. H., Ivanova, M. Y., and Rescorla, L. A. (2011). *Manual for the ASEBA brief problem monitor (BPM)*. Burlington, VT: University of Vermont.

American Psychological Association Division 16 and 44 (2015). *Key terms and concepts in understanding gender diversity and sexual orientation among students*. Available online at: https://www.apa.org/pi/lgbt/programs/safe-supportive/lgbt/key-terms.pdf (accessed October 1, 2022).

Arthur, M. W., Briney, J. S., Hawkins, J. D., Abbott, R. D., Brooke-Weiss, B., and Catalano, R. F. (2007). Measuring risk and protection in communities using the communities that care youth survey. *Eval. Program. Plan.* 30, 197–211. doi: 10.1016/j.evalprogplan.2007.01.009

Aspenlieder, L., Buchanan, C. M., McDougall, P., and Sippola, L. K. (2009). Gender nonconformity and peer victimization in pre-and early adolescence. *Int. J. Dev.* 3, 3–16. doi: 10.3233/DEV-2009-3103

Barber, B. K. (1997). Introduction: Adolescent socialization in context-the role of connection, regulation, and autonomy in the family. *J. Adolesc. Res.* 12, 5–11.

Barch, D. M., Albaugh, M. D., Avenevoli, S., Chang, L., Clark, D. B., Glantz, M. D., et al. (2018). Demographic, physical and mental health assessments in the adolescent brain and cognitive development study: Rationale and description. *Dev. Cogn. Neurosci.* 32, 55–66. doi: 10.1016/j.dcn.2017.10.010

Bochicchio, L., Reeder, K., Aronson, L., McTavish, C., and Stefancic, A. (2021). Understanding factors associated with suicidality among transgender and gender-diverse identified youth. *LGBT Health* 8, 245–253. doi: 10.1089/lgbt.2019.0338

Bortz, K., and Safer, J. D. (2018). Transgender, gender nonconforming teens have diminished perceptions of health. *Infect. Dis. Child.* 31:22.

Buchanan, N. T., Perez, M., Prinstein, M. J., and Thurston, I. B. (2021). Upending racism in psychological science: Strategies to change how science is conducted, reported, reviewed, and disseminated. *Am. Psychol.* 76, 1097–1112. doi: 10.1037/amp0000905

Casey, B. J., Cannonier, T., Conley, M. I., Cohen, A. O., Barch, D. M., Heitzeg, M. M., et al. (2018). The adolescent brain cognitive development (ABCD) study: Imaging acquisition across 21 sites. *Dev. Cogn. Neurosci.* 32, 43–54. doi: 10.1016/j.dcn.2018.03.001

Chaarani, B., Hahn, S., Allgaier, N., Adise, S., Owens, M. M., Juliano, A. C., et al. (2021). Baseline brain function in the preadolescents of the ABCD Study. *Nat. Neurosci.* 24, 1176–1186. doi: 10.1038/s41593-021-00867-9

De Bellis, M. D., Keshavan, M. S., Frustaci, K., Shifflett, H., Iyengar, S., Beers, S. R., et al. (2002). Superior temporal gyrus volumes in maltreated children and adolescents with PTSD. *Biol. Psychiatry* 51, 544–552. doi: 10.1016/S0006-3223(01)01374-9

Drescher, C. F., Kassing, F., Mahajan, A., and Stepleman, L. M. (2023). The impact of transgender minority stress and emotion regulation on suicidality and self-harm. *Psychol. Sex.* doi: 10.1080/19419899.2023.2164867

Etkin, A., and Wager, T. D. (2007). Functional neuroimaging of anxiety: A meta-analysis of emotional processing in PTSD, social anxiety disorder, and specific phobia. *Am. J. Psychiatry* 164, 1476–1488. doi: 10.1176/appi.ajp.2007.07030504

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R. Z., Heeringa, S., et al. (2018). Recruiting the ABCD sample: Design considerations and procedures. *Dev. Cogn. Neurosci.* 32, 16–22. doi: 10.1016/j.dcn.2018.04.004

Gordon, A. R., Conron, K. J., Calzo, J. P., White, M. T., Reisner, S. L., and Austin, S. B. (2018). Gender expression, violence, and bullying victimization: Findings from probability samples of high school students in 4 US school districts. *J. Sch. Health* 88, 306–314. doi: 10.1111/josh.12606

Greytak, E. A., Kosciw, J. G., Villenas, C., and Giga, N. M. (2016). *From teasing to torment: School climate revisited. A survey of us secondary school students and teachers.* New York, NY: GLSEN.

Hagler, D. J., Hatton, S. N., Cornejo, M. D., Makowski, C., Fair, D. A., Dick, A. S., et al. (2019). Image processing and analysis methods for the adolescent brain cognitive development study. *Neuroimage* 202:116091. doi: 10.1016/j.neuroimage.2019.116091

Hein, T. C., and Monk, C. S. (2017). Research review: Neural response to threat in children, adolescents, and adults after child maltreatment–a quantitative meta-analysis. *J. Child Psychol. Psychiatry* 58, 222–230. doi: 10.1111/jcpp.12651

Hendricks, M. L., and Testa, R. J. (2012). A conceptual framework for clinical work with transgender and gender nonconforming clients: An adaptation of the minority stress model. *Prof. Psychol.* 43, 460–467. doi: 10.1037/a0029597

Hill, J. P., and Lynch, M. E. (1983). "The Intensification of Gender-Related Role Expectations during Early Adolescence," in *Girls at Puberty*, eds J. Brooks-Gunn and A. C. Petersen (Boston, MA: Springer), doi: 10.1007/978-1-4899-0354-9_10

Ho, D. E., Imai, K., King, G., and Stuart, E. A. (2011). MatchIt: Nonparametric preprocessing for parametric causal inference. *J. Stat. Softw.* 42, 1–28. doi: 10.18637/jss

Hu, L. T., and Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Struct. Equ. Model.* 6, 1–55. doi: 10.1080/10705519909540118

Johns, M. M., Lowry, R., Andrzejewski, J., Barrios, L. C., Demissie, Z., McManus, T., et al. (2019). Transgender identity and experiences of violence victimization, substance use, suicide risk, and sexual risk behaviors among high school students—19 states and large urban school districts, 2017. *Morb. Mortal. Wkly. Rep.* 68, 67–71. doi: 10.15585/mmwr.mm6803a3

Keding, T. J., and Herringa, R. J. (2016). Paradoxical prefrontal–amygdala recruitment to angry and happy expressions in pediatric posttraumatic stress disorder. *Neuropsychopharmacology* 41, 2903–2912. doi: 10.1038/npp.2016.104

Kiyar, M., Kubre, M. A., Collet, S., Bhaduri, S., T'sjoen, G., Guillamon, A., et al. (2022). Minority stress and the effects on emotion processing in transgender men and cisgender people: A study combining fMRI and 1H-MRS. *Int. J. Neuropsychopharmacol.* 25, 350–360. doi: 10.1016/j.jbtep.2020.101629

Kosciw, J. G., Clark, C. M., Truong, N. L., and Zongrone, A. D. (2020). *The 2019 national school climate survey: The experiences of lesbian, gay, bisexual, transgender, and queer youth in our Nation's schools.* New York, NY: GLSEN.

Landolt, M. A., Bartholomew, K., Saffrey, C., Oram, D., and Perlman, D. (2004). Gender nonconformity, childhood rejection, and adult attachment: A study of gay men. *Arch. Sex. Behav.* 33, 117–128. doi: 10.1023/B:ASEB.0000014326.64934.50

Loso, H., Dube, S. L., Chaarani, B., Ivanova, M., Garavan, H., Johns, M. M., et al. (2023). Associations between gender nonconformity, school environments, family conflict and emotional and behavioral health among children ages 10 to 11. *J. Adolesc. Health.* [in press].

Lowry, R., Johns, M. M., Gordon, A. R., Austin, B., Robin, L. E., and Kann, L. K. (2018). Nonconforming gender expression and associated mental distress and substance use among high school students. *JAMA Pediatr.* 172, 1020–1028. doi: 10.1001/jamapediatrics.2018.2140

Martin, C. L., and Ruble, D. N. (2010). Patterns of gender development. *Annu. Rev. Psychol.* 61, 353–381. doi: 10.1146/annurev.psych.093008.100511

McQuillan, M. T., Kuhns, L. M., Miller, A. A., McDade, T., and Garofalo, R. (2021). Gender minority stress, support, and inflammation in transgender and gender-nonconforming youth. *Transgend. Health* 6, 91–100. doi: 10.1089/trgh.2020.0019

Meyer, I. H. (1995). Minority stress and mental health in gay men. *J. Health Soc. Behav.* 36, 38–56. doi: 10.2307/2137286

Meyer, I. H. (2003). Prejudice, social stress, and mental health in lesbian, gay, and bisexual populations: Conceptual issues and research evidence. *Psychol. Bull.* 129, 674–697.

Meyer, I. H., and Dean, L. (1998). "Internalized homophobia, intimacy, and sexual behavior among gay and bisexual men," in *Stigma and sexual orientation: Understanding prejudice against lesbians, gay men, and bisexuals*, ed. G. M. Herek (Thousand Oaks, CA: Sage Publications), 160–186. doi: 10.1037/0033-2909.129.5.674

Miller, J. G., Ho, T. C., Humphreys, K. L., King, L. S., Foland-Ross, L. C., Colich, N. L., et al. (2020). Early life stress, frontoamygdala connectivity, and biological aging in adolescence: A longitudinal investigation. *Cereb. Cortex* 30, 4269–4280. doi: 10.1093/cercor/bhaa057

Paley, A. (2021). *National survey on LGBTQ youth mental health, 2021.* West Hollywood, CA: The Trevor Project.

Petersen, A. C., Crockett, L., Richards, M., and Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *J. Youth Adolesc.* 17, 117–133. doi: 10.1007/BF01537962

Potter, A., Dube, S., Allgaier, N., Loso, H., Ivanova, M., Barrios, L. C., et al. (2021). Early adolescent gender diversity and mental health in the Adolescent Brain Cognitive Development study. *J. Child. Psychol. Psychiatry* 62, 171–179. doi: 10.1111/jcpp.13248

Roberts, A. L., Rosario, M., Corliss, H. L., Koenen, K. C., and Austin, S. B. (2012). Elevated risk of posttraumatic stress in sexual minority youths: Mediation by childhood abuse and gender nonconformity. *Am. J. Public Health* 102, 1587–1593. doi: 10.2105/AJPH.2011.300530

Rosseel, Y. (2012). Lavaan: An R package for structural equation modeling. *J. Stat. Softw.* 48, 1–36. doi: 10.18637/jss.v048.i02

RStudio Team (2020). *RStudio: Integrated Development for R.* Boston, MA: RStudio, PBC.

Schaefer, E. S. (1965). A configurational analysis of children's reports of parent behavior. *J. Consult. Psychol.* 29, 552–557. doi: 10.1037/h0022702

Spivey, L. A., and Prinstein, M. J. (2019). A preliminary examination of the association between adolescent gender nonconformity and suicidal thoughts and behaviors. *J. Abnorm. Child Psychol.* 47, 707–716. doi: 10.1007/s10802-018-0479-6

Thorne, B. (1993). *Gender play: Girls and boys in school.* New Brunswick, NJ: Rutgers University Press.

Toomey, R. B., McGuire, J. K., and Russell, S. T. (2012). Heteronormativity, school climates, and perceived safety for gender nonconforming peers. *J. Adol.* 35, 187–196.

van Beusekom, G., Collier, K., Bos, H., Sandfort, T., and Overbeek, G. (2020). Gender nonconformity and peer victimization: Sex and sexual attraction differences by age. *J. Sex. Res.* 57, 234–246. doi: 10.1080/00224499.2019.1591334

Weissman, D. G., Jenness, J. L., Colich, N. L., Miller, A. B., Sambrook, K. A., Sheridan, M. A., et al. (2020). Altered neural processing of threat-related information in children and adolescents exposed to violence: A transdiagnostic mechanism contributing to the emergence of psychopathology. *J. Am. Acad. Child Adolesc. Psychiatry* 59, 1274–1284. doi: 10.1016/j.jaac.2019.08.471

Wilson, B. D. M., Choi, S. K., Herman, J. L., Becker, T. L., and Conron, K. J. (2017). *Characteristics and mental health of gender nonconforming adolescents in California: Findings from the 2015–2016 California Health Interview Survey.* Los Angeles, CA: UCLA Center for Health Policy Research.

Winkler, A. M., Ridgway, G. R., Webster, M. A., Smith, S. M., and Nichols, T. E. (2014). Permutation inference for the general linear model. *Neuroimage* 92, 381–397. doi: 10.1016/j.neuroimage.2014.01.060

Winkler, A. M., Webster, M. A., Vidaurre, D., Nichols, T. E., and Smith, S. M. (2015). Multi-level block permutation. *Neuroimage* 123, 253–268. doi: 10.1016/j.neuroimage.2015.05.092

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Equity, diversity, and inclusion in developmental neuroscience: Practical lessons from community-based participatory research

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Exclusion of racialized minorities in neuroscience directly harms communities and potentially leads to biased prevention and intervention approaches. As magnetic resonance imaging (MRI) and other neuroscientific techniques offer progressive insights into the neurobiological underpinnings of mental health research agendas, it is incumbent on us as researchers to pay careful attention to issues of diversity and representation as they apply in neuroscience research. Discussions around these issues are based largely on scholarly expert opinion without actually involving the community under study. In contrast, community-engaged approaches, specifically Community-Based Participatory Research (CBPR), actively involve the population of interest in the research process and require collaboration and trust between community partners and researchers. This paper outlines a community-engaged neuroscience approach for the development of our developmental neuroscience study on mental health outcomes in preadolescent Latina youth. We focus on "positionality" (the multiple social positions researchers and the community members hold) and "reflexivity" (the ways these positions affect the research process) as conceptual tools from social sciences and humanities. We propose that integrating two unique tools: a positionality map and Community Advisory Board (CAB) into a CBPR framework can counter the biases in human neuroscience research by making often invisible–or taken-for-granted power dynamics visible and bolstering equitable participation of diverse communities in scientific research. We discuss the benefits and challenges of incorporating a CBPR method in neuroscience research with an illustrative example of a CAB from our lab, and highlight key generalizable considerations in research design, implementation, and dissemination that we hope are useful for scholars wishing to take similar approaches.

KEYWORDS

community-based participatory research (CBPR), community advisory board (CAB), community-engaged research, developmental neuroscience, latino/a/x families

Equity, diversity, and inclusion in developmental neuroscience: practical lessons from community-based participatory research

Mental health concerns account for a considerable percentage of the United States (U.S.) disease burden (Substance Abuse and Mental Health Services Administration, 2020) and are highly prevalent among ethnically and racially minoritized adults and youth (Dankwa-Mullan et al., 2010). As magnetic resonance imaging (MRI) and other neuroscientific techniques offer progressive insights into the neurobiological underpinnings of mental illness and become more incorporated into the mental health research agenda, it is incumbent on us as researchers that we pay careful attention to issues of diversity and representation as they apply in neuroscience. Problematically, many discussions around these issues are based on academic expert opinion without involving the community under study. In contrast, community-engaged approaches, such as Community-Based Participatory Research (CBPR), actively involve the population of interest in the research process and depend on collaboration between community partners and researchers (Mikesell et al., 2013). Community partners provide opportunities for open conversation about lived experiences that can guide efforts for promoting inclusion. This article outlines a community-engaged approach to neuroscience that intentionally includes community members in the research process. Our goal is to share our lab's experiences with incorporating CBPR approaches into developmental neuroscience protocols so that researchers can assess the opportunities afforded by such approaches and consider including them in their own work. We use our efforts to incorporate CBPR methods into our ongoing study on mental health and neurodevelopmental outcomes in preadolescent Latina youth as an illustrative example and provide specific tools, materials, and guidelines for future neuroscience research that aims to incorporate a community-engaged agenda.

Many neuroscience studies focus either intentionally on race and ethnicity (i.e., racialized perceptions or cognition) or study local samples with shared cultural, ethnic, or racial experiences and backgrounds. However, despite the diversity of the populations we study, an intentional focus on representing diverse voices in our research is often neglected by neurosciences. In fact, most neuroimaging studies do not even report the racial and ethnic demographic composition of their samples (Goldfarb and Brown, 2022). Equitable science should be a leading motive for neuroscience as we navigate a racialized terrain that disproportionately excludes historically stigmatized and oppressed groups from research. If our inferences aim to reflect generalizable conclusions that benefit basic science and clinical goals, all groups should be included in the scientific process.

Three leading factors contribute to equity issues plaguing human neuroscience research: (1) lack of diversity in the neuroscience workforce leading to unacknowledged bias in scientific assumptions and scientific agendas that are often not aligned with the goals of the community under study; (2) lack of diversity in research samples and over-representation of Western and highly educated societies relative to the global population resulting in biases favoring white research participants (Henrich et al., 2010); and (3) insufficient transparency about participant demographics in neuroscience research prohibiting demographic group comparisons across samples. Addressing these issues requires neuroscientists to become more culturally competent if they intend to work with specific marginalized populations, focusing on sensitivity in research questions, hypothesis formation, and especially research methods (Henrich et al., 2010; Webb et al., 2022a). Because demographic factors, including sex, race, ethnicity, and socioeconomic status affect (either directly or through associated mediators) neural structure, function, and related behaviors, overlooking diversity has major implications for scientific reproducibility, generalizability, and the development of prevention and intervention efforts. We contend that a community-engaged approach can help address the unacknowledged bias and lack of diversity and inclusion in neuroscience research.

In the following sections, we first highlight the ways in which human neuroscience research has historically ignored the experiences of marginalized groups and led to biased knowledge generation in neuroimaging. Next, we describe features of interdisciplinary methods that may be adopted to actively counter these biases in neuroscientific research. Specifically, we describe "positionality" as a tool for acknowledging contextualized social positions of the researchers and the community they study, and CBPR from sociology and public health as mechanisms for community-engaged research. Within the CBPR framework, we detail how to build a Community Advisory Board (CAB, a group of community members that collaborates with and advises the researchers) as a practical tool for collaborating with the community in an effort to promote diversity, equity, and inclusion. We conclude by discussing the benefits and challenges of incorporating a CAB in neuroscientific community-engaged research and highlight key generalizable considerations in research design, implementation, and dissemination that we hope are useful for scholars wishing to take similar approaches.

Bias in neuroscientific research

Marginalized communities, particularly those who have experienced historical oppression due to their race and ethnicity, have not only been disproportionately excluded from neuroscientific research but have also been actively harmed by intentional and unintentional biases (Webb et al., 2022a). Importantly, the conclusions drawn from such biased research find their way back to the communities under study, which further escalates systemic biases and mistrust against scientists. As neuroscientists, it has taken us far too long to realize that our research questions, hypotheses, and methods can introduce biases if we single-mindedly focus on our own (often prejudiced) assumptions. If we do not open communication channels and check in with our research participants, we will invariably continue to exacerbate the problem. In extant research, certain subsets of the population, including Black and brown people, have been too often viewed as not worthy of studying scientifically, or too "challenging" to recruit, leading to severe underrepresentation of marginalized groups in neuroscientific research.

Black, Latina, and other women of color, who are further marginalized by the interaction of gender and race, are particularly absent in neuroscience research (Spates, 2012; Gatzke-Kopp, 2016). For example, a systematic literature review reported that women and racial/ethnic minorities were underrepresented in functional magnetic resonance imaging (fMRI) studies of cardiovascular disease (Jones et al., 2020). This is especially problematic as certain ethnically and racially minoritized groups, like Black people, experience elevated rates of cardiovascular disease compared to their white counterparts (Loehr et al., 2008; Leigh et al., 2016). Similarly in the mental health domain, Latina girls, who are also underrepresented in neuroscientific research, demonstrate higher levels of untreated anxiety relative to their Black and white peers (McLaughlin et al., 2007). This exclusion of racialized minorities in neuroscience research directly harms communities and potentially encourages the development of biased prevention and intervention approaches.

Many electrophysiological devices that inform physical and mental health treatments were not designed to handle phenotype variability, contributing to a systemic exclusion of and erasure of data from people with darker skin and coarse or curly hair (e.g., Afro-Latino/a/x identifying) (Parker and Ricard, 2022; Webb et al., 2022a). Taking the technology used by our lab as an example, MRI uses a head coil that restricts big, afro-textured hair and sew-in hair extensions can have metal tracks that prevent an individual from entering an MRI bore (Thompson, 2009). The MRI machine itself also places great demands on participants, particularly children. Children must approach a very large, gray, loud, and strange machine, lie down on a table, and allow the experimenter to slowly glide them into the confined space of the scanner bore, where their head is restricted. Any of these things alone may induce worry, stress, and negative affect, and MRI procedures have been demonstrated to elicit feelings ranging from minor apprehension to severe panic, to increase cortisol levels, and to activate the sympathetic nervous system. The experienced stress during an fMRI experiment can potentially profoundly influence baseline neural activity; the perception of task stimuli, task engagement, and performance; as well as the physiology leading to functional activation patterns (Michalska et al., 2020). The degree to which the scanner environment influences MRI data varies with dispositional traits and demographic variables, which, depending on the study population and design, can lead to inaccurate interpretations of the resulting MRI data. For minoritized children, who have not previously been exposed to medical or research environments, experiencing such a novel and scary procedure might prove particularly daunting. In addition, MRI-induced negative affect will likely be amplified in children exposed to lifelong racialized stressors, including distrust of medical services, exhibiting signs of threat hypervigilance. Therefore, what neuroscientists might deem as "atypical" or "problematic" responses in minoritized youth, may instead be driven by chronic stress experiences that potentiate pre-scan anxiety.

Mounting evidence shows the effects of lived experiences on psychological processes (Torres et al., 2011; Berger and Sarnyai, 2015; Harnett et al., 2019; Mekawi et al., 2020; Bird et al., 2021; Fani et al., 2021, 2022; Webb et al., 2022b). As such, methodological tools can both be subject to bias against certain phenotypes shared by marginalized races and capture individual differences resulting from experiences that may co-vary with those phenotypes. For example, mental health symptoms that can arise from the experiences of racism, such as post-traumatic stress disorder, anxiety, hypervigilance, and anhedonia, may be reflected in psychophysiology data

(Martínez et al., 2014; Harnett et al., 2019). Racial differences in the neural and behavioral responses to threats have been, at least in part, attributed to exposure to negative life experiences (Harnett et al., 2019), which occur at disproportionately higher rates in communities of color (Slopen et al., 2016) and may provide new insight into the mechanisms underlying racial disparities in mental health.

Approaches to counter bias

Although no coding schema is perfect at encapsulating the rich and diverse identities of our research populations, researchers should be mindful and explicit of their selected operationalization of race and ethnicity. When testing group differences by gender, race, ethnicity, socioeconomic status, and their intersections, researchers should consider including measures developed from the perspective of the identified population, including measures that characterize larger systems of inequity and oppression. For example, measures quantifying experienced racism, life events, or neighborhood characteristics rather than (or in addition to) ethnic or racial categories can be incorporated to better identify why any observed differences exist and ascertain the structural systems that perpetuate them. This type of bottom-up thinking and operationalization in neuroscience has been termed "situated neuroscience" by feminist neuroscience scholars (Einstein, 2012; Walsh and Einstein, 2020), who argue that research findings must be contextualized within lived experiences. Whereas the traditional approach to science views the scientist in the role of the "observer" or the "outsider," a *situated neuroscience* approach instead urges the scientist to consider their own social situation as well as that of the people they study. The multiplex of social locations (social group membership, geographical location, cultural background, age, etc.) from which the researcher sits in and their relative position with respect to others influences the way they experience their environment. Arguably, those at the top of social hierarchies can easily lose sight of the nature of social reality in their scientific pursuits and consequently miss critical questions about the social world (Harding, 2015). The practice of intentionally acknowledging how one's social position shapes the generation of knowledge, or "positionality," is a practice frequently employed by ethnographers (e.g., Rose, 1997; Reyes, 2020) and feminist theorists (Harding, 2004, 2015). We believe that positionality is not only useful for ethnographic and feminist research but also for neuroscience research (or in general all research). Through the practice of positionality and contextualizing the persons involved in research (including the researcher), we are able to "situate" our study and make the invisible relationships and taken-for-granted assumptions visible. One way to delineate positionality in a research study is by creating a so-called "positionality map," sometimes also referred to as a "social identity map" or "standpoint map" (Jacobson and Mustafa, 2019). This map organizes in a diagram the standpoint of the scientist or knowledge-producer, making people more aware of the power inherent in positions of scientific authority. We elaborate on our own positionality mapping in forthcoming sections (see **Figure 1** for our positionality map).

Whereas positionality involves explicitly identifying researchers' social positions relative to the population under study, "reflexivity" is the process of critically examining how these positions affect the research process and resulting data (Chiseri-Strater, 1996). Reflexivity, alongside positionality, is an inductive approach favored by qualitative researchers and ethnographers conducting community-engaged field research. This approach aspires to reduce the power relations inherent in research and empower the community by facilitating their involvement in the design, implementation, and outcomes of research. Even though it might seem counterintuitive or even antithetical to combine such an inductive method with the often deductive objectives of neurosciences, emerging examples from a situated neuroscience approach indicate otherwise. For example, an influential community-engaged neurobiological study on the effects of female genital circumcision on the central nervous system and chronic pain in Somali Canadian women centered women's experiences via a CAB that gave input and guidance on the study (Einstein, 2012). By reflecting on her own position as a white female immigrant American neuroscientist in Canada and co-producing knowledge using the definitions, standards, and perspectives of the community, Einstein (2012) portrayed the lived experiences of the community she studies alongside the neurophysiological data. This blended approach empowers both researchers and study participants as persons embedded in their environments and experiences and counters the frequently reductionist views of the brain. After all, isn't the goal of neuroscience to reveal what experiences are "like" for people (i.e., neurobiological mechanisms for thinking, affect, behavior, development, etc.)? Below we outline our own approach to CBPR via the formation of a CAB in our neurodevelopmental study of Latina girls and their families.

Community-engaged research

A "*community*" is an interdependent group of people that share sets of characteristics, culture, values, and norms and come together by a sense of overall care for what happens to one another, understanding that what happens to one individual affects many others as they navigate similar relationships within a social structure and specific geographical location (Nutbeam and Kickbusch, 1998; MacQueen et al., 2001). As researchers, we recruit from communities and study people who belong to communities, if not the whole communities themselves. Importantly, even though all human research is in fact the study of people embedded in communities, limited

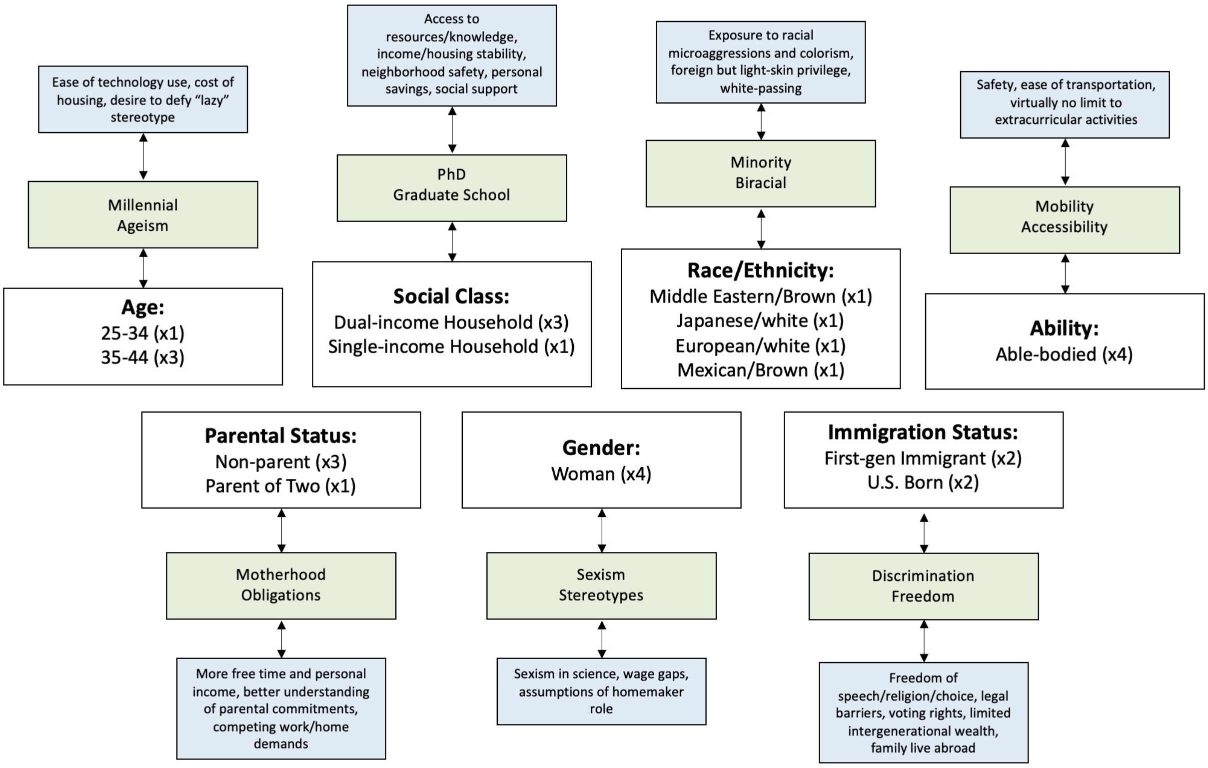


FIGURE 1
Positionality map. Tier 1 (white boxes) represents the identity categories selected for the current study (with a number representing how many individuals share a particular identity). Tier 2 (green boxes) specifies how these identities impact our lives and Tier 3 (blue boxes) elaborates further on the particularities of these identities.

work considers the impact of this research *on* the community. For instance, qualitative social sciences traditionally have an interest in the communities they study and emphasize building relationships with the people who are studied, taking into account the community members' perspectives and researchers' own positionality (Jacobson and Mustafa, 2019). This approach is particularly useful when the research is focused on "hard to reach" populations who are socially excluded from sectors in society, which limits their access to resources and inhibits their motivation to seek resources (Flanagan and Hancock, 2010). Individuals with mental health disorders or children with anxiety or conduct problems can be considered hard-to-reach populations. Due to numerous and compounding structural barriers, people who belong to marginalized communities are often reluctant to participate in research, limiting generalizability of research findings on mental health outcomes.

In response to escalating demand at multiple societal levels (e.g., community leaders, policymakers, funding agencies) calling for the broadening of methodological approaches and involvement of impacted communities in research, we are experiencing a gradual (albeit slow) shift in public health research agendas (Ahmed and Palermo, 2010). *Community-engaged research*, conceptualized as an avenue through which the complex cultural issues that affect health disparities in underserved communities can be addressed (Michener et al., 2012), is defined as the process of working collaboratively with groups of people affiliated by: (a) geographic proximity, (b) special interest, or (c) similar situations, to address issues affecting the wellbeing of those people and encourages community-academic partnerships (Drahota et al., 2016). One of the most important aspects of community-engaged research is the condition that community members work with researchers as equal interested parties and actively shape the research they are a part of Andrews et al. (2013). There are several types of community-engaged research aimed at empowering the community under study (Annett and Rifkin, 1995; Fetterman et al., 1996; Rifkin, 1996; United States Environmental Protection Agency, 2015). In this article, we focus on CBPR, which takes a partnership approach to research by involving interested community partners in all facets of the research process (Cornwall and Jewkes, 1995; Faridi et al., 2007). In other words, CBPR asks: how will the lives of people in communities be impacted by a specific piece of research and do those people have a voice in whether and how the research will be conducted?

CBPR dates to the early 1930s and is predominantly used by public health researchers in generating health-enhancing programs that evolve through community members (Lewin, 1947; Faridi et al., 2007; Freire, 2018). This framework is embedded within public health education, but has become increasingly interdisciplinary, entering departments of sociology, psychology, and more (Medicine, 1997; Sun et al., 2022). As noted above, CBPR is a collaborative research approach that actively involves communities directly affected by the issue under study in every aspect of the research process, from design to dissemination. This brings about mutual ownership of the products produced from research (Viswanathan et al., 2004). CBPR aims to improve health and well-being via a reciprocal transfer of expertise between the research team and community partners with an overarching goal of bi-directional learning, equal exchange of knowledge, and shared power in decision making (Castille, 2018). CBPR initiatives such as CABs include community members as research partners at multiple steps in the research process. This relationship offers researchers the opportunity to situate themselves and the people they study and provides a baseline for reflexivity. The researcher learns about and acknowledges shared and distinct experiences and social locations of persons involved in the study.

CBPR is employed by first identifying a key population or geographic location of interest, which takes place in the planning stages of research. As is the case for our work, this population might be connected to the local sample of a research study. CBPR is one of the most intensive community-engaged research approaches, in which researchers and community members share power in the identification of research topics and questions, the application of results, and the dissemination of findings (Minkler, 2010; Yuan et al., 2016). Of note, partnerships systematically embedded in the research process maximize the applicability of the research findings (Pasick et al., 2010). Overall, CBPR aims to enhance the interpretation of an issue via collaboration with those most affected and subsequently integrate that knowledge for the improvement and wellbeing of the community of focus (Green et al., 1995; Israel et al., 2001).

All phases of a CBPR project involve a close-knit collaboration and a strong foundation for mutual understanding, respect, and trust between the participating members. Community collaborators act as informational liaisons between scientists and community, typically forming a group of approximately 6–12 people. These individuals can be interested parties in the community, members of the community themselves, or under-represented individuals. They make up the CAB and agree to this position with full awareness of what participation in this capacity entails. This means that there must be mutually agreed upon goals and a co-generated governance structure, including rules of conduct, ensuring continued collaboration from the beginning to the end stages of a research project. In the following section, we provide a concrete example of a neuroscience study conducted by our research team that integrates a CBPR research strategy.

An illustration from a community-engaged neuroscience approach

The Kids Interaction and Neurodevelopment (KIND) Laboratory at the University of California Riverside (UCR) leverages MRI and psychophysiological methods to study the neurodevelopment of emotion understanding in typically developing children as well as children with pediatric anxiety and disruptive behavior problems. The primary ongoing longitudinal study at the KIND Lab, the *KIND Lab Girls Study* (*KLG Study*), focuses on preadolescent Latina girls and their families. Around the end of 2019, shortly before the start of the COVID-19 pandemic, the KIND Lab began a collaboration with colleagues from the UCR sociology department (SLS and RBF) to center the voices of the local community (Latino/a/x families in the Riverside catchment area) and better understand the cultural experiences shaping their mental health.

UCR is situated in the two-county area in Southern California, referred to as the Inland Empire (IE). This rural area encompasses the largest county in the United States, San Bernardino county, characterized as a major warehousing and distribution hub for global corporations (Ebner, 2020). Although immigration and emigration have undergone transitions in recent years, the IE remains home to a large population of Latino/a/xs experiencing elevated levels of psychological distress that raises mental health concerns (Barragán et al., 2020). This population also significantly under-utilizes mental health services compared to non-Hispanic white Americans, making them a priority at-risk community (Rao et al., 2007). Underutilization of services potentially stems from experiences of stigma and discrimination (Link and Hatzenbuehler, 2016). Although there has been an overall shift in mental health services, cultural stigmas persist and serve as barriers to attitudes toward help-seeking (Vogel et al., 2006; Wei et al., 2015; Zhou et al., 2022). These barriers around mental health stigma also affect the participation of these historically underserved communities in scientific research studies on mental health, particularly in adolescents.

The *KLG Study* did not start out with a CBPR emphasis, instead, it began with a focus on the neural bases of disruptive behavior disorder and conduct problems in Latina youth based on our prior work (Michalska et al., 2015, 2016). However, in the process of collecting data and informally speaking with families, we learned that what girls in our community were instead struggling with was elevated panic, and separation and social anxiety, exacerbated by social stressors. Problematically, Latina adolescents experience more internalizing symptoms and higher rates of untreated anxiety than their white, Black, and Latino peers (McLaughlin et al., 2007; Tran et al., 2014; Kann et al., 2018; Stafford and Draucker, 2020). Indeed, to date, even though we did not specifically recruit *KLG Study* participants for anxiety symptoms, 28.3% of child participants meet diagnostic criteria for anxiety disorder based on parental reports on the Screen for Child Anxiety Related Emotional Disorders (SCARED; Birmaher et al., 1997), and 30.8% have levels of anxiety in the subclinical range. In our interviews, we were also struck by the unique socialization experiences of Latinx communities that potentially impact mental health outcomes. For example, Latino/a/x parents play a pivotal role in shaping how their children process emotions (Michalska and Davis, 2019) and understand experiences that relate to ethnic-racial discrimination (Ayón, 2016), which may play a protective role in the association between racialized stressors and children's mental health symptoms. Parents influence the development of behavioral adjustments to help or hinder their children's emotion regulation in emotionally charged encounters (Kochanska, 2002). Thus, our research pays particular attention to the influence of ethnic-racial value socialization practices among Latina mothers on their children's emotion expression, recognition, and regulation when they engage in threat and safety learning, as well as mother-child interactions during tasks. Based on this context and with guidance from the UCR Center for Health Disparities Research, we re-evaluated the aims of our study to prioritize families' concerns on our research agenda and center their lived experiences. We began by creating our own positionality map as a platform for self-reflexive analysis (see **Figure 1**).

Researcher positionality mapping

As reviewed above, a positionality map allows us to critically examine our research roles as they pertain to identity, power, and privilege, and develop attitudes that embrace cultural humility (Collins et al., 2018). Because researchers are primary vessels through which information is filtered to generate data, our social identities affect how we interpret this information (Leibing and McLean, 2007; McLean, 2007; Day, 2012; Jacobson and Mustafa, 2019). Identities can include race/ethnicity, sexual orientation, ability, age, and citizenship (Dhamoon and Hankivsky, 2011; Collins, 2015; Jacobson and Mustafa, 2019). Because identities are fluid and ever-changing, identifying them is a complex process, particularly in the context of developmental research where participants are followed longitudinally over extended periods of time. Here (and in general), we believe that positionality mapping should be a routine and regular practice. Our positionality map represents an initial step in reflecting on how our current identities shape our perspectives as researchers (Day, 2012; Jacobson and Mustafa, 2019) and we intend to return to it regularly as the *KLG Study* progresses. We have shared our positionality maps with select CAB members during a workshop series and we intend to incorporate them in future meetings with the entire CAB.

Informed by previous work on positionality (Jacobson and Mustafa, 2019), our research team reflected on the identities that were most relevant for the focus of the *KLG Study* on Latina girls and their families. Per prior guidelines, we focused on facets of our social identity that help us better understand the power relations imbued in our research, as well as those uniquely impacted by the social and political climate our KIND Lab is located in. Tier 1 (white boxes) represents the following selected social identities: social class, race/ethnicity, ability, parental status, gender, age range, and immigration status. The research team that completed the positionality mapping exercise included two faculty and two graduate students (in addition to a larger research group comprised of graduate and undergraduate trainees in the KIND Lab) who participated in CAB meetings. The two faculty members included: (1) a white Polish-Austrian woman with expertise in developmental neuroscience and pediatric anxiety; (2) a Brown Turkish woman with expertise in inter-group relations and racial health disparities. The two graduate students included: (1) a Latina mother and doctoral student in sociology with training in school and medical sociology, who had also completed coursework in community-engaged research, and (2) an Asian-American woman and doctoral student in developmental psychology with training in the neurodevelopment of anxiety in underrepresented youth and their parents. Tier 2 (green boxes) specifies how each of these identities impact our lived experiences and Tier 3 (blue boxes) further elaborates on the nuances of these identities. As an example, we discussed our team's parental status and ethnic composition due to our focus on maternal parenting among Latina mothers. One of our four research team members is also a Latina mother, making them uniquely equipped to empathize with community members' parental demands, whereas other team members acknowledge they have more free time and personal income or may benefit from racial privilege due to European ancestry. Mapping identities can shed light on our explicit and hidden identities, which can strengthen a study (i.e., shared gender identities among the research team and our participants in our study) or reveal our hidden assumptions and worldviews (i.e., racial privilege, social class advantages, and ableism). The positionality map fosters awareness of our positions and the way they shape the production and interpretation of knowledge (Campbell and Wasco, 2000; Jacobson and Mustafa, 2019). For example, it has allowed our research team to better identify our "blind spots" and expand our group to include and recruit members whose identities were previously inadequately represented. It has also created an opening for eliciting counternarratives that deprivilege researcher expertise and enable us to ask questions that were initially not on our research agenda but the community considers urgent. Doing so as a collaborative process allows for multiple interpretations from a variety of entry points and perspectives. Our plan is to sustain an awareness of these multiple perspectives as we continue to collect and analyze our data.

Community-researcher partnership

With guidance from the UCR Center for Health Disparities Research, the research team partnered with Latina mothers residing in the IE and participating in the *KLG Study* to form the project's CAB, named the "Emotional Learning Research Community Advisory Board". Following prior recommendations (Newman et al., 2011) our research team targeted 10–15 community advisors. All CAB-related procedures were approved by the Institutional Review Board at UCR. In our submission for protocol approval, we described the CAB meetings as a series of community outreach discussion meetings that would be conducted with a subset of our participants who had consented to be re-contacted by the lab. We specified that these meetings would take the form of an informal discussion in a neutral location outside the institution (e.g., a local library) to make everyone feel comfortable in the discussion space. We note that due to the COVID-19 pandemic, these meetings were ultimately carried out in a virtual format via Zoom. Aligning with CBPR research orientation, meetings provided a space for CAB members to give feedback on our research efforts, specifically, as well as how we might be of service to the community more generally. Even though participation was voluntary, we thought it important for participants to be compensated for their time, that we would not engage in formal data collection, and that meetings would not be used for data collection purposes, but rather an evaluation of the laboratory's current functions and operations.

Informed by previously established criteria (Newman et al., 2011) as well as our continued working relationships with our participating families, we identified specific community members of diverse socioeconomic backgrounds and age groups who might serve as community representatives. These representatives included mothers who had participated in previous studies conducted by our lab, and whose participating children ranged in anxiety symptoms from non-anxious to clinically anxious thresholds. We contacted these individuals via phone and email, and those who expressed interest were sent a virtual consent form (see **Supplementary material**) in which they agreed to attend two 60–90-min virtual Zoom meetings, scheduled approximately 6 months apart (June 2020 and December 2020), with subsequent meetings planned. We had a 100% retention rate across the two meetings, with the same eight mothers who attended the first CAB meeting also attending the second. Meeting dates and times were determined based on the general availability of the CAB members who were compensated at a rate equal to what the lab pays traditional research participants per meeting ($50–$100). We took creative measures during COVID stay-at-home rules, and to express our appreciation for their time and effort, our research team had pizzas delivered to each representative's home address (with their consent) in the hour prior to the first meeting. Each of the two meetings are explained in detail in the proceeding section, drawing from our meeting agenda script (see **Supplementary material** for an outline of the first meeting).

Community advisory board meetings

CAB meetings were led by the first author and attended by all three co-authors, as well as other KIND Lab trainees. Meetings were scheduled for 1 hour. Prior to each meeting, the first author created an agenda that was distributed to the CAB members along with materials to be discussed. The agenda tentatively included topics in a specific order, with the first meeting focused on our laboratory recruitment efforts (e.g., traction of our recruitment fliers) and research protocols (e.g., comfort with fMRI) and the second focused on members' experiences of sociodemographic determinants of mental health (e.g., race/ethnicity, political ideology). It was agreed that if time ran out we would roll topics over to the next meeting.

Our priority was to build rapport between our research team and the community representatives (Alvarez et al., 2006). For Latino/a/x families, structural barriers such as lack of transportation, need for childcare, costs of participation related to lost time at work, competing family responsibilities, and limited language-appropriate recruitment and informed consent processes can all engender anxiety and mistrust of the scientific community. One way the team established trust was via a CAB facilitator, the first author, who identifies as a Latina mother and who led the CAB meetings. We began the meeting with a light icebreaker asking people to share their names and favorite sandwich. After introductions and the icebreaker, questions from the agenda were guided by a facilitator and the co-principal investigators (KJM and RBF) (see **Supplementary material**). The first set of questions asked about the clarity of our *KLG Study* consent forms. CAB members shared that there was sufficient information and they appreciated the straightforward language. They also noted that they felt comfortable asking questions if anything was unclear. Building rapport had a positive impact on outcomes for researchers and community members simultaneously, and some research suggests that rapport holds unique promise for community transformation as it involves community members themselves, in contrast with traditional research retrieval methods (Sousa, 2022).

The next set of questions centered around any worries and anxieties about CAB members' overall research experience in the *KLG Study*, specifically regarding clinical interviews and MRI scanning. To elicit constructive feedback on our protocols, we primed CAB members with neutral rather than valenced questions. Our aim was to establish a neutral starting point for the conversation, and allow members to guide the direction of the discussion based on their personal experiences with our procedures. Most mothers shared how they and their daughters had positive interactions with KIND Lab researchers, and some mothers revealed that their daughters were initially anxious and overwhelmed in anticipation of the MRI, due to their unfamiliarity with the equipment.

Next, community members reflected on the ongoing experiences of Latina girls in the community and their motivation to participate in the *KLG Study*. One member described the dearth of psychological services, asserting that youth were disadvantaged by the lack of investment in mental health practitioners in the IE region. Another member articulated their motivation to elevate the perspectives of women of color to science. They discussed the impact of generational experiences and cycles of trauma they were trying to break and their desire to expose their daughters to institutions of higher education and scientific inquiry centered around mental health and wellbeing. Some mothers disclosed that one of the factors motivating them to participate in the study was the opportunity to show their daughter what a university campus looks like.

Another set of questions covered the recruitment process. Our research team asked about members' motivations for participating in the *KLG Study*. We shared our current recruitment flier and solicited feedback from CAB members. Among other observations, CAB members pointed out that the language did not reflect the community values or the way they thought about their children's behaviors, concluding that the flier seemed targeted toward college students, rather than families. All members noted that the flier did not appear child-friendly or family oriented, adding it did little to capture their attention. They then brainstormed ways to modify the flier so that it could speak to the specific needs of children in their community, recommending more colors, different wording, and additional information about resources and payment. Ambiguity was generally viewed as a deterrent to potential participation. CAB members also shared recommendations on possible recruitment venues, and thoughts about engaging families in different spaces. Among the recommendations were guest speaking at schools, university tours of the lab to demystify the research and environment, and joining forces with other health networks in the IE. Engaging the community and offering training for members of the community align with one of the guiding principles of community-engaged research (Battaglia et al., 2020).

CAB members were invited to suggest how the KIND Lab could better serve their families, to which they responded by requesting resources that might act as a gateway to services like counseling and therapy. Members viewed their participation in our research as an entry point for conversations with their children about mental health. They also proposed ways we might earn the trust of community members who were more hesitant to participate in our research (e.g., via partnering with community health centers). These conversations sparked a discussion about what we as researchers of socioemotional development might be able to provide participating families, given our available resources. One CAB member expressed interest in art therapy, and several other members chimed in with enthusiasm agreeing that their children could benefit from such an approach. Thanks to this suggestion, the KIND Lab decided to design and implement an art therapy workshop series. Three Saturday morning workshops were hosted on campus, each lasting approximately an hour and a half, scheduled approximately 2 weeks apart. The goals of the workshops were to connect with community members and provide children with tools they could use to manage stressors through artistic expression.

The first art therapy workshop was facilitated by a professional art therapist, who invited participants to visually explore their emotions using paper, color markers, gel pens, glue, scissors, and magazines. The therapist guided children in exercises that prompted them to identify and challenge unhelpful thoughts, and use art as a coping strategy to regulate and overcome these thoughts when they arise (see **Figure 2** for an illustrative example). Participants completed minor assent forms and parents completed consent forms, indicating permission for photographs to be taken by a professional photographer while they participated in the lessons. The second art workshop was facilitated by a professional dance artist, who led children through a series of movement and dance exercises that provided them with non-verbal, embodied tools for coping with anxiety and other challenging emotions. This workshop was held in a university theater and dance space that enabled ample freedom of motion. The third and final workshop of the year was facilitated by a self-published children's author, who was also a CAB member. She shared how her journey of writing a book allowed her to cope with a difficult life circumstance and then led children in conceptualizing and creating their own storybooks using illustrations and narrative. Attendance at each workshop ranged from two children and their caregivers to ten children and their caregivers. At the end of the series, the team compiled participants' artwork and workshop photos into customized printed books for each participant. Even though each child received a book to take home, all three workshops emphasized the healing quality of the creative process itself. It was thanks to our CAB members that we were able to provide a resource the community would find valuable.

The theme of the second CAB meeting centered around race, ethnicity, identity, and how to appropriately address participants, as well as the impact of ethnic-racial discrimination

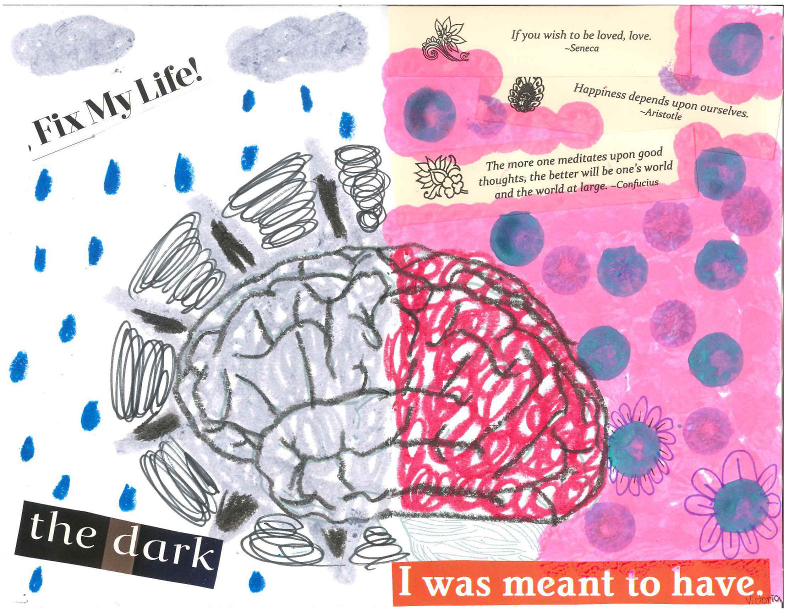


FIGURE 2
Art created by one of the participants in the art therapy workshop series.

on children's daily lives. The research team asked CAB members about their ethnic-racial identity and their preferred terms (e.g., Latinx vs. Latina/o). This generated lively discussion, with responses reflecting varied use of identity labels, with some CAB members expressing misgiving about the term "Latinx" as they are not of Latin descent while acknowledging differences in adoption depending on generation, geography, and even political orientation. One member disliked the term "Latinx" saying it felt too scholarly and did not accurately represent her identity as a Mexican-origin Latina woman. Others agreed that they did not identify with this term, adding that it sounded like an English-based construct and unnatural in Spanish. Based on this feedback and to center the voices of community members, our research team decided to adopt the community's preferred ethnic identity labels for any communication with parents. However, in recognition that gender is not binary, we have also added the Latino/a/x in the current manuscript. A planned youth panel will similarly ask youth about their attitudes and preferences.

The second topic focused on political climate and immigration experiences. Because of the U.S. immigration policy context and surrounding anti-immigrant sentiment at the time of the second meeting (i.e., the Trump presidency), our research team asked about members' attitudes toward disclosing immigration and discrimination experiences in a laboratory setting. Mothers generally felt that discussing immigration status might hinder participation due to fear of questions about legality, although some mothers shared that they would be willing to disclose their status if their identity were protected. Several CAB members also discussed the stigma of being a Latina immigrant in this country and the toll it can take on the mental health of the community. Comments in the meeting focused on how to incorporate these experiences into the team's research agenda and regional mental health services more broadly, while protecting anonymity. U.S. immigration policy has grown more restrictive in recent decades subjecting Latino/a/x immigrant families to inequitable treatment on the basis of their actual or perceived immigrant status. Restrictive policies directed toward immigrants who are undocumented have untoward effects on the health of Latino/a/xs, regardless of their status. Being an immigrant and being undocumented have become conflated with being Latino/a/x; more specifically, assumptions about a person's origin and legal status are based on racial markers (Ayón and Philbin, 2017). The *KLG Study* will be among the first to leverage neuroimaging to examine how associations between immigration threat and mental health shape brain development during transitions to adolescence.

The final theme of the meeting captured the notion that political ideology also influences emotional wellbeing, particularly given the tumultuous political divide during the time of the meeting. Mothers hinted at the toll the political climate was having on them and their daughters. We closed our meeting with a conversation about how the political atmosphere may interfere with people's trust in science and subsequently impact participation rates. In response to the community members' emphasis on the primacy of sociocultural context in shaping emotional health in their families, our research team substantially expanded existing

KIND Lab protocols. For example, our team partnered with Dr. Cecilia Ayón, a faculty member in the Department of Public Policy with specific expertise in community-based research with Latino/a/x immigrant families at the intersection of sociopolitical context, immigrant health, family wellbeing, and ethnic-racial socialization. Dr. Ayón has engaged in research aiming to inform and assess the effectiveness of culturally and contextually grounded interventions. Guided by CAB member feedback and in consultation with Dr. Ayón, *KLG Study* data collection was modified to adapt a Latino/a/x parental ethnic-racial socialization questionnaire to a child-appropriate version that would be administered to children, among several additional questionnaires probing discrimination and socialization experiences.

The *KLG Study* data analysis has been significantly impacted by the CAB meetings, with our biases and positionality informing the lens through which results are interpreted, disseminated, and communicated. Had our research team not incorporated a CBPR approach, many of our ongoing research directions would not exist. Beyond data and with community needs in mind, we share a biannual KIND Lab Newsletter with participating families (Figure 3), where we share any papers or conference proceedings that have been published with our sample, highlighting results in easily accessible language. We also keep a running tab of free or low-cost community mental and physical health resources that we update regularly.

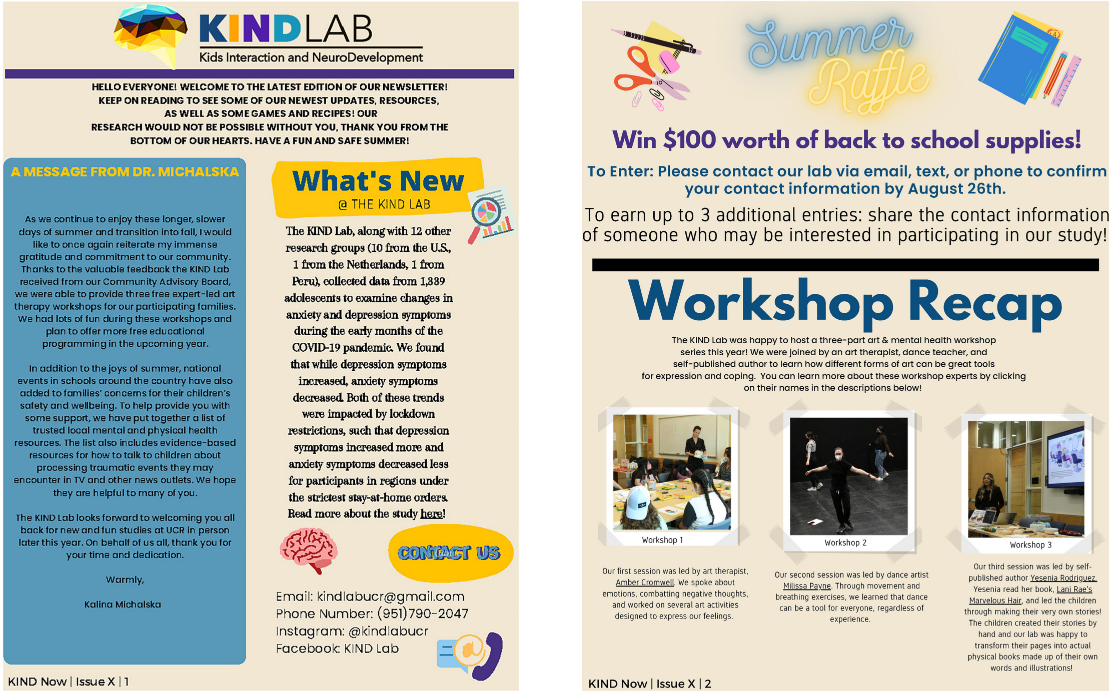
In the following section, we want to leave other scientists in the neuroscience community with some considerations for building their own CAB and embarking on inclusivity within the scope of their work. Table 1 outlines the steps of consideration in developing the CAB and the purpose as a brief explanation. Labs may also want to consider the following:

Before the CAB meeting/considering population of interest:

- Who is a part of the community you are considering a collaboration with?
- Who are the interested parties in the community?
- Who in your research team will take the lead to communicate with community members?
- What are the community members' positionalities?
- What is your research team's positionality?
- How will you recruit community members to become CAB members?
- What types of topics will be discussed at the CAB meeting?
- When will agreements, consent, and agendas be shared with CAB members?

During the CAB meeting:

- Where will the meeting take place to ensure equal grounds for CAB members and researchers?
- How will CAB members be compensated for their time?



KINDLAB
Kids Interaction and NeuroDevelopment

HELLO EVERYONE! WELCOME TO THE LATEST EDITION OF OUR NEWSLETTER! KEEP ON READING TO SEE SOME OF OUR NEWEST UPDATES, RESOURCES, AS WELL AS SOME GAMES AND RECIPES! OUR RESEARCH WOULD NOT BE POSSIBLE WITHOUT YOU, THANK YOU FROM THE BOTTOM OF OUR HEARTS. HAVE A FUN AND SAFE SUMMER!

A MESSAGE FROM DR. MICHALSKA

As we continue to enjoy these longer, slower days of summer and transition into fall, I would like to once again reiterate my immense gratitude and commitment to our community. Thanks to the valuable feedback the KIND Lab received from our Community Advisory Board, we were able to provide three free expert-led art therapy workshops for our participating families. We had lots of fun during these workshops and plan to offer more free educational programming in the upcoming year.

In addition to the joys of summer, national events in schools around the country have also added to families' concerns for their children's safety and wellbeing. To help provide you with some support, we have put together a list of trusted local mental and physical health resources. The list also includes evidence-based resources for how to talk to children about processing traumatic events they may encounter in TV and other news outlets. We hope they are helpful to many of you.

The KIND Lab looks forward to welcoming you all back for new and fun studies at UCR in person later this year. On behalf of us all, thank you for your time and dedication.

Warmly,

Kalina Michalska

What's New
@ THE KIND LAB

The KIND Lab, along with 12 other research groups (10 from the U.S., 1 from the Netherlands, 1 from Peru), collected data from 1,339 adolescents to examine changes in anxiety and depression symptoms during the early months of the COVID-19 pandemic. We found that while depression symptoms increased, anxiety symptoms decreased. Both of these trends were impacted by lockdown restrictions, such that depression symptoms increased more and anxiety symptoms decreased less for participants in regions under the strictest stay-at-home orders. Read more about the study here!

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Summer Raffle

Win $100 worth of back to school supplies!

To Enter: Please contact our lab via email, text, or phone to confirm your contact information by August 26th.

To earn up to 3 additional entries: share the contact information of someone who may be interested in participating in our study!

Workshop Recap

The KIND Lab was happy to host a three-part art & mental health workshop series this year! We were joined by an art therapist, dance teacher, and self-published author to learn how different forms of art can be great tools for expression and coping. You can learn more about these workshop experts by clicking on their names in the descriptions below!

Workshop 1

Our first session was led by art therapist, Amber Cromwell. We spoke about emotions, combatting negative thoughts, and worked on several art activities designed to express our feelings.

Workshop 2

Our second session was led by dance artist Milissa Payne. Through movement and breathing exercises, we learned that dance can be a tool for everyone, regardless of experience.

Workshop 3

Our third session was led by self-published author Yesenia Rodriguez. Yesenia read her book, Lani Rae's Marvelous Hair, and led the children through making their very own stories! The children created their stories by hand and our lab was happy to transform their pages into actual physical books made up of their own words and illustrations!

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FIGURE 3
Excerpted pages from our KIND Lab Newsletter.

TABLE 1 CAB considerations and purpose.

Consideration	Purpose
Schedule a team meeting to discuss topic options and logistics.	Ensure the team is on the same page of identifying 6–12 potential CAB members to meet with and topics to focus on.
Discuss positionality at the team meeting.	Become aware of team's working identities and privileges that may affect the research by completing a positionality map individually and as a group.
Reach out to potential CAB members via whatever communication is appropriate and accessible (e.g., email, telephone, written mail, social media).	Begin rapport and provide information on what CAB participation entails.
Formalize CAB member participation with consent and agreement.	Safeguards transparency, accountability, and follow-through.
Secure compensation for CAB member participation.	Ensure the compensation amount for the CAB members' time and effort is fair.
Schedule a team meeting to finalize the CAB meeting agenda, draft conversational questions for the CAB members, and elect meeting note takers and facilitators.	Establish clear roles for each member of the research team and have a list of questions/topics prepared for the CAB members (e.g., what are current issues in your community? what types of questions should be considered in the research?) This will ensure the meeting time is spent as efficiently as possible.
Distribute meeting information to CAB members.	Give CAB members a chance to reflect and prepare for the topics your team is planning to discuss.
Hold the CAB meeting.	Ensure the meeting works with your CAB members' schedules and is considerate of their time. Progress through the planned questions and topics in a manner that is sensitive to the natural flow of the conversation (i.e., CAB members may prefer to spend more time on some topics than others). Allow CAB members to speak freely and only interject to break moments of silence or shift away from topics that have run their course.
Hold a brief team meeting following the CAB discussion.	While the meeting and feelings about the meeting are still fresh, briefly discuss what went smoothly and what needs adjusting in future CAB meetings.
Send thank you notes to CAB members and share meeting notes.	Build and maintain as much transparency with the CAB members as possible. This is foundational to CBPR.
Repeat steps to discuss the last meeting and plan for the next meeting.	Each meeting should inform the topics to be covered and adjustments to be made in the following meeting.
Determine how the CAB meeting information will be incorporated into the research and impact the community you are collaborating with.	Ensure information obtained during the CAB meeting is implemented into your research in concrete ways (e.g., consider topics the community has deemed especially important, offer resources the community would find the most helpful, etc.).

- How will conversation during the meeting be navigated?
- How many team members will be present during the meeting?
- Who will lead the meeting? Who will take notes during the meeting?
- How will rapport be built with CAB members?
- How many and how often will meetings be?

After the CAB meeting:

- When, if any are planned, will the next meeting be?
- How will CAB members be retained?
- When will previous meeting notes be shared with CAB members?
- How will the information and knowledge shared in the meeting be of use to the community?

Conclusion and implications

In this paper, we briefly highlighted the ways in which human neuroscience research has overlooked historically marginalized groups, reproducing systemic inequities. We propose that these biases can be revealed through practices and tools from interdisciplinary and qualitative research, such as positionality and reflexivity, and actively countered through a community-engaged research approach, particularly CBPR. In a pursuit to offer a detailed roadmap for integrating CBPR into neuroscience research, we outline the ways our lab has incorporated two specific CBPR methodologies, a positionality map and a CAB, into an ongoing, longitudinal neuroimaging study on the mental health outcomes of preadolescent Latina youth. We provide a thorough overview of our positionality map, the development of our CAB and our CAB meetings, and the benefits and challenges of incorporating a CAB in neuroscience research.

In order for a just and fair neuroscience that represents the voices from all segments of the population, human neuroscience studies need an interdisciplinary lens that not only includes diverse samples but also takes into account the perspectives and positions of the community members under study. Historically, communities under study, and particularly ethnically and racially minoritized communities, have been left out of the conversations that shape the agenda and direction of neuroscience studies (Mikesell et al., 2013). Even if it's an unintended consequence, such exclusion promotes the development of biased prevention and intervention approaches, such as medical protocols, mental health recommendations, and governmental policy creation. Our paper outlined how representing the voices of our community partners provide opportunities for bi-directional learning and incorporating their lived experiences to guide approaches for co-created science. As can be seen from our example, the KIND Lab CAB has offered us unique ways for shaping our research by providing substantial feedback for our research design (e.g., inclusion of the questions or topics in our survey modules), recruitment and our outreach (e.g., through the community art workshops we have designed) for our developmental affective neuroscience study on mental health outcomes in preadolescent Latina youth. There is still much work to be explored to reach a true co-created neuroscience; but our team is intentionally working toward expanding this interdisciplinary work into our lab as we continue our dialogue with our CAB members.

Community-engaged research can also have a positive impact on science by increasing public trust in the scientific process. Including communities in the design and interpretation stages of research can serve as a powerful learning opportunity for community members to experience first-hand how research is conducted. This could be especially empowering for young people, given that agency and purpose are central to achieving the developmental tasks of this formative period (Fuligni, 2019). Additionally, including communities in the interpretation and dissemination of the research can also help researchers to identify the aspects of the results that are meaningful to the target populations and—given that communities are rarely the intended audience of scientific publications—provide insights into the alternative ways through which to communicate the study results to those who may be impacted.

Our study also has several limitations. For example, we coincidentally began our CBPR efforts roughly around the same time the COVID-19 pandemic started. Due to the ambiguity and anxiety around this rapidly emerging global pandemic and the new social distancing measures, we carried all our research and community engagement efforts remotely. We held all of our meetings online, which posed challenges to building rapport and trust with the community. However, by remaining in regular contact with our CAB members, maintaining rapport during meetings, and providing food options and compensation for their time, we put effort into creating a trusting meeting environment. As a result, we had full engagement from our CAB members and a willingness to continue participating in future CAB meetings. Some other limitations of our CBPR approach included funding, time, and training constraints. Launching our CBPR approach required that we secured supplementary funding (via an NIH-funded Center Grant from the Center for Health Disparities Research at UCR), spent significant time in revising our methodology, building rapport with community members, and training our research team on best community-engaged research practices. These efforts were substantial and we acknowledge that working within these parameters might pose barriers for other researchers attempting to incorporate CBPR methods in their research.

Finally, we would like to acknowledge the ethical dimensions of CBPR and community-engaged research, particularly power imbalances and inter-cultural sensitivity. Even though CBPR methods aim to empower the community by giving a voice to community members in shaping the research processes or dissemination, in reality a complete leveling of the field is elusive. Power imbalances between researchers and community members– both due to their often more advantaged social locations such as education or social class and institutional affiliation– might create undue influence on the participating community members, shaping CBPR interaction dynamics or outcomes. Similarly, when researchers and the community members are from different social and cultural backgrounds (e.g., in our case, whereas all CAB members were Latina and many of our Research Assistants were Latino/a/x, the majority of our senior research team was not), this can create issues of insufficient inter-cultural sensitivity. The positionality map that we offer in this paper is particularly useful in making these power imbalances and cultural differences visible. Through this exercise, researchers will better be equipped to identify and challenge these ethical issues.

As we outlined in this paper, community-engaged research, and CBPR, is an opportunity to facilitate impactful change via long-term community-academic partnerships in the realm of neuroscience. The mutual cultivation of trust and sharing of cultural and scientific knowledge can bring tangible resources and information to those outside the academic community who are most impacted by the outcomes, propelling toward a just, equitable, and diverse neuroscience.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Author contributions

SL, JM, RF, and KM contributed to conception and design of the study and wrote sections of the manuscript. RF provided direction on the community engagement component of the study. SL wrote the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnint.2022.1007249/full#supplementary-material

References

Ahmed, S. M., and Palermo, A. G. (2010). Community engagement in research: Frameworks for education and peer review. *Am. J. Public Health* 100, 1380–1387. doi: 10.2105/AJPH.2009.178137

Alvarez, R. A., Vasquez, E., Mayorga, C. C., Feaster, D. J., and Mitrani, V. B. (2006). Increasing minority research participation through community organization outreach. *West. J. Nurs. Res.* 28, 541–563. doi: 10.1177/0193945906287215

Andrews, J. O., Cox, M. J., Newman, S. D., Gillenwater, G., Warner, G., Winkler, J. A., et al. (2013). Training partnership dyads for community-based participatory research: Strategies and lessons learned from the community engaged scholars program. *Health Promot. Pract.* 14, 524–533. doi: 10.1177/1524839912461273

Annett, H., and Rifkin, S. B. (1995). *Guidelines for rapid participatory appraisals to assess community health needs: A focus on health improvements for low-income urban and rural areas*. Geneva: World Health Organization.

Ayón, C. (2016). Talking to Latino children about race, inequality, and discrimination: Raising families in an anti-immigrant political environment. *J. Soc. Soc. Work Res.* 7, 449–477. doi: 10.1086/686929

Ayón, C., and Philbin, S. P. (2017). "Tú No Eres de Aquí": Latino children's experiences of institutional and interpersonal discrimination and microaggressions. *Soc. Work Res.* 41, 19–30. doi: 10.1093/swr/svw028

Barragán, A., Yamada, A.-M., Gilreath, T. D., and Lizano, E. L. (2020). Protective and risk factors associated with comorbid mental health disorders and psychological distress among latinx subgroups. *J. Hum. Behav. Soc. Environ.* 30, 635–648. doi: 10.1080/10911359.2020.1734515

Battaglia, T. A., Freund, K. M., Haas, J. S., Casanova, N., Bak, S., Cabral, H., et al. (2020). Translating research into practice: Protocol for a community-engaged, stepped wedge randomized trial to reduce disparities in breast cancer treatment through a regional patient navigation collaborative. *Contemp. Clin. Trials* 93:106007. doi: 10.1016/j.cct.2020.106007

Berger, M., and Sarnyai, Z. (2015). "More than skin deep": Stress neurobiology and mental health consequences of racial discrimination. *Stress* 18, 1–10. doi: 10.3109/10253890.2014.989204

Bird, C. M., Webb, E. K., Schramm, A. T., Torres, L., Larson, C., and deRoon-Cassini, T. A. (2021). Racial discrimination is associated with acute posttraumatic stress symptoms and predicts future posttraumatic stress disorder symptom severity in trauma-exposed black adults in the United States. *J. Trauma. Stress* 34, 995–1004. doi: 10.1002/jts.22670

Birmaher, B., Khetarpal, S., Brent, D., Cully, M., Balach, L., Kaufman, J., et al. (1997). The screen for child anxiety related emotional disorders (SCARED): Scale construction and psychometric characteristics. *J. Am. Acad. Child Adolesc. Psychiatry* 36, 545–553. doi: 10.1097/00004583-199704000-00018

Campbell, R., and Wasco, S. M. (2000). Feminist approaches to social science: Epistemological and methodological tenets. *Am. J. Commun. Psychol.* 28, 773–791. doi: 10.1023/A:1005159716099

Castille, D. (2018). *Community-based participatory research program (CBPR)*. Bethesda, MD: National Institutes of Health.

Chiseri-Strater, E. (1996). Turning in upon ourselves: Positionality, subjectivity, and reflexivity in case study and ethnographic research. *Ethics Represent. Qual. Stud.* 1, 115–133.

Collins, P. H. (2015). Intersectionality's definitional dilemmas. *Annu. Rev. Sociol.* 41, 1–20. doi: 10.1146/annurev-soc-073014-112142

Collins, S. E., Clifasefi, S. L., Stanton, J., Straits, K. J., Gil-Kashiwabara, E., Rodriguez Espinosa, P., et al. (2018). Community-based participatory research (CBPR): Towards equitable involvement of community in psychology research. *Am. Psychol.* 73:884. doi: 10.1037/amp0000167

Cornwall, A., and Jewkes, R. (1995). What is participatory research? *Soc. Sci. Med.* 41, 1667–1676. doi: 10.1016/0277-9536(95)00127-S

Dankwa-Mullan, I., Rhee, K. B., Stoff, D. M., Pohlhaus, J. R., Sy, F. S., Stinson, N. Jr., et al. (2010). Moving toward paradigm-shifting research in health disparities through translational, transformational, and transdisciplinary approaches. *Am. J. Public Health* 100(Suppl. 1), S19–S24. doi: 10.2105/AJPH.2009.189167

Day, S. (2012). A reflexive lens: Exploring dilemmas of qualitative methodology through the concept of reflexivity. *Qual. Sociol. Rev.* 8, 60–85. doi: 10.18778/1733-8077.8.1.04

Dhamoon, R. K., and Hankivsky, O. (2011). Why the theory and practice of intersectionality matter to health research and policy. *Health Inequit. Can. Intersect. Frameworks Pract.* 1, 16–50.

Drahota, A., Meza, R. D., Brikho, B., Naaf, M., Estabillo, J. A., Gomez, E. D., et al. (2016). Community-academic partnerships: A systematic review of the state of the literature and recommendations for future research. *Milbank Q.* 94, 163–214. doi: 10.1111/1468-0009.12184

Ebner, N. (2020). Thinking racial capitalism from the Inland empire. *City* 24, 668–673. doi: 10.1080/13604813.2020.1781415

Einstein, G. (2012). "Situated neuroscience: Exploring a biology of diversity," in *Neurofeminism: Issues at the intersection of feminist theory and cognitive science*, eds R. Bluhm, H. Maibom, and A. J. Jacobson (London: Palgrave McMillan), 145–174. doi: 10.1057/9780230368385_8

Fani, N., Carter, S. E., Harnett, N. G., Ressler, K. J., and Bradley, B. (2021). Association of racial discrimination with neural response to threat in Black women in the US exposed to trauma. *JAMA Psychiatry* 78, 1005–1012. doi: 10.1001/jamapsychiatry.2021.1480

Fani, N., Harnett, N. G., Bradley, B., Mekawi, Y., Powers, A., Stevens, J. S., et al. (2022). Racial discrimination and white matter microstructure in trauma-exposed black women. *Biol. Psychiatry* 91, 254–261. doi: 10.1016/j.biopsych.2021.08.011

Faridi, Z., Grunbaum, J. A., Sajor Gray, B., Franks, A., and Simoes, E. (2007). Community-based participatory research: Necessary next steps. *Prev. Chronic Dis.* 4:A70.

Fetterman, D. M., Kaftarian, S. J., and Wandersman, A. (1996). *Empowerment evaluation: Knowledge and tools for self-assessment and accountability*. Thousand Oaks, CA: SAGE Publications.

Flanagan, S. M., and Hancock, B. (2010). 'Reaching the hard to reach'–Lessons learned from the VCS (voluntary and community sector). A qualitative study. *BMC Health Serv. Res.* 10:92. doi: 10.1186/1472-6963-10-92

Freire, P. (2018). *Pedagogy of the oppressed: 50th anniversary edition*. London: Bloomsbury Publishing.

Fuligni, A. J. (2019). The need to contribute during adolescence. *Perspect. Psychol. Sci. J. Assoc. Psychol. Sci.* 14, 331–343. doi: 10.1177/1745691618805437

Gatzke-Kopp, L. M. (2016). Diversity and representation: Key issues for psychophysiological science. *Psychophysiology* 53, 3–13. doi: 10.1111/psyp.12566

Goldfarb, M. G., and Brown, D. R. (2022). Diversifying participation: The rarity of reporting racial demographics in neuroimaging research. *Neuroimage* 254:119122. doi: 10.1016/j.neuroimage.2022.119122

Green, L. W., George, M. A., Daniel, M., Frankish, C. J., Herbert, C., Bowie, W. R., et al. (1995). *Study of participatory research in health promotion*. Vancouver: University of British Columbia.

Harding, S. G. (2015). *Objectivity and diversity*. Chicago, IL: University of Chicago Press.

Harding, S. G. (Ed.) (2004). *The feminist standpoint theory reader: Intellectual and political controversies*. London: Psychology Press. doi: 10.7208/chicago/9780226241531.001.0001

Harnett, N. G., Wheelock, M. D., Wood, K. H., Goodman, A. M., Mrug, S., Elliott, M. N., et al. (2019). Negative life experiences contribute to racial differences in the neural response to threat. *Neuroimage* 202:116086. doi: 10.1016/j.neuroimage.2019.116086

Henrich, J., Heine, S., and Norenzayan, A. (2010). Most people are not WEIRD. *Nature* 466:29. doi: 10.1038/466029a

Israel, B. A., Schulz, A. J., Parker, E. A., and Becker, A. B. (2001). Community-based participatory research: Policy recommendations for promoting a partnership approach in health research. *Educ. Health* 14, 182–197. doi: 10.1080/13576280110051055

Jacobson, D., and Mustafa, N. (2019). Social identity map: A reflexivity tool for practicing explicit positionality in critical qualitative research. *Int. J. Qual. Methods* 18:1609406919870075.

Jones, L. M., Ginier, E., Debbs, J., Eaton, J. L., Renner, C., Hawkins, J., et al. (2020). Exploring representation of diverse samples in fmri studies conducted in patients with cardiac-related chronic illness: A focused systematic review. *Front. Hum. Neurosci.* 14:108. doi: 10.3389/fnhum.2020.00108

Kann, L., McManus, T., Harris, W. A., Shanklin, S. L., Flint, K. H., Queen, B., et al. (2018). Youth risk behavior surveillance–United States, 2017. *Morb. Mortal. Wkly. Rep. Surveill. Summ.* 67, 1–114. doi: 10.15585/mmwr.ss6708a1

Kochanska, G. (2002). Mutually responsive orientation between mothers and their young children: A context for the early development of conscience. *Curr. Dir. Psychol. Sci.* 11, 191–195. doi: 10.1111/1467-8721.00198

Leibing, A., and McLean, A. (2007). "Learn to value your shadow!" An introduction to the margins of fieldwork," in *The shadow side of fieldwork: Exploring the blurred borders between ethnography and life*, eds A. McLean and A. Leibing (Hoboken, NJ: Blackwell Publishing Ltd), 1–28. doi: 10.1002/9780470692455.ch

Leigh, J. A., Alvarez, M., and Rodriguez, C. J. (2016). Ethnic minorities and coronary heart disease: An update and future directions. *Curr. Atheroscler. Rep.* 18, 1–10. doi: 10.1007/s11883-016-0559-4

Lewin, K. (1947). Frontiers in group dynamics: II. Channels of group life, social planning, and action research. *Hum. Relat.* 1, 143–153. doi: 10.1177/001872674700100201

Link, B., and Hatzenbuehler, M. L. (2016). Stigma as an unrecognized determinant of population health: Research and policy implications. *J. Health Polit. Policy Law* 41, 653–673. doi: 10.1215/03616878-3620869

Loehr, L. R., Rosamond, W. D., Chang, P. P., Folsom, A. R., and Chambless, L. E. (2008). Heart failure incidence and survival (from the atherosclerosis risk in communities study). *Am. J. Cardiol.* 101, 1016–1022. doi: 10.1016/j.amjcard.2007.11.061

MacQueen, K. M., McLellan, E., Metzger, D. S., Kegeles, S., Strauss, R. P., Scotti, R., et al. (2001). What is community? An evidence-based definition for participatory public health. *Am. J. Public Health* 91, 1929–1938. doi: 10.2105/ajph.91.12.1929

Martínez, K. G., Franco-Chaves, J. A., Milad, M. R., and Quirk, G. J. (2014). Ethnic differences in physiological responses to fear conditioned stimuli. *PLoS One* 9:e114977. doi: 10.1371/journal.pone.0114977

McLaughlin, K. A., Hilt, L. M., and Nolen-Hoeksema, S. (2007). Racial/ethnic differences in internalizing and externalizing symptoms in adolescents. *J. Abnorm. Child Psychol.* 35, 801–816. doi: 10.1007/s10802-007-9128-1

McLean, A. (2007). "When the borders of research and personal life become blurred: Thorny issues in conducting," in *The shadow side of fieldwork*, eds A. McLean and A. Leibing (Hoboken, NJ: Blackwell Publishing Ltd), 262.

Medicine, I. (1997). *Healthy communities: New partnerships for the future of public health*. Washington, DC: National Academies Press.

Mekawi, Y., Watson-Singleton, N. N., Kuzyk, E., Dixon, H. D., Carter, S., Bradley-Davino, B., et al. (2020). Racial discrimination and posttraumatic stress: Examining emotion dysregulation as a mediator in an African American community sample. *Eur. J. Psychotraumatol.* 11:1824398. doi: 10.1080/20008198.2020.1824398

Michalska, K. J., and Davis, E. L. (2019). The psychobiology of emotional development: The case for examining sociocultural processes. *Dev. Psychobiol.* 61, 416–429. doi: 10.1002/dev.21795

Michalska, K. J., Decety, J., Zeffiro, T. A., and Lahey, B. B. (2015). Association of regional gray matter volumes in the brain with disruptive behavior disorders in male and female children. *Neuroimage Clin.* 7, 252–257. doi: 10.1016/j.nicl.2014.12.012

Michalska, K. J., Gardiner, G., and Hughes, B. L. (2020). "What neuroscience can tell us about social situations: Challenges and opportunities," in *The Oxford handbook of psychological situations*, eds J. Rauthmann, R. Sherman, and D. Funder (Oxford: Oxford University Press).

Michalska, K. J., Zeffiro, T. A., and Decety, J. (2016). Brain response to viewing others being harmed in children with conduct disorder symptoms. *J. Child Psychol. Psychiatry* 57, 510–519.

Michener, L., Cook, J., Ahmed, S. M., Yonas, M. A., Coyne-Beasley, T., and Aguilar-Gaxiola, S. (2012). Aligning the goals of community-engaged research: Why and how academic health centers can successfully engage with communities to improve health. *J. Assoc. Am. Med. Coll.* 87, 285–291. doi: 10.1097/ACM.0b013e3182441680

Mikesell, L., Bromley, E., and Khodyakov, D. (2013). Ethical community-engaged research: A literature review. *Am. J. Public Health* 103, e7–e14. doi: 10.2105/AJPH.2013.301605

Minkler, M. (2010). Linking science and policy through community-based participatory research to study and address health disparities. *Am. J. Public Health* 100, S81–S87. doi: 10.2105/AJPH.2009.165720

Newman, S. D., Andrews, J. O., Magwood, G. S., Jenkins, C., Cox, M. J., and Williamson, D. C. (2011). Community advisory boards in community-based participatory research: A synthesis of best processes. *Prev. Chronic Dis.* 8:A70.

Nutbeam, D., and Kickbusch, I. (1998). Health promotion glossary. *Health Promot. Int.* 13, 349–364. doi: 10.1093/heapro/13.4.349

Parker, T. C., and Ricard, J. A. (2022). Structural racism in neuroimaging: Perspectives and solutions. *Psychiatry* 9:e22. doi: 10.1016/S2215-0366(22)00079-7

Pasick, R., Oliva, G., Goldstein, E., and Nguyen, T. (2010). "Community-Engaged research with community-based organizations: A resource manual for UCSF researchers," in *From the series: UCSF clinical and translational science institute (CTSI) resource manuals and guides to community-engaged research*, ed. P. Fleisher (San Francisco, CA: University of California).

Rao, D., Feinglass, J., and Corrigan, P. (2007). Racial and ethnic disparities in mental illness stigma. *J. Nerv. Ment. Dis.* 195, 1020–1023. doi: 10.1097/NMD.0b013e31815c046e

Reyes, V. (2020). Ethnographic toolkit: Strategic positionality and researchers' visible and invisible tools in field research. *Ethnography* 21, 220–240. doi: 10.1177/1466138118805121

Rifkin, S. B. (1996). Paradigms lost: Toward a new understanding of community participation in health programmes. *Acta Trop.* 61, 79–92. doi: 10.1016/0001-706X(95)00105-N

Rose, G. (1997). Situating knowledges: Positionality, reflexivities and other tactics. *Prog. Hum. Geogr.* 21, 305–320. doi: 10.1191/030913297673302122

Slopen, N., Shonkoff, J. P., Albert, M. A., Yoshikawa, H., Jacobs, A., Stoltz, R., et al. (2016). Racial disparities in child adversity in the U.S.: Interactions with family immigration history and income. *Am. J. Prev. Med.* 50, 47–56. doi: 10.1016/j.amepre.2015.06.013

Sousa, J. W. (2022). "Relationship as resistance: Partnership and vivencia in participatory action research," in *Handbook on participatory action research and community development*, ed. R. Stoecker (Cheltenham: Edward Elgar Publishing), 396–416.

Spates, K. (2012). The missing link" The exclusion of black women in psychological research and the implications for black women's mental health. *Sage Open* 2:2158244012455179.

Stafford, A. M., and Draucker, C. B. (2020). Barriers to and facilitators of mental health treatment engagement among Latina adolescents. *Commun. Ment. Health J.* 56, 662–669. doi: 10.1007/s10597-019-00527-0

Substance Abuse and Mental Health Services Administration (2020). *2020 National survey of drug use and health (NSDUH) releases*. Washington, DC: U.S. Department of Health and Human Services.

Sun, J., Goforth, A. N., Nichols, L. M., Violante, A., Christopher, K., Howlett, R., et al. (2022). Building a space to dream: Supporting indigenous children's survivance through community-engaged social and emotional learning. *Child Dev.* 93, 699–716. doi: 10.1111/cdev.13786

Thompson, C. (2009). Black women, beauty, and hair as a matter of being. *Womens Stud.* 38, 831–856. doi: 10.1080/00497870903238463

Torres, L., Yznaga, S. D., and Moore, K. M. (2011). Discrimination and Latino psychological distress: The moderating role of ethnic identity exploration and commitment. *Am. J. Orthopsychiatry* 81:526. doi: 10.1111/j.1939-0025.2011.01117.x

Tran, A. N., Ornelas, I. J., Kim, M., Perez, G., Green, M., Lyn, M. J., et al. (2014). Results from a pilot promotora program to reduce depression and stress among immigrant Latinas. *Health Promot. Pract.* 15, 365–372. doi: 10.1177/1524839913511635

United States Environmental Protection Agency (2015). *Evaluating EPA's programs*. Washington, DC: United States Environmental Protection Agency.

Viswanathan, M., Ammerman, A., Eng, E., Garlehner, G., Lohr, K. N., Griffith, D., et al. (2004). *Community-based participatory research: Assessing the evidence: Summary. AHRQ evidence report summaries*. Rockville, MD: Agency for Healthcare Research and Quality. doi: 10.1037/e439622005-001

Vogel, D. L., Wade, N. G., and Haake, S. (2006). Measuring the self-stigma associated with seeking psychological help. *J. Couns. Psychol.* 53, 325–337. doi: 10.1037/0022-0167.53.3.325

Walsh, R., and Einstein, G. (2020). Transgender embodiment: A feminist, situated neuroscience perspective. *J. Int. Netw. Sex. Ethics Polit.* 8, 56–70. doi: 10.3224/insep.si2020.04

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022a). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Webb, E. K., Bird, C. M., deRoon-Cassini, T. A., Weis, C. N., Huggins, A. A., Fitzgerald, J. M., et al. (2022b). Racial discrimination and resting-state functional connectivity of salience network nodes in trauma-exposed black adults in the United States. *JAMA Netw. Open* 5:e2144759. doi: 10.1001/jamanetworkopen.2021.44759

Wei, Y., McGrath, P. J., Hayden, J., and Kutcher, S. (2015). Mental health literacy measures evaluating knowledge, attitudes and help-seeking: A scoping review. *BMC Psychiatry* 15:291. doi: 10.1186/s12888-015-0681-9

Yuan, N. P., Gaines, T. L., Jones, L. M., Rodriguez, L. M., Hamilton, N., and Kinnish, K. (2016). Bridging the gap between research and practice by strengthening academic-community partnerships for violence research. *Psychol. Violence* 6, 27–33. doi: 10.1037/vio0000026

Zhou, E., Kyeong, Y., Cheung, C. S., and Michalska, K. J. (2022). Shared cultural values influence mental health help-seeking behaviors in Asian and Latinx college students. *J. Racial Ethn. Health Disparities* 9, 1325–1334. doi: 10.1007/s40615-021-01073-w

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A call to leverage a health equity lens to accelerate human neuroscience research

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Investigation of health inequities tend to be examined, in human neurosciences, as biological factors at the level of the individual. In actuality, health inequities arise, due largely in part, to deep-seated structural factors. Structural inequality refers to the systemic disadvantage of one social group compared to others with whom they coexist. The term encompasses policy, law, governance, and culture and relates to race, ethnicity, gender or gender identity, class, sexual orientation, and other domains. These structural inequalities include but are not limited to social segregation, the intergenerational effects of colonialism and the consequent distribution of power and privilege. Principles to address inequities influenced by structural factors are increasingly prevalent in a subfield of the neurosciences, i.e., cultural neurosciences. Cultural neuroscience articulates the bidirectional relationship between biology and environmental contextual factors surrounding research participants. However, the operationalization of these principles may not have the intended spillover effect on the majority of human neurosciences: this limitation is the overarching focus of the present piece. Here, we provide our perspective that these principles are missing and very much needed in all human neuroscience subdisciplines to accelerate our understanding of the human brain. Furthermore, we provide an outline of two key tenets of a health equity lens necessary for achieving research equity in human neurosciences: the social determinants of health (SDoH) framework and how to deal with confounders using counterfactual thinking. We argue that these tenets should be prioritized across future human neuroscience research more generally, and doing so is a pathway to further gain an understanding of contextual background intertwined with the human brain, thus improving the rigor and inclusivity of human neuroscience research.

KEYWORDS

human neuroscience, health equity, social determinants of health (SDoH), health inequities, confounders, counterfactual

1. Introduction

Human neuroscience research has experienced remarkable growth, particularly due to technological advancements such as magnetic resonance imaging over the past 50 years. Despite methodological progress, a pressing challenge remains: understanding the impact of historically entrenched policies and principles on neuroscience research, from the inception of scientific inquiries to the dissemination of findings. Cultural neuroscience, a burgeoning field within the human neurosciences, investigates the relationship between human culture and neurobiological processes (Chiao et al., 2010). However, the practices within this branch of neuroscience have not yet led to a spill-over effect on the majority of human neuroscience research, leaving them as exceptional approaches rather than standard procedures in study design and publication. Currently, there is a limited focus on understanding how broader systemic factors influence outcomes related to the human brain. As straightforward as this critique may be, it remains a significant blind spot in today's current mainstream human neuroscience efforts and perpetuates an on-going barrier in our pursuit to fully understand the human brain. The present perspective presents a call for significantly more attention toward leveraging a health equity lens in human neuroscience research. In doing so, we hope to contribute to the growing literature that echoes this call (Ricard et al., 2022; Webb et al., 2022; La Scala et al., 2023). Once a critical mass sharing these goals among neuroscientists is achieved, we believe a new era of accelerated understanding of the human brain will follow, creating a novel path divergent from the exclusionary practices in scientific history (Rutherford, 2021b).

An overarching aim of human neuroscientific research is to understand how the human brain works. A benefit of this increased understanding is to help people with these novel discoveries. Through increased understanding of the brain, we can better support optimization of neurobiological pathways and their function to promote health and wellbeing while decreasing the prevalence of diseases and disorders. As scientists uniquely situated at the intersection of public health and developmental human neurosciences, we seek to contribute to the accumulating critique of human neuroscience research that clear and problematic blind spots exist and offer our value of leveraging a health equity lens to begin to address these blind spots. In doing so, we acknowledge and operationalize the health equity lens for use in human neuroscience research. We recognize that implementing health equity-focused investigations in the realm of human neuroscience presents considerable challenges, primarily due to the absence of relevant variables within extant neuroscientific data sets. Furthermore, the scarcity of funding opportunities for the creation of new, inclusive data sets and the inherent difficulties in challenging prevailing norms compound these obstacles. Consequently, our current understanding is not exemplary; nonetheless, it represents the most advanced knowledge available at present, and serves as a foundation for initiating individual trajectories aimed at accelerating and broadening the scope of human neuroscience research. The equity lens seeks to embrace the biology-environment interaction of human health and disease. The current challenge in human neurosciences is in expanding to these biology-environment interactions to uncover potential blind spots (Bendesky and Bargmann, 2011). This perspective seeks to give the reader brief examples of societal constructs within the past that contribute to these persistent blind spots in human neuroscience. In doing so, we hope to offer a starting point to human neuroscientists who desire to employ a health equity lens in their research. We write this as both an amendment to the field, as well as encouragement to neuroscientists to consider the intersection of neuroscience and health equity in their own research and be part of the much-needed change in our neuroscience field for the embedment of equitable human neuroscience research.

2. Societal constructions of human research

A health equity lens is quick to recognize and elucidate how large proportions of health issues stem not solely from the individual, but also from the structures surrounding the individual. Current structures that drive ongoing inequities were laid by imperialist roots (Roy, 2018). Historical structural factors set the tone for the present-day environment in which human neuroscience research operates: mainly intergenerational wealth- and privilege- dominated (Abiodun, 2019). One such example of historical context leaving lasting impact on today's structural resources is colonialism, which has resulted in lasting changes in power and resources for entire communities that pesrist today (Czyzewski, 2011; Sherwood, 2014; Araújo et al., 2020). These historical structural factors continue to influence current contextual factors surrounding brain health and may have implications for neurodevelopmental and psychiatric disorders in later life (Gajwani and Minnis, 2022). Thus, attributing an individual's neurobiological outcome solely to individual-level factors (e.g., genetics, biological vulnerabilities, or personal decisions) misses critical contributions of the more significant systemic factors at play, such as resources, power, intergenerational factors, discrimination and autonomy (Gee and Ford, 2011). Most efforts in neuroscience to go beyond individual-level factors tend only to reach intermediary measures (**Figure 1** in orange boxes) and is limited in the examination of the surrounding structural factors' (i.e., governance, macroeconomic policies, social policies, public policies, race and ethnicity, income) impact on the brain. For instance, neuroscience often attributes individual brain health outcomes to individual-level risk (e.g., material circumstances, behavioral and biological factors, psychosocial factors, genetics), yet, here, we challenge this pitfall by demonstrating that structural factors shape these same individual-level risk factors as well as the individual brain health outcomes. Thus, without substantial consideration of these structural factors, we may have erroneously overemphasized the significance of individual-level, and underemphasized structural factors when understanding the human brain.

Progress in human neuroscience depends on understanding these structural factors, so often shaped by imperialist policies and principles. A paradigm shift toward this goal is the remembrance of past injustices and cultivating a "*Just Memory*." A *Just Memory* is memory work that recalls both one's own, as well as, the other's historical background (Nguyen, 2013). Research has demonstrated the detrimental effects of intergeneration trauma, and so, we are a product of generational osmosis (Bezo and Maggi, 2015; Danieli et al., 2016; O'Neill et al., 2016; Berckmoes et al., 2017; Costa et al., 2018; Williams et al., 2018). The implications of integrating health equity with human neurosciences are significant, as it serves to acknowledge the various contextualizing intergenerational structural factors that may lead to neurobiology that underlie risk and resilience for psychological and mental health outcomes. However, this shift requires a complex roadmap: one that we

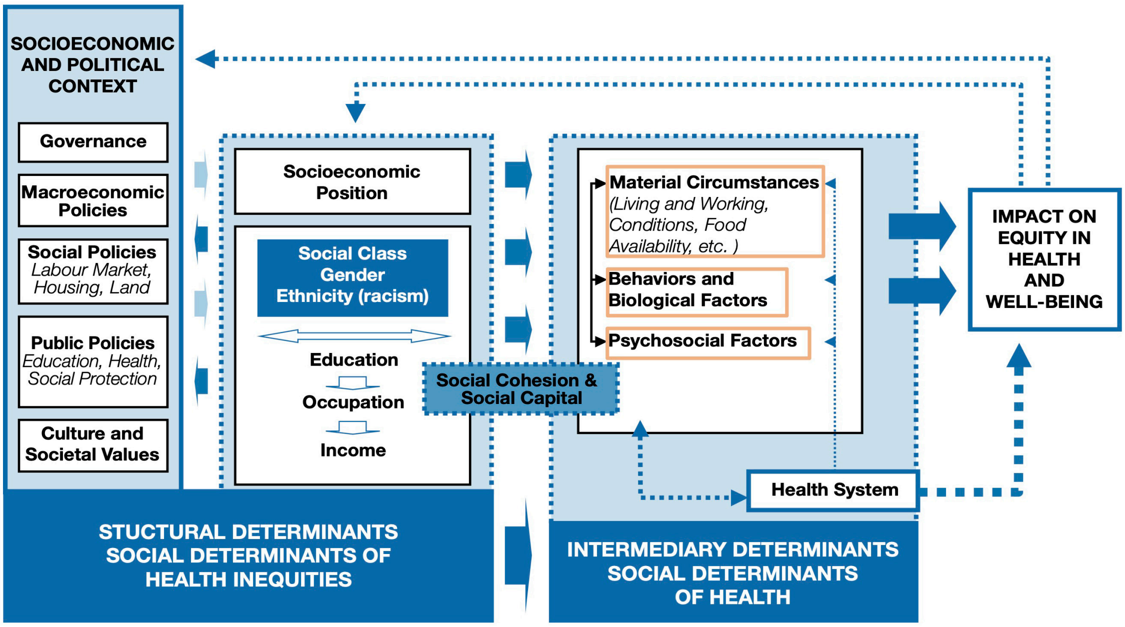

FIGURE 1
The World Health Organization (WHO) social determinants of health framework structural factors, deeply rooted in imperial policies, influence individual-level factors. Neuroscience often attributes individual brain health outcomes to individual factors (highlighted in orange boxes in the modified figure to emphasize where the majority of factors examined in the human neuroscience research fall; e.g., behaviors and biological factors, psychosocial factors), yet this diagram demonstrates that individual factors are only a small piece of the story. Individual factors are shaped, in part, by the larger socioeconomic and political context; thus, these larger contextualizing structural factors are largely missing from human neuroscientific research at present. Originally published by the World Health Organization (Solar and Irwin, 2010) on page 6 in A conceptual framework for action on the social determinants of health. Permission was granted to reproduce this diagram.

suggest should first be guided by the epistemic deconstruction of population stereotypes. To contextualize the inheritance of inequities within scientific hegemony and offer two key tenets of health equity that may add to the human neurosciences, we invite readers to be an active part of the expansion of inculcating macrolevel structural factors using two key tenets outlined further to begin the needed shift in human neurosciences.

One reason contemporary neuroscience today continues to perpetuate this limited scope in investigation of how structural factors influence neurobiological processes may be due, in part, to epistemic injustices. Here, we define *scientific epistemic injustice* as a cultural injustice that occurs when the concepts and categories by which research participants understand themselves and their world, are replaced by the concepts and categories by the researcher and the research world. In other words, a pitfall for all researchers is to falsely impose their own worldviews in their scientific methodology, viewing the participating community members through assumptions and therefore, often overly narrow lens. With this pitfall, research can end up biased, with worldviews and values held by the research team being falsely emphasized, while those held by the participating community members are misunderstood or overlooked. The prevailing state perpetuates the risk of drawing erroneous and detrimental conclusions in contemporary human neuroscience literature. This persistence may be attributed to the predominance of privilege and power within the field, which originates from historical systemic factors that continue to influence current practices of wealth and privilege establishment and preservation. The broader academic milieu, where research is primarily conducted, reflects these enduring impacts of historical systemic factors (Stewart and Valian, 2018). Unlike other STEM disciplines, human neuroscience delves into the study of the human condition, which is profoundly shaped by present contextual factors related to historical structural determinants. Indeed, numerous scholars have underscored the significant ethical obligations associated with disseminating findings on biological aspects, such as the human brain, as opposed to non-biological research domains, given that public perceptions of brain discoveries tend to be less amendable (Tolwinski, 2019). Those who have benefited from historical systemic factors that continue to drive privilege today tend to hold administrative control over human neuroscience studies (Kim and Sasaki, 2014; Abiodun, 2019). Human brains develop not merely based on individual molecular or genetic events: cultural and structural factors also influence the brain in parallel. As with all things human, inequality and inequity are important, yet under studied, drivers of human brain outcomes, and their functional outcomes such as behavior, cognition, and mental health.

Brain outcomes result from a constellation of factors: some of which are unknown by the researcher, creating blind spots in our attempt to uncover how the brain develops, functions, and retains resilience to disease and disorder. If neuroscience is to address current blind spots, then our discipline needs to effectively recognize epistemic injustices in our research studies. When all key factors remain uncertain, researchers tend to revert to their own worldviews to help scaffold their understanding of the complex research findings on the human brain. When in a position of not knowing how to model these uncertainties in research, it is human nature to experience the tendency to revert to imposing our own worldview onto the population under study or disregard essential factors in the structure and parametrization of our models that are related to the participant (Saini, 2020). Intergenerational forces shape the structure of human societies, partially or wholly defining the outcomes we study. Thus, it is of great importance to factor in the social and environmental drivers present in our society, which often result from downstream and lasting effects of historical structural factors.

2.1. Health equity tenet 1: the social determinants of health (SDoH)

There are communities of people that experience the world differently, and these lived experiences are relevant to scientific progress. After studying the social environment of the African-American communities in 1899, Dr. W. E. B. Du Bois recognized the role of sociohistorical contextual factors that played into the daily life of the community and how they defined health behaviors and diseases (Du Bois and Anderson, 2014). In other words, events that are unwitnessed in the present, still define our research today. As Dr. Du Bois summarized it; "A complete study must not confine itself to the group but must especially notice the environment: the physical environment of the city, sections and houses, the far mightier social environment—the surrounding world of custom, wish, whim and thought which envelopes this group and powerfully influences its development" (Du Bois and Anderson, 2014). So, the question arises: *Are we accounting for sociohistorical contextual factors embedded in a community when conducting our own neuroscientific research?* For this, neuroscientists will benefit by thinking about their research through a Social Determinants of Health (SDoH) lens. Thus, we challenge fellow neuroscientists to think beyond bio-physiological measures on the individual level. SDoH requires considerations beyond the individual level, and incorporates the conditions where people are born, live, learn, work, and play (Braveman and Gottlieb, 2014). Application of the SDoH lens more regularly into the neurosciences is needed because neural correlates extend to and from the SDoH. As illustrated by the World Health Organization (WHO) SDoH framework (**Figure 1**), SDoH (e.g., social protection and socioeconomic resources) can influence our individual-level research findings (Solar and Irwin, 2010). Therefore, it is a disservice to think of neurobiological pathways without integrating these outcomes to socio-historical events that are still relevant in shaping our neurobiology today. The following hypothetical presents a neuroscientific claim in order to demonstrate limited applicability, threats to internal and external validity of the study and violation of epistemic virtues. We posit that this example represents a recurrent pattern in both historical and current human neuroscientific literature:

> *Neuroscientists, aware that exposure to "X" adversely affects adult neurophysiological health, seek to investigate the consequences of prenatal exposure to "X" on fetal brain development. They examine brain volumes in children with prenatal exposure to "X" and recruit participants from a population stereotypically considered "high-risk" and disproportionately impacted by exposure to "X." In doing so, they believe this approach enhances the statistical sensitivity of their experimental design to detect a real lasting impact of exposure to "X" on childhood brain development if one truly exists. Study findings reveal reduced brain volumes and lower IQ scores in children with prenatal exposure to "X" compared to unexposed children. Thus, the researchers conclude that their study demonstrates that prenatal exposure to "X" causes lasting harm on childhood neurological development. The recommendations made from their study include more targeted interventions to specific populations to better protect pregnancies from the potential harm of exposure to "X," so that individuals can better protect their pregnancies from "X."*

This hypothetical scenario highlights the limited applicability of the study's findings due to inadequate generalizability, as it targets a specific population with a historical reputation for being "high-risk." However, the origin of this historical reputation (e.g., systemic oppression, discriminatory stereotypes, or a history of scientific publications labeling the community as highly impacted by exposure to "X") is not considered. Thus, the researchers cannot definitively demonstrate that exposure to "X" is the primary cause of brain and cognitive outcomes, as they fail to conceptualize exposure to "X" within broader contextual factors. The targeted "high-risk" population demonstrates potential flaws in experimental design stemming from unchallenged stereotypes and researchers' epistemic views, leading to bias in study design and interpretation of findings. In doing so, neuroscientists inadvertently create publishable "evidence" that reinforces pre-existing stereotypes and epistemic views rather than challenging them, as advocated in this perspective piece. The narrow focus on "X" can lead to amplified and false conclusions about the magnitude of harm caused by "X." Contextual factors may partially or entirely account for prenatal exposure to "X"' and brain alterations. Further, the widespread use of cognitive correlates to demonstrate the functionality of brain alterations remains problematic when following the *status quo* in using IQ data, given the known cultural insensitivities of IQ scores (Frisby and Henry, 2016; Hood et al., 2022). Despite the glaring problematic nature of this approach, it is often the current *status quo* today among neuroscientific investigation in human neuroscience. The outlined issues become even more harmful when exposure to "X" is viewed as the responsibility of the individual, such as a behavioral choice (e.g., lifestyle causing hypertension during pregnancy, or substance use as a teratogen, or obesity), effectively causing such neuroscientific publications to drive shame, blame and stigma toward entire communities. This masks the parallel narrative of historical and current SDoH factors that also impact pregnancy, health, and brain development. Incorporating SDoH conceptualization in human neuroscience can begin to challenge many of these blind spots and harmful practices within today's *status quo*. By conceptualizing exposure to "X" as a "symptom" of SDoH factors, it is viewed as a correlate or symptom reflecting SDoH factors, rather than the sole cause of brain outcomes. Here, our example illustrates how adopting SDoH conceptualization can more accurately point to historical and cross-generational roots with on-going impact. Without a SDoH framework, the magnitude of the effect of exposure to "X" is erroneously overemphasized, resulting in false conclusions.

2.2. Health equity tenet 2: counterfactuals, contexts, and confounders

"Genetics loads the gun but the environment pulls the trigger" (Stern and Kazaks, 2009). Counterfactual theory involves comparing scenarios related to the occurrence of an outcome under contrasting exposure states (Bours, 2021). It seeks to answer whether the outcome would remain the same or differ if an exposed individual had not been exposed. Counterfactual thinking contrasts contextual factors surrounding the outcome, indicating that the exposure under study may be associated with the outcome in one scenario but not in another. This approach seeks to equalize the background risks associated with research participants, ensuring comparability. To illustrate the application of counterfactual thinking to, for example, colonialism and its downstream effects, requires one to employ a *Just Memory*. This involves understanding the research participants' sociohistorical background to adequately adjust for confounding variables. Historical contexts can still influence current contexts, making them vital for interpreting results from human neuroscience research. Utilizing a counterfactual framework can help integrate historical and current contextual factors in neuroscience research. For example, within the counterfactual framework, considering colonialism in human neuroscience involves contrasting the lived intergenerational experiences of research participants under colonialism and its oppressive policies against the experiences they would have had without the exposure to coloniality. Quantifying this contrast necessitates understanding confounding variables within the study design.

Confounding refers to outcome differences resulting from variations in the baseline risks of comparison groups (Brooke and Finlayson, 2022). Confounding variables affect the primary relationship under study, leading to spurious associations. Essentially, confounding introduces ambiguity within counterfactual scenarios. Accounting for confounding partially addresses the lived experiences of health inequities among research participants. Moreover, employing an SDoH framework is crucial to satisfactorily account for participants' lived experiences. By examining counterfactuals and confounders in the context of socially constructed determinants, we can better integrate basic sciences to understand and translate meaningful results for our communities. We emphasize the importance of studying both neurobiological outcomes and the participants' environment, not in isolation but in conjunction with prevalent social fissures. For example, when investigating the impact of parenting on childhood brain outcomes, not only do parallel and co-occurring confounders likely play a role (e.g., current experienced stressors, racism, resources), but also historical factors that have led to current co-occurring confounders and may serve as counterfactuals (e.g., historical slavery, structural racism like redlining, discrimination-based incarceration, race-based incarceration of a co-parent, geographical food deserts, experienced parenting styles under historical extreme trauma/stressors, among others). Consider the following intuition pump, revolving around counterfactuals and confounders, envision two hypothetical scenarios: Scenario A, in which colonialism played a significant role in shaping the course of history and the development of human neurosciences, and Scenario B, in which colonialism never occurred. In Scenario A, colonial powers exerted control over vast territories, imposing their scientific paradigms, language, and culture on colonized populations. Consequently, the development of human neurosciences was heavily influenced by the dominant scientific paradigms and methodologies of the colonizers. In Scenario B, societies developed independently, with diverse cultures and knowledge systems contributing to the growth of human neurosciences. This scenario would feature a more equitable distribution of scientific contributions and a richer understanding of the human brain and its functions, derived from various cultural perspectives and intellectual traditions. Some aspects influenced by colonialism include but are not limited to:

- Eurocentric perspectives: Colonial powers promoted their own scientific paradigms and methodologies, often disregarding or undermining the knowledge systems and practices of colonized populations. As a result, the development of human neurosciences has largely been shaped by Eurocentric perspectives, which may have limited the inclusion of diverse viewpoints and methodologies.
- Language and communication: The colonizers imposed their languages on colonized territories, leading to the dominance of these languages in scientific research and communication. Consequently, human neuroscience research conducted in non-European languages may have been overlooked or undervalued, resulting in a potential loss of valuable insights and knowledge.
- Access to resources and funding: Colonial powers often controlled the allocation of resources and funding for scientific research, favoring their own scientific agendas and priorities. This has led to the development of human neurosciences being heavily skewed toward the interests and perspectives of the colonizers, while neglecting or marginalizing the research interests of the colonized populations.
- Education and training: Colonizers established educational institutions and training programs in the colonized territories, often modeled after their own systems. These institutions and programs emphasized the scientific paradigms and methodologies of the colonizers, further reinforcing their dominance in the field of human neurosciences.
- Research ethics and practices: The development of human neurosciences under colonial influence may have been accompanied by ethical issues and questionable research practices, including the exploitation of colonized populations as research subjects without proper informed consent or the disregard for cultural sensitivities and values.
- Dissemination of knowledge: The scientific knowledge generated by the colonizers was often disseminated through their own channels, such as scientific journals and conferences, which may have limited the accessibility and visibility of research conducted by non-European scientists or those from colonized territories.

Now, consider the confounders—factors that may influence the relationship between colonialism and the development of human neurosciences. These factors could include economic systems, access to resources, technological advancements, and socio-political dynamics, among others. In both scenarios, these confounders might lead to disparities in the development and dissemination of scientific knowledge.

By comparing Scenario A and Scenario B, we can better understand the impact of colonialism on human neurosciences and the potential benefits of integrating diverse knowledge systems. This thought experiment highlights the importance of considering counterfactuals and confounders when examining the complex relationship between colonialism and scientific development. It encourages reflection on the biases and limitations present in our current understanding of human neurosciences and urges consideration of how we might move toward a more inclusive and representative approach to scientific inquiry. By acknowledging these influences, the scientific community can work toward a more inclusive and representative approach to human neuroscience research, which recognizes the value of diverse knowledge systems and encourages collaboration among researchers from varied research disciplines.

3. Conclusion

While human experiences are dynamic, it is grounded in persistent structural factors largely related to imperialist policies and principles, which continue to have a strong hold on human neuroscience, and our pursuit to study it. Historical eugenic policies are rooted in present-day human neuroscience methodology, mislabeled but still trickle down to the principles in how we measure the human brain, accounting for covert misinterpretations [For further reading, we highly recommend the works of Gould (1978), Gee et al. (2019), Ford (2020), and Rutherford (2021a)]. For example, a theory conceptualized by Samuel Morton in the 19th century that anthropometric cranial measurements determine intelligence persists today despite wide opposition (Mitchell, 2018). Human neuroscience has largely overlooked decades-to-centuries of mismeasurement born out of oppression, power, and privilege, and how these have impacted the context in which human neuroscience research is conducted, by whom, with whom and for whom. Moving the needle in human neurosciences will need intentional and collaborative effort to effectively avoid epistemic injustices, apply a SDoH lens, and address counterfactuals and confounding variables as they arise in our own neuroscience research (Carter et al., 2022). Along with these two key tenets of health equity and the growing literature (Carter et al., 2022; Girolamo et al., 2022; Green et al., 2022; Ricard et al., 2022; Webb et al., 2022) that call to expand our understanding of how larger contextualizing structural factors drive persistent brain health inequities, human neuroscience has the potential to move the needle toward authentic justice, equity, diversity, and inclusion, while also accelerating our pursuit to study the human brain.

Data availability statement

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

VR and KU contributed to the conception. VR took the lead in writing and editing the manuscript. KU contributed to critical revisions and editing of this manuscript. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abiodun, S. J. (2019). "Seeing Color," a discussion of the implications and applications of race in the field of neuroscience'. *Front. Hum. Neurosci.* 13:280. doi: 10.3389/FNHUM.2019.00280/BIBTEX

Araújo, C. A., Ray, J. G., Figueiroa, J. N., and Alves, J. G. (2020). "BRAzil magnesium (BRAMAG) trial: a double-masked randomized clinical trial of oral magnesium supplementation in pregnancy." *BMC Pregn. Child.* 20:1–7. doi: 10.1186/s12884-020-02935-7

Bendesky, A., and Bargmann, C. I. (2011). Genetic contributions to behavioural diversity at the gene-environment interface. *Nat. Rev. Genet.* 12, 809–820. doi: 10.1038/NRG3065

Berckmoes, L. H., Eichelsheim, V., Rutayisire, T., Richters, A., and Hola, B. (2017). "How legacies of genocide are transmitted in the family environment: a qualitative study of two generations in rwanda". *Societies* 7:24. doi: 10.3390/SOC7030024

Bezo, B., and Maggi, S. (2015). "Living in "survival mode:" intergenerational transmission of trauma from the holodomor genocide of 1932–1933 in Ukraine". *Soc. Sci. Med.* 134, 87–94. doi: 10.1016/J.SOCSCIMED.2015.04.009

Bours, M. J. L. (2021). 'Tutorial: a nontechnical explanation of the counterfactual definition of effect modification and interaction'. *J. Clin. Epidemiol.* 134, 113–124. doi: 10.1016/J.JCLINEPI.2021.01.022

Braveman, P., and Gottlieb, L. (2014). "The social determinants of health: it's time to consider the causes of the causes". *Public Health Rep.* 129:19. doi: 10.1177/00333549141291S206

Brooke, B. S., and Finlayson, S. R. G. (2022). "Critical assessment of surgical outcomes and health services research – ClinicalKey," in *Sabiston book of surgery*, 21st Edn, ed. C. Townsend (Amsterdam: Elsevier), 159–169. Available online at: https://www.clinicalkey.com/#/content/book/3-s2.0-B9780323640626000086 (accessed August 29, 2022).

Carter, S. E., Mekawi, Y., and Harnett, N. G. (2022). "It's about racism, not race: a call to purge oppressive practices from neuropsychiatry and scientific discovery". *Neuropsychopharmacology* 2022, 1–2. doi: 10.1038/s41386-022-01367-5

Chiao, J. Y., Hariri, A. R., Harada, T., Mano, Y., Sadato, N., Parrish, T. B., et al. (2010). "Theory and methods in cultural neuroscience". *Soc. Cogn. Affect. Neurosci.* 5, 356–361. doi: 10.1093/scan/nsq063

Costa, D. L., Yetter, N., and Desomer, H. (2018). 'Intergenerational transmission of paternal trauma among US civil war ex-POWs'. *Proc. Natl. Acad. Sci. U.S.A.* 115, 11215–11220. doi: 10.1073/PNAS.1803630115/SUPPL_FILE/PNAS.1803630115.SAPP.PDF

Czyzewski, K. (2011). Colonialism as a broader social determinant of health. *Int. Indig. Policy J.* 2:215. doi: 10.18584/IIPJ.2011.2.1.5

Danieli, Y., Norris, F. H., and Engdahl, B. (2016). "Multigenerational legacies of trauma: modeling the what and how of transmission". *Am. J. Orthopsy.* 86, 639–651. doi: 10.1037/ORT0000145

Du Bois, W. E. B., and Anderson, E. (2014). A social study *"The philadelphia negro"*. (University of Pennsylvania Press). doi: 10.9783/9780812201802

Ford, C. L. (2020). "Commentary: addressing inequities in the era of COVID-19: the pandemic and the urgent need for critical race theory". *Family Commun. Health* 43, 184–186. doi: 10.1097/FCH.0000000000000266

Frisby, C. L., and Henry, B. (2016). Science, politics, and best practice: 35 years after larry p. *Contemp. School Psychol.* 20, 46–62. doi: 10.1007/S40688-015-0069-3

Gajwani, R., and Minnis, H. (2022). "Double jeopardy: implications of neurodevelopmental conditions and adverse childhood experiences for child health". *Eur. Child Adoles. Psychiatry* 1, 1–4. doi: 10.1007/S00787-022-02081-9/FIGURES/1

Gee, G. C., and Ford, C. L. (2011). "Structural racism and health inequities: old issues. New directions". *Soc. Sci. Res. Race* 8, 115–132. doi: 10.1017/S1742058X11000130

Gee, G. C., Hing, A., Mohammed, S., Tabor, D., and Williams, D. (2019). Racism and the life course: taking time seriously. *Am. J. Public Health* 109, S43–S47. doi: 10.2105/AJPH.2018.304766

Girolamo, T., Parker, T. C., and Eigsti, I. M. (2022). "Incorporating dis/ability studies and critical race theory to combat systematic exclusion of black, indigenous, and people of color in clinical neuroscience". *Front. Neurosci.* 16:1533. doi: 10.3389/FNINS.2022.988092/BIBTEX

Gould, S. J. (1978). "Morton's ranking of races by cranial capacity. Unconscious manipulation of data may be a scientific norm". *Science* 200, 503–509. doi: 10.1126/SCIENCE.347573

Green, K. H., Groep, I. H., Brinke, L. W., Cruijsen, R., Rossenberg, F., and Marroun, H. E. (2022). "A perspective on enhancing representative samples in developmental human neuroscience: connecting science to society". *Front. Integrat. Neurosci.* 16:111. doi: 10.3389/FNINT.2022.981657/BIBTEX

Hood, E., Boone, K., Miora, D., Cottingham, M., Victor, T., Zeigler, E., et al. (2022). Are there differences in performance validity test scores between African American and white American neuropsychology clinic patients? *J. Clin. Exp. Neuropsychol.* 44, 31–41. doi: 10.1080/13803395.2022.2069230

Kim, H. S., and Sasaki, J. Y. (2014). "Cultural neuroscience: biology of the mind in cultural contexts". *Annu Rev. Psychol.* 65, 487–514. doi: 10.1146/ANNUREV-PSYCH-010213-115040

La Scala, S., Mullins, J. L., and Firat, R. B. (2023). Equity, diversity, and inclusion in developmental neuroscience: Practical lessons from community-based participatory research. *Front. Integr. Neurosci.* 16:141. doi: 10.3389/FNINT.2022.1007249

Mitchell, P. W. (2018). The fault in his seeds: lost notes to the case of bias in samuel george morton's cranial race science. *PLoS Biol.* 16:7008. doi: 10.1371/journal.pbio.2007008

O'Neill, L., Fraser, T., Kitchenham, A., and McDonald, V. (2016). "Hidden burdens: a review of intergenerational, historical and complex trauma, implications for indigenous families". *J. Child Adoles. Trauma* 11, 173–186. doi: 10.1007/S40653-016-0117-9

Nguyen, V. T. (2013). "just memory: war and the ethics of remembrance". *Am. Literary History* 25, 144–163. doi: 10.1093/ALH/AJS069

Ricard, J. A., Parker, T. C., Dhamala, E., Kwasa, J., Allsop, A., and Holmes, A. J. (2022). "Confronting racially exclusionary practices in the acquisition and analyses of neuroimaging data". *Nat. Neurosci.* 26, 4–11. doi: 10.1038/s41593-022-01218-y

Roy, R. D. (2018). *Science still bears the fingerprints of colonialism*. Available online at: https://www.smithsonianmag.com/science-nature/science-bears-fingerprints-colonialism-180968709/ (accessed August 18, 2022).

Rutherford, A. (2021a). "A cautionary history of eugenics". *Science* 373:1419. doi: 10.1126/SCIENCE.ABM4415

Rutherford, A. (2021b). "Race, eugenics, and the canceling of great scientists". *Am. J. Phys. Anthropol.* 175, 448–452. doi: 10.1002/AJPA.24192

Saini, A. (2020). "Want to do better science? Admit you're not objective". *Nature* 579:175. doi: 10.1038/D41586-020-00669-2

Sherwood, J. (2014). "Colonisation – it's bad for your health: the context of Aboriginal health". *Contemp. Nurse* 46, 28–40. doi: 10.5172/CONU.2013.46.1.28

Solar, O., and Irwin, A. (2010). A conceptual framework for action on the social determinants of health. *Soc. Determ. Health Dis.* 2010:852.

Stern, J., and Kazaks, A. (2009). *Obesity: A reference handbook*. Santa Barbara, CA: ABC-CLIO, LLC, 322.

Stewart, A. J., and Valian, V. (2018). An inclusive academy: achieving diversity and excellence. *Inclus. Acad.* doi: 10.7551/MITPRESS/9766.001.0001.

Tolwinski, K. (2019). "Fraught claims at the intersection of biology and sociality: managing controversy in the neuroscience of poverty and adversity". *Soc. Stud. Sci.* 49, 141–161. doi: 10.1177/0306312719839149

Webb, E. K., Cardenas-Iniguez, C., and Douglas, R. (2022). "Radically reframing studies on neurobiology and socioeconomic circumstances: a call for social justice-oriented neuroscience". *Front. Integrat. Neurosci.* 16:104. doi: 10.3389/FNINT.2022.958545/BIBTEX

Williams, M. T., Printz, D. M. B., and DeLapp, R. C. T. (2018). "Assessing racial trauma with the trauma symptoms of discrimination scale". *Psychol. Viol.* 8, 735–747. doi: 10.1037/VIO0000212

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Systems Thinking in an era of climate change: Does cognitive neuroscience hold the key to improving environmental decision making? A perspective on Climate-Smart Agriculture

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Systems Thinking (ST) can be defined as a mental construct that recognises patterns and connections in a particular complex system to make the "best decision" possible. In the field of sustainable agriculture and climate change, higher degrees of ST are assumed to be associated with more successful adaptation strategies under changing conditions, and "better" environmental decision making in a number of environmental and cultural settings. Future climate change scenarios highlight the negative effects on agricultural productivity worldwide, particularly in low-income countries (LICs) situated in the Global South. Alongside this, current measures of ST are limited by their reliance on recall, and are prone to possible measurement errors. Using Climate-Smart Agriculture (CSA), as an example case study, in this article we explore: (i) ST from a social science perspective; (ii) cognitive neuroscience tools that could be used to explore ST abilities in the context of LICs; (iii) an exploration of the possible correlates of systems thinking: observational learning, prospective thinking/memory and the theory of planned behaviour and (iv) a proposed theory of change highlighting the integration of social science frameworks and a cognitive neuroscience perspective. We find, recent advancements in the field of cognitive neuroscience such as Near-Infrared Spectroscopy (NIRS) provide exciting potential to explore previously hidden forms of cognition, especially in a low-income country/field setting; improving our understanding of environmental decision-making and the ability to more accurately test more complex hypotheses where access to laboratory studies is severely limited. We highlight that ST may correlate with other key aspects involved in environmental decision-making and posit motivating farmers *via* specific brain networks would: (a) enhance understanding of CSA practices (e.g., *via* the frontoparietal network extending from the dorsolateral prefrontal cortex (DLPFC) to the parietal cortex (PC) a control hub involved in ST and observational learning) such as tailoring training towards developing improved ST abilities among farmers and involving observational learning more explicitly and (b) motivate farmers to use such practices [e.g., *via* the network between the DLPFC and nucleus accumbens

(NAc)] which mediates reward processing and motivation by focussing on a reward/emotion to engage farmers. Finally, our proposed interdisciplinary theory of change can be used as a starting point to encourage discussion and guide future research in this space.

KEYWORDS

Global South, Systems Thinking (ST), climate change, mobile data collection, Climate Smart Agriculture (CSA)

1. Introduction

Systems Thinking (ST) can be defined as a mental construct that recognises patterns and connections in a particular system to make the "best decision" possible given a particular goal. In a number of environmental fields including sustainable agriculture and fisheries management, higher degrees of ST are thought to be associated with "better" (e.g., optimal given preferred outcomes and understood constraints environmental decision making in a variety of country settings (e.g., Gray, 2018; Lalani et al., 2021; Aminpour et al., 2022). For example, recent studies in a North American setting have shown that higher degrees of ST correlate with the use of conservation practices, including pest management practices (e.g., Bardenhagen et al., 2020), holistic management/agricultural practices (Mann et al., 2019) and cover crops (Church et al., 2020). Higher degrees of ST have also been associated with the use of Conservation Agriculture (CA) in Mozambique (e.g., Lalani et al., 2021) and more recently with sustainable groundwater management in India (Sanga and Koli, 2023). Social science methods have often measured degrees of "systems thinking" by exploring the qualitative and quantitative attributes of individual mental models often through analysing concepts or cognitive maps. Methods used to elucidate mental models through cognitive maps such as Fuzzy Cognitive Mapping (FCM), rely upon participants to represent their thinking process. Yet defining and measuring "systems thinking" remains challenging (Gray, 2018). Thus, tacit knowledge, and subconscious cognitions remain inaccessible, even though they may play important roles in systems thinking and/or environmental decision making especially since such decisions rely on: (1) understanding a system's composition and (2) incorporating and adapting to new changing conditions as they happen to make both short term and long term strategies for human behaviour. Additionally, complexities have been found in other areas of sustainable behaviour which rely on self-reports which are prone to biases. Leeuwis et al. (2022) suggest that neuroscience tools can provide an additional implicit measurement, for instance, when the verbalised attitudes/intention reported may not be consistent with actual behaviour. Moreover, studies that look at neuroscience and sustainability are scarce and fragmented (Leeuwis et al., 2022). Furthermore, digital mobile technologies whilst not novel in the field of cognitive neuroscience and/or cognitive psychology have mostly been utilised in highly controlled settings and in higher-income countries (Bhavnani et al., 2022). Sawe (2019) has further argued that the benefits of neuroscience tools in the area of environmental policy research provide a number of benefits including improving our understanding of how decision making differs among individuals; the specific behavioural nudges that can have an influence on decision making and the ability to make population level inferences by looking at what types of decision making processes are predictive of national behaviour. All of these may overlap and interact depending on the scale/population of interest (ibid). Furthermore, engaging lower-income countries in such research will be important given the majority of the world resides in lower-income countries and these are the populations most likely to benefit from such research as such "thinking" is culturally embedded (Valdes-Sosa et al., 2021).

1.1. Other examples of social science frameworks used to explore environmental decision making[1]

A number of social science frameworks and methods have been used to explore environmental decision making (including farmers' decision making) more broadly. Some examples include Multi-Criteria Decision Analysis (MCDA) (e.g., Kiker et al., 2005) and the utilisation of Agent-Based Modelling (ABM) such as Zolfagharipoor and Ahmadi (2021) who employ the ABM approach to simulate a local groundwater market in central Iran and incorporate the theory of planned behaviour to explore the agents' intention of participating in the market. Similarly, Streefkerk et al. (2023) also used ABM and coupled a spatially distributed hydrological model to a human behavior-centered ABM and found agropastoralists in Kenya respond differently to drought due to differences in perceptions of their environment. Benhangi et al. (2020) recently employed an interesting methodological framework to assess the "learning capacity" (incorporating the learning process and learning outcomes) of water users in Iran and found that water users' responses were associated with factors such as social memory which negatively impacted water use. Other authors have developed a socio-cognitive conceptual framework that explicitly considers feedback from ecosystems to land use

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[1] We have used environmental decision making, human decision making and farmers' decision making interchangeably. However, there is a large body of literature on farmers' decision making and other forms of environmental decision making. We have only provided a few examples for the purpose of this perspective piece.

systems and how changes in ecosystems services then reflect in land management decisions. The authors' found farmers' behaviours were not always synonymous with their attitudes towards ecosystem services (i.e., their decisions on changes in ecosystem services were not reflective of their underlying beliefs towards ecosystem services) and other factors including topographic constraints or farmer individual and household characteristics also played a part in land-management decisions (Lamarque et al., 2014). Finally in a review article, seeking to understand how people make decisions and analyse social-ecological systems, Binder et al. (2013) analysed 10 established frameworks for analysing social-ecological systems and found that there are three types; those exploring the social impact on the environment, others focussed on the environmental impact on social domains and those that incorporate both social and environmental impacts with feedback loops.

But how can current social science frameworks and advancements in cognitive neuroscience be used to better understand culturally embedded knowledge or ways of thinking, ST, and human decision making, especially since climate change and human thinking and responses are critical for all human societies?

We posit that in addition to traditional social science methodologies of measuring ST, integrating cognitive neuroscience approaches that measure brain activity, can detect neural correlates[2] of these otherwise inaccessible cognitive patterns. By pairing cognitive neuroscience methods with social or psychological measures of systems thinking, we can not only access hidden forms of cognition, but we can also begin to outline the neural mechanisms and corresponding psychological processes involved in improved environmental decision making. The following uses Climate Smart Agriculture (CSA) as a case study with the backdrop of the importance of applying these tools/approaches to low-income country (LICs) settings.[3]

1.2. A case study of environmental decision making: the case of climate smart agriculture

Agricultural production contributes substantially to climate change: yearly greenhouse gas (GHG) emissions from agriculture account for 11% of total anthropogenic GHG emissions, not including land use change from natural vegetation/forests to agriculture (Poeplau and Don, 2015; De Pinto et al., 2020). The significant role that agriculture plays in contributing to climate change has increased the importance of Climate Smart Agriculture (CSA) both from the potential of contributing to mitigation and also more importantly to climate change adaptability. CSA is an approach based on three main objectives: (i) sustainably increasing agricultural productivity and incomes; (ii) adaptation and building of resilience to climate change; and (iii) reducing and/or removing greenhouse gas emissions, where possible (FAO, 2022a). A CSA practice is considered to be context-specific and dependent on a range of factors (e.g., local, socio-economic, and environmental factors) and implemented at the field level (FAO, 2022a).

CSA practices have been associated with improvements in natural resource sustainability (e.g., soil and land) and preservation of vital ecosystems which contribute to enhancing resilience and climate change induced vulnerabilities both at the farm/household level and wider landscape level (Saran et al., 2022). Future climate change scenarios have increasingly highlighted the negative effects on agricultural productivity worldwide (e.g., Nelson et al., 2014) and this is likely to be especially acute in low-income countries (LICs), particularly for those situated in the Global South (e.g., Morton, 2007).

1.3. CSA in Africa

Two-thirds of the world's poorest people reside in rural areas (76% are located in Africa) and are primarily engaged in agriculture (World Bank, 2014; IFAD, 2020). Although Africa has had the largest annual rate of net forest loss (3.9 million hectares) over the period 2010–2020 (FAO, 2020) and this has steadily increased in recent decades; Africa is still the smallest contributor to global greenhouse gas emissions though the most vulnerable to the impacts of climate change (Gonzalez-Sanchez et al., 2019). Some authors have suggested there exists limited scope for carbon sequestration *via* certain CSA practices such as crop residue retention due to the "sink saturation effect" i.e., a point being reached when no net carbon sequestration takes place beyond this; the authors do point out that improving the organic matter in soils is still desirable given changing conditions (e.g., Berthelin et al., 2022). Moreover, recent studies at a regional level in Africa (Gonzalez-Sanchez et al., 2019) and modelling at a global scale have suggested that these practices can increase food production for millions of people and reduce GHG emissions (De Pinto et al., 2020). For example, CA has been associated with an increase in productivity, improvements in household income, and enhanced food security at the household-level in Mozambique (e.g., Nkala et al., 2011; Lalani et al., 2021). Others have found that CA usage in Zambia, for instance, has substantially increased maize production and reduced household poverty (Abdulai, 2016)[4].

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[2] By neural correlates we use the broad definition: "brain activity that "corresponds with and is necessary to produce a particular experience" (Dingman, 2019).

[3] Whilst this perspective essay has broader relevance for other countries/LICs in the Global South we have mainly focussed on Sub-Saharan Africa and Southern Africa in particular (e.g., Malawi and Mozambique). We envisage piloting the approach in one of these countries where the research team has prior experience of working on this topic and living in the region. Where relevant we have referred to other countries.

[4] For the purposes of this article sustainable agriculture is used interchangeably with CSA. In short, Conservation Agriculture (CA) is defined as the simultaneous application of three principles: (i) minimum soil disturbance (i.e., no-tillage); (ii) maintenance of a permanent soil cover such as through the retention of crop residues, and; (iii) diversification of plant species via crop rotations and/or crop sequences/associations. Although context-specific and locally adapted,

However, farmers must identify what is considered "climate-smart" in their own contexts (e.g., biophysical, socio-economic, etc.) (De Pinto et al., 2020). Whilst there have been many successes (e.g., Kassam et al., 2017), CSA practices are often perceived as "knowledge-intensive" and notwithstanding other constraints it has been suggested this can deter farmers from using such practices (e.g., De Pinto et al., 2020). In a number of LICs (including in Sub-Saharan Africa), the use/local adaptation of practices remains low[5] (Makate, 2019). Practices such as crop burning and tillage are widely used which have led to widespread soil degradation further limiting the potential for agriculture production (Rockström et al., 2009). It is important to note, however, that elements of "modern" agriculture and the application of science and technology have been historically linked to colonial structures in Africa (Moyo, 2010). For example, the focus on monocultures and subsequent investment in the processing of sugarcane and other crops (e.g., tobacco) in Malawi stemmed from white settlers in the 1800s (Buchanan, 1885; Woods, 1993; Moyo, 2010). Moreover, settlers were amazed to find local people cultivating crops such as maize and beans in mixtures (e.g., intercropping which is considered to be among the oldest indigenous agriculture production techniques in tropical Africa) as well as the practice of minimum tillage as local farmers tilled the land at a very shallow depth (less than 25 cm deep) which was described as a "mere scratching of the soil surface" (Buchanan, 1885 cited in Moyo, 2010; Rogé et al., 2016) It has thus been argued that land degradation is in part attributed to a legacy of colonial policies which discouraged these indigenous practices (Rogé et al., 2016). Thus, Moyo et al. (2022) have recently advocated for the co-creation of knowledge which includes farmers' indigenous knowledge (local knowledge) and scientific knowledge thereby leading to more holistic knowledge[6]. Our focal point is thus SSA where both culture (ways of thinking) and environmental conditions (regional and local) are immensely diverse; farmers' indigenous knowledge has historically often been discarded (e.g., Kerr et al., 2022; Moyo et al., 2022) and demand for food and nutrition security/climate change adaptation remains constant if not increasing (FAO, 2021). Recently, neuroscience researchers have also called on the neuroscience community to conduct more work globally on environmental conservation including the use of no-tillage (i.e., forms part of CSA practices) (Keifer and Summers, 2021).

But do farmers that use CSA practices have individual thinking patterns that are unique from those that do not (e.g., increased or decreased ST or not) and how do we know what types of thinking lead to better human adaptations to a changing climate?

This perspective essay outlines a research agenda to explore systems thinking from both a social science perspective and a cognitive neuroscience lens in order to help elucidate key mechanisms of decision making with respect to CSA practices. The article is structured as follows: (i) ST from a social science perspective; (ii) cognitive neuroscience tools that could be used to explore ST abilities in the context of LICs; (iii) an exploration of the possible correlates of systems thinking: observational learning, prospective thinking/memory and the theory of planned behaviour and (iv) a proposed theory of change highlighting the integration of social science frameworks and a cognitive neuroscience perspective that can be used to enhance our understanding of ST and farmers' decision making.

2. Systems thinking—a social science perspective

Measures of ST have indicated decision-makers that show more evidence of ST/indicators correlate with more desirable human and environmental outcomes (see Aminpour et al., 2022) given competing outcomes and depending on what the decision-maker needs wants to optimise. However most of this research has been limited to social science disciplines. While ST has been a popular approach for decades to understand "better" and value-laden decision making (Stave and Hopper, 2007; Skaza and Krystyna, 2009), there remain significant gaps in understanding how ST is promoted and how to assess and measure ST understanding. The popularity of promoting ST across disciplines is based on two major benefits. First, ST relies on the notion that if decision-makers, formally or informally, can develop skill sets that allow them to think deeply (and demonstrate that through cognitive mapping empirical evidence) about the complex dynamics of systems, they are better prepared to predict a system's behaviour, and engineer solutions that lead to more favourable outcomes (see identifying "leverage points" discussed in Meadows, 2008). Additionally, since ST is a highly generic, synthetic, and generalizable construct, it can also be a useful way for decision-makers to integrate and synthesise knowledge across domains (Arnold and Wade, 2015). Such systemic thinking generates habits of mind (Kay and Foster, 1999; Steinkuehler and Duncan, 2008) that are useful frameworks for reasoning about and abstracting over a range of systems that underlie personal or global problems (Tabacaru et al., 2009). For example, Sterling et al. (2010) have argued that a systems view of the interacting biophysical and cultural systems at the core of biological diversity can result in more effective conservation targets and strategies.

2.1. The importance of understanding individual mental models

To understand individual farmers' perceptions, research has traditionally focused on understanding and measuring their "mental models" as they relate to CSA and behaviours. The notion of mental models, which was first introduced by Craik (1943), has been widely used to study how individuals and groups understand the world and make decisions within it (see review

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CA is considered to be the core production system component of CSA which is, however, broader in scope and includes other domains (e.g., De Pinto et al., 2020; for a more detailed description see FAO, 2022a and FAO, 2022b; Mkomwa and Kassam, 2022).

[5] There are many examples, however, where farmers' indigenous knowledge are climate smart by nature. For example, the indigenous Zai pit system used to improve soil fertility and conserve water in many parts of Africa.

[6] It is beyond the scope of this article to discuss the extensive literature on this topic. For a good overview see Šūmane et al. (2018).

by Jones et al., 2011). These internal models are often elicited and represented through concept or cognitive mapping. A cognitive map can be thought of as a graphical map that reflects mental processing, which is comprised of collected information and a series of cognitive abstractions by which individuals filter, code, store, refine and recall information about physical phenomena and experiences into an external representation (Vanwindekens et al., 2013; Vuillot et al., 2016; Levy et al., 2018). Therefore, understanding variation in farmer mental models, and indeed in some cases how consistent these perceptions align with measurements of external "reality", can shed light on human decision making and subsequent behavioural intentions and behaviours (Halbrendt et al., 2014).

2.2. Concept mapping to represent mental models

Concept mapping is often used to externally represent individual mental models and as an additional tool to explore dimensions of ST. For example, knowledge of a specific topic is represented graphically with directional lines used to illustrate relationships between concepts (Novak and Cañas, 2006). It has also been used in prior research exploring students' ST with respect to sustainability issues (Brandstädter et al., 2012). Concept generation is a process of first-order thinking involving memorization and knowledge combination, and also higher-order thinking involving memorizing, reasoning, relational thinking, and knowledge organization (Zvacek et al., 2012; Taura and Nagai, 2013).

2.3. Using Fuzzy cognitive maps to represent mental models

One recent and semi-quantitative way to measure individual mental models has come through Fuzzy Cognitive Mapping (FCM). FCM has been used in many contexts ranging from fisheries management to agricultural development to generate graphical models of complex systems that are useful for decision making, illuminate the core presumptions of local stakeholders, structure complex problems for scenario development, and understand degrees of ST (e.g., Halbrendt et al., 2014; Lalani et al., 2021). FCM has become popular because it takes a bottom-up approach and can incorporate a range of individual, community-level, and expert knowledge into an accessible and standardized format to better understand individual mental model variation among communities or stakeholder groups but also elucidate more the more "community-level" understanding that to some extent highlights societal understanding and their associated behaviours (see Aminpour et al., 2022). FCMs are semi-quantitative instantiations of graph theory, the structure between state space variables can be represented mathematically. These structural measures are generated by converting cognitive maps into an adjacency matrix filled with positive or negative values that define relationships between variables on a scale between +1 and −1. Representing the structural relationships of these concepts in a matrix allows each variable to be categorized in one of three ways: (1) as a driving variable, i.e., forcing component; (2) receiving variable, i.e., impacted component; or (3) an ordinary variable, i.e., intermediate component (Nayaki et al., 2014). A variable's relative importance for the system can be determined by the strength of its incoming and outgoing edges using centrality measurements common to network analyses (see Özesmi and Özesmi, 2004). FCMs can also be characterized by a range of other quantitative metrics, including density, which allows models to be compared with each other based on their overall structure (see Gray et al., 2015 for a review of structural metrics). Importantly, FCMs can run "what-if" scenarios (Kosko, 1986; Özesmi and Özesmi, 2004). That is, FCM computation can show the relative changes in the state of the system's components given a particular input or combination of inputs (i.e., a forced manipulation in the state of the system, also known as system "activation"). When one component is activated (i.e., sends a signal), it triggers a cascade of changes to other system components based on how they are connected and in this way represents the dynamics of a personal scenario in an individual's mental model. This process continues in several iterations until the initial signal has passed through the entire FCM and all components reach a steady state. By comparing the system state at the beginning with that at the end of the process, we can assess the direction and strength of impact that the change has had on all other components. Such FCM simulations provide the toolset for a dynamic analysis of mental models and have been used by many researchers to represent belief-based predictions (e.g., Jones et al., 2011; Halbrendt et al., 2014; Stier et al., 2017; Cholewicki et al., 2019). For more information about the scenario analysis and equations see Özesmi and Özesmi (2004) and Aminpour et al. (2020).

2.4. Measuring degrees of systems thinking using network analysis

Systems thinking is an important skill that helps humans understand and manage complex systems (Senge and Sterman, 1992) and because of FCMs semi-quantitative and dynamic analytical capabilities, research has recently begun to define network-based metrics with degrees of ST. In particular, the ability to define components and understand the dynamics of a system in a systematic way can improve farmers' engagement with sustainability issues, because these are always complex with intertwined social, environmental, and economic aspects (Aminpour et al., 2022). Farmers who use higher degrees of systems thinking can better understand the complex dynamics of a system: they are more likely to better predict a system's behaviour, identify leverage points (Meadows, 2008), and evaluate the trade-offs between different decisions made within the system. In addition, Levy et al. (2018) have shown that the degree of "systems thinking" can be measured using network analysis of mental models that represent perceived causal structures between system components. As such, network metrics that measure the degree of complexity, non-linearity, non-hierarchical causation, cyclic (closed loop) interdependence, and feedback representation may exemplify higher levels of systems thinking. So-called "micro-motifs" allow for the clustering of cognitive maps on a spectrum to indicate the degree of systems thinking in decision making mental models.

3. Measuring systems thinking through the use of mobile tools in LICs and a cognitive neuroscience lens

While FCM and related network approaches have made some strides in measuring systems thinking, they are limited by their reliance upon participants' meta-cognition, recall, honesty, and ability to articulate their thoughts and possible measurement errors given the complexity of the task. This leaves early, subconscious, tacit, and socially-undesirable patterns of thinking inaccessible, even though those may play important roles in environmental decision making. In contrast, neuroscience measures of brain activity can access these kinds of cognition by observing their neural correlates by pairing the network measures from concept mapping with brain activity (e.g., Hu et al., 2019).

Systems thinking relies on efficiency, effectiveness, and reliability (Grohs et al., 2018) of a complex neuroarchitecture. The neural activity that governs our everyday lives involves an intricate coordination of many processes that can be attributed to a variety of brain regions. At best, the numerous dynamic networks underpinning systems thinking can be understood using a systems-level approach such as neuroimaging (Hu and Shealy, 2018; Hu et al., 2019) which enables the collection of objective physiological data during cognitive activity. Hu et al. (2019) used functional near-infrared spectroscopy (fNIRS) to measure and compare BOLD response among engineering students during concept generation and concept listing exercises, to measure systems thinking, for grand challenges to sustainability. The authors showed that engineering students generated significantly more concepts when using concept maps than making linear lists. During tasks of mapping and listing concepts, the BOLD response which is a measure of cognitive activation, was significantly different in two brain regions: the dorsolateral prefrontal cortex (DLPFC) and parietal cortex (PC) (**Figure 1**). This is a significant finding because both the DLPFC and PC are brain regions known to be involved in higher order executive functions, adaptive thinking (Bembich et al., 2014), and sequence processing (Köhler et al., 1995), all key components of concept mapping.

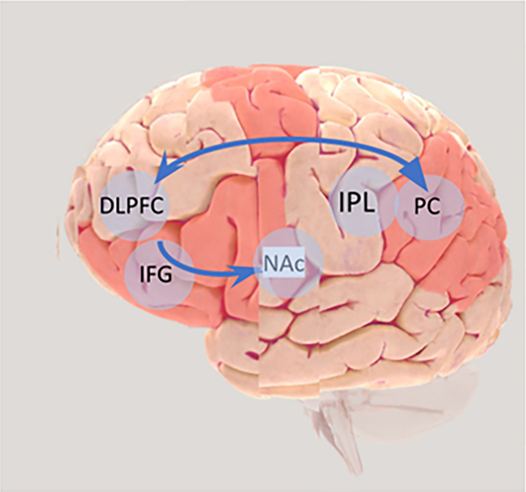

FIGURE 1
The frontoparietal network, indicated by the arrow, extending from the dorsolateral frontal (DLPFC) cortex to the parietal cortex (PC) is a control hub involved in Systems Thinking (ST), observational learning. This region also overlaps with the putative mirror neuron system extending from the inferior frontal gyrus (IFG) to the inferior parietal lobule (IPL). The network between the DLPFC and nucleus accumbens (NAc) mediates reward processing and motivation which is important for observational learning. DLPFC is also linked with pro-environmental behaviour. Source: Image of Brain produced using 3D Brain (brainfacts.org).

To measure systems thinking in "field" settings in LICs, the field neuroimaging protocol needs to outline considerations for travelling with and setting up a portable neuroimaging laboratory in low-resource contexts.

3.1. What are the appropriate tools that can be used in a LIC setting?

When considering the appropriate neuroimaging tool, it is worth bearing in mind that electroencephalogram (EEG) provides temporal resolution in the milliseconds range while functional magnetic resonance imaging (fMRI) provides a high level of spatial resolution. Recent methodologies such as functional Near Infrared Spectroscopy (fNIRS) provide better temporal resolution than fMRI and better spatial resolution than EEG (Lloyd-Fox et al., 2010). Researchers use fNIRS to study experimental tasks related to thinking (Pike et al., 2014), decision making (Cazzell et al., 2012), and problem-solving (Leff et al., 2009) because it is more ambulatory compared to EEG and allows for the flexibility to study human cognition in "real life" settings compared to fMRI (Irani et al., 2007). Both fNIRS and fMRI measure changes in oxygenated blood, or oxygenated haemoglobin, and deoxygenated haemoglobin to give a readout of brain activity. fNIRS neuroimaging is well-suited for field research (Baker et al., 2017). A key advantage of fNIRS is its portability (i.e., some systems may fit in a suitcase), ease of use, and the fNIRS system also tolerates movement well compared to fMRI. fNIRS have superior temporal resolution to fMRI and also has good spatial resolution; the fNIRS' depth of recording in the human cortex is less than fMRI, measuring about 3–4 cm in depth, which is well-suited for studying cortical functions (Jasińska and Guei, 2018). A limitation of using fNIRS is that the spatial resolution is limited compared to fMRI and therefore considered less appropriate when deeper brain structures (such as the nucleus accumbens) are of primary interest (Kopton and Kenning, 2014). This could be a limitation of using the technology, but in the absence of better portable technology fNIRS could offer a reasonable solution. Mobile EEG tools are also available for recording brain activity and have field recording potentials. However, these are more applicable to consumer applications. While recent research has demonstrated the accessibility, feasibility, and usability of Electroencephalography (EEG; e.g., EMOTIV +) in a rural area (predominantly agricultural area) of India. Similar research using EEG has been conducted in Malawi, The Gambia, and Bangladesh (Bhavnani et al., 2022), and further work is required to establish mobile EEG methodologies for neurodevelopmental research (Lau-Zhu et al., 2019). Compared to more traditional research-grade high-density EEG systems, mobile EEG has been used in a limited number of research studies and has better applications in sports, neurofeedback, and motor rehabilitation. For this type of research (e.g., exploration of neural correlates of ST) neuroscience experts from the University of Geneva have recommended using Near-Infrared Spectroscopy (NIRS) (e.g., https://neurolite.ch/en/products/nirs/portalite-mkii; University of Geneva, Personal Communication). Advantages include better spatial coverage, rapid onboard data collection, and the ability for a non-specialist with relatively limited training to gather data (ibid). Whilst it has been noted that EEG and fNIRS have excluded participation among participants due to hair structure, skin pigmentation, etc. (e.g., Green et al., 2022; Webb et al., 2022), these alternative designs allow for the ability to engage a wide variety of participants irrespective of skin pigmentation[7] (University of Geneva, Personal Communication).

4. Correlates of systems thinking: observational learning, prospective thinking/memory and the theory of planned behaviour?

We have highlighted in the previous section how such methodologies may be incorporated in an "in-the-field" setting particularly in an LIC context. The task ahead is to then explore to what extent these neural correlates of ST are associated with other aspects involved in environmental decision making. The following makes the case for including observational learning, prospective thinking/memory, and constructs that form part of the theory of planned behaviour that have played important roles in our understanding of environmental decision making including CSA practices/other pro-environmental behaviours in a wide variety of country settings (e.g., Kondylis et al., 2016; Lalani et al., 2016; Maertens et al., 2020; Doell et al., 2021).

4.1. Observational learning

Observational learning occurs through the observation of others even when this may happen in the context of other activities (Fryling et al., 2011). It requires observing the actions of others which is also known to vicariously recruit brain regions traditionally associated with action execution (Rizzolatti and Craighero, 2004; Gazzola and Keysers, 2009; Caspers et al., 2010). Several studies have reported that the fronto-parietal human mirror neuron system (hMNS) is strongly recruited while observing actions during the learning of new motor patterns through imitation of other's actions (Buccino et al., 2004; Vogt et al., 2007; Fabbri-Destro and Rizzolatti, 2008; Cross et al., 2009). The same hMNS is also activated when participants simply view the actions of others without needing to replicate them, or when they simply execute these actions (Gazzola and Keysers, 2009).

The hMNS was found to be strongly activated while participants were observing others' actions during the acquisition of motor patterns (Caspers et al., 2010). Traditionally, cognitive neuroscience has therefore focussed on the hMNS (Ramsey et al., 2021).

More recently, this has extended beyond the hMNS and involved the extended motor network. Whilst there are a number of types of observational learning (see Ramsey et al., 2021 for a comprehensive review) we refer to the subtype of observational learning (observational motor learning) that requires: (i) an action being observed; and (ii) an enduring change to motor performance must occur (Ramsey et al., 2021). Two types of tasks are involved, namely: (i) sequence learning (e.g., learning to dance or ride a bike) usually measured by serial reaction time, and (ii) motor adaptation (concerned with maintaining consistent performance in light of bodily/environmental changes) studying using visuomotor adaptation tasks (Ramsey et al., 2021).

Calvo-Merino et al. (2006) showed that mirror neuron development relates to the previous motor experience of performing that action; importantly highlighting there are differences by gender. In this study, expert dancers were shown videos of ballet moves that were familiar to both genders. Interestingly, when dancers viewed moves from their "own motor repertoire" (i.e., in this case gender) higher premotor, parietal, and cerebellar activity was found (Calvo-Merino et al., 2006). It is also argued that sensorimotor experience enables mirror neurons to be created by the experience of observing and practicing the action (Heyes, 2009). Interesting parallels can be made with the knowledge and use of sustainable land management techniques. Kondylis et al. (2016) found in communities that were randomly selected to have a trained female extension officer in Mozambique (and encouraged to train other women) that higher levels of knowledge and adoption of pit planting (CSA practice) were found among women farmers.

4.2. Current observational learning research methods

Three main types of task design are currently used in observational learning research (Kang et al., 2021). Monfardini et al. (2008) employed a visuomotor learning task design where participants were tasked to watch an actor making motor responses according to the stimulus presentation with post-response feedback (i.e., a binary response regarding whether the actor made the right choice where their reaction times were also recorded). One advantage of this design is that it allows the detection of brain activity when participants retrieve rules (Kang et al., 2021). Monfardini et al. (2013) later built on this design by introducing the learning by observation task (LeO) whereby participants (whilst being scanned by fMRI) were asked to learn stimulus-response associations by watching a video demonstration of an expert performing the correct visuomotor associations which enabled the identification and comparison of brain networks "mediating processing of errors and successes during individual and observational learning" (Monfardini et al., 2013). Burke et al. (2010) employed an observational learning task "two-armed bandit problem" where participants had to make a choice based on two abstract stimuli to either gain a stochastic reward or avoid a stochastic punishment. Of the two stimuli one provided a consistently good outcome (reward or absence of punishment 80%

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[7] We envisage using NIRS given these specific advantages and its portability/ease of use.

of the time) and the other a consistently bad outcome (punishment or absence of a reward 20% of the time) whilst being scanned by fMRI.

4.3. A systems approach to understanding observational learning

Various researchers have suggested that direct simulation of observed social events through mirror-like mechanisms are at the heart of this experiential understanding of others by activation of matching neural substrates in the observer through which the action can be understood (Rizzolatti et al., 2001; Gallese, 2003; Wicker et al., 2003; Goldman and Sripada, 2005; Keysers and Gazzola, 2006). While some researchers focus on the role of motor areas in social cognition (e.g., motor theory of social cognition, Jacob and Jeannerod, 2005), others describe a more embodied simulation that involves a linkage between the first and third person experiences of actions, sensations, and emotions (Keysers and Gazzola, 2006). Although there is no doubt that one can understand others' emotions *via* inferential mental processes (as during the observation of emotions), there is clear evidence that brain structures involved in the integration and control of emotions, like the insula and the anterior cingulate, respond both when one feels an emotion (e.g., pain or disgust) owing to natural stimuli, or when one observes that emotion in others (Carr et al., 2003; Gallese, 2003; Wicker et al., 2003; Singer et al., 2004). This is a relevant mechanism which could be hypothesised to allow a direct first-person understanding of others' emotions, especially in the context of positive emotions (e.g., Doell et al., 2021). Doell et al. (2021) showed that observational learning played a key role in commitment to pro-environmental behaviours. More specifically, those with higher levels of positive trait affect (those that tend to experience positive emotions with respect to positive environmental outcomes) were found to commit more pro-environmental behaviour and achieve greater shifts in positive state. These shifts occurred for pro-environmental behaviour that was committed by the individual and for those that were learned from others (observed).

Thus, it has been argued that the process of learning by observation is mediated by brain regions encompassing the dorsal fronto-parietal, the fronto-striatal, and the cerebellar networks. It partly exploits the same neural system mediating individual learning, visuomotor transformations, and the control of goal-direct attention (Monfardini et al., 2013). As a flexible hub of cognitive control, the frontoparietal network carries information about the items stored in working memory and governs the cascade of attentional processes that underlie complex cognitive functions and fluid intelligence (Duncan, 2010, 2013; Stoewer et al., 2010). Functional connectivity between the frontoparietal network and the nucleus accumbens which is involved in reward processing and motivation may also be involved in learning by observation. Hence, we hypothesize that ST leverages the same cognitive flexibility of the prefrontal cortex, involving either the dorsolateral prefrontal cortex (DLPFC) or the parietal cortex, that drives observational learning (Kang et al., 2021) (**Figure 1**).

For example, Maertens et al. (2020) found that farmers that participated in season-long farmer-led demonstrations in Malawi formed beliefs about the usefulness of the specific CSA practices though these were dependent in part on how similar their own conditions were to the demonstration plot and how well the demonstration plot performed. The authors suggest that the learning process is a two-stage process by which farmers first formulate beliefs based on their own "first-hand and local experience" which then provides an impetus to invest time in learning about the specific practices. These observations seem to indicate a strong link between the ability to recruit higher cognitive networks to learn from observations and execute action subsequently. Thus, this may go beyond the hMNS to include areas of reward and cognitive control as with respect to social learning, reward centers coordinate learning by direct experience (Ramsey et al., 2021).

Learning about sustainable behaviour (e.g., CSA practices) through observation of peers is critical to encourage farmers towards sustainable agricultural practices. This aspect of observational learning and storing the information as part of the brain's executive functioning, and retrieving the information later to improve future behaviour, supports prospective memory. Successful prospective thinking (described in the next section) enables a person to anticipate a future intention. When evaluating sustainable practices, especially when thinking prospectively, it is important to shift from thinking about individual parts and to adopting a more systems approach by focusing more on the linkages and interactions of each action. Ramsey et al. (2021) have also argued for more research using fNIRS; integrating observational learning with motivations, goals, and intentions and exploring how learning occurs in groups and in real-life situations.

4.4. Prospective thinking/memory

Another important factor that determines the likelihood of farmers adopting pro-sustainable behaviour is their ability to project themselves adopting the behaviour in the future, referred to as prospective thinking (Schacter et al., 2012). It requires the ability to flexibly retrieve and recombine information from past experiences into simulation and mental imagery related to future events (Szpunar, 2010; D'Argembeau et al., 2011; D'Argembeau and Demblon, 2012; Schacter et al., 2012). This involves a core network of brain regions, featuring the hippocampus (HC) and the ventromedial prefrontal cortex (vmPFC) (Schacter et al., 2017). The HC plays an important role in recombining memories to mentally simulate future events (Wu et al., 2015). The vmPFC provides contextual details and imagines the future situation (Barron et al., 2013; Benoit et al., 2014).

Brevers et al. (2021) showed that prospective thinking about sustainable behaviours activates a brain network involving the vmPFC, HC, and parahippocampal gyrus. Additionally, activation of vmPFC was triggered during prospective thinking of highly feasible sustainable behaviours. Increasing sustainable behaviours were rated as more feasible suggesting that forming sustainable or "good habits" might be more efficient (Galla et al., 2015; Wood, 2019) or less effortful (Inzlicht and Schmeichel, 2012; Inzlicht et al., 2014) compared with reducing unsustainable or "bad" ones.

Implicit memory interventions have also been suggested that can be further strengthened by neuroscientific tools to monitor processes before behaviour change occurs (e.g., Leeuwis et al., 2022). However, it is argued that only when action is regularly performed does habit emerge which can be defined as automatic responses from memory that led to behaviour in the past (Verplanken and Orbell, 2022). Possible measures have included self-reports of habitised behaviour (Verplanken and Orbell, 2003), reaction time measures of context-response associations (e.g., Neal et al., 2012) or speed of response switching (e.g., Luque et al., 2020).

The following section outlines the most common model used to understand human behaviour. Notwithstanding this, other authors have also highlighted that more research on attitudes, intention behaviour, and habits is warranted (e.g., Gardner et al., 2021).

4.5. The theory of planned behaviour

The Theory of Planned Behaviour (TPB) is the most common social-psychological theoretical framework used to understand the dynamics of decision making and human behaviour (Ajzen, 1991; Brosch et al., 2014). It posits that human behaviour is guided by three specific considerations: behavioural beliefs such as the advantages and disadvantages associated with the behaviour; the opinions of significant others towards the behaviour (normative beliefs), and beliefs about possible factors that may hinder or facilitate the performance of the behaviour (control beliefs) (Ajzen, 2019). Moreover, the aggregated beliefs produce a positive or negative attitude, subjective norm (i.e., social pressure to conform to the respective behaviour as a result of normative beliefs), and perceived behavioural control (i.e., to what extent the individual perceives to have control over engaging in the behaviour based on control beliefs) (Ajzen, 2006). These together shape an individual's behavioural intention. Moreover, the stronger the attitude, subjective norm, and perceived behavioural control the stronger one's intention is likely to be to perform the behaviour under study (Davis et al., 2002). It is also proposed that an individual will act on their intention where there exists actual behavioural control (perceived behavioural control can act as a proxy) and the opportunity presents itself (Ajzen, 2006). The type of instruments used to measure these constructs are based on elicitation of beliefs in a free-response format (e.g., to understand accessible behavioural beliefs such as advantages and disadvantages of the behaviour which in theory are important determinants of attitude) and then implementation of a questionnaire using self-reports (see e.g., Ajzen, 1991). Extensions to the framework have been proposed such as the incorporation of appraisal-emotion variables which helped to explain additional variance in the intention that is not explained by the current variables (i.e., emotion is only considered as a background factor in the current TPB model) (see Brosch et al., 2014). The authors posit that alongside the TPB variables both the pattern of an individual's appraisal and an individual's emotional reactivity in certain situations allow for enhanced understanding of an individual's intention, especially with respect to engaging in energy-saving behaviours (Brosch et al., 2014). Lalani et al. (2016) found the TPB model explains a high proportion of variation in intention to use CA (a component of CSA) for smallholder farmers in a district of Northern Mozambique. Farmers' attitude was found to be the strongest predictor of intention followed by perceived behavioural control and subjective norm. More positive environmental beliefs and pro-environmental behaviour have also been linked to brain activity within the DLPFC (e.g., Baumgartner et al., 2019) (**Figure 1**).

In this section, we have outlined that specific brain activity associated with ST may correlate with other key aspects involved in environmental decision making in this case CSA. Key brain regions/networks of interest include the frontoparietal network extending from the DLPFC to the parietal cortex (PC) a control hub involved in ST and observational learning. Moreover, the network between the DLPFC and nucleus NAc mediates reward processing and motivation which is important for observational learning and pro-environmental behaviour. We posit that it would be important to engage these brain structures to: (a) enhance understanding of CSA practices (e.g., *via* the frontoparietal network) such as tailoring training towards developing ST (e.g., Gray et al., 2019) among farmers and involving observational learning explicitly and (b) motivate farmers to use such practices (*via* the network between the DLPFC and NAc which mediates reward processing and motivation by focussing on a reward/emotion to engage farmers. The following section outlines an interdisciplinary approach to measuring ST, possible correlates of ST, and the use of CSA practices by farmers.

5. Proposed theory of change (TOC) and limitations

Figure 2 proposes a Theory of Change (TOC) that will allow us to measure the mechanisms behind systems thinking, correlates with other important aspects of environmental decision making and to what extent this is associated with the use of CSA practices. We have highlighted the possible links/correlations that exist (highlighted by the lines but because the directionality is unknown we have not sought to propose what the effects are in the figure). The numbered nodes from each box/theme highlight possible indicators/metrics that we feel are worth considering. Background factors and the Adoption of Sustainable Practices Index used by Bardenhagen et al. (2020) which provides information on the practices used by farmers and the participation in social learning activities will help to explore to what extent such factors mediate ST/observational learning and use of CSA practices (**Figure 2**).

Whilst there are clear examples of studies exploring ST with cognitive neuroscience tools (i.e., through concept mapping and the use of fNIRS) in a laboratory setting (e.g., Hu et al., 2019) to our knowledge there is no research to date exploring the relationship between ST and observational learning and/or the use of CSA practices involving mobile neuroscience tools/measures in an LIC. A recent systematic literature review on systems thinking in engineering found that the triangulation of ST *via* multiple assessment types such as the use of concept mapping and fNIRS (Hu and Shealy, 2018) is likely to be beneficial (Dugan et al., 2022). To this end, we have proposed using NIRS and concept mapping similar to the approach taken by Hu and Shealy (2018) and the use of FCM which therefore provides several forms of triangulation (**Figure 2**).

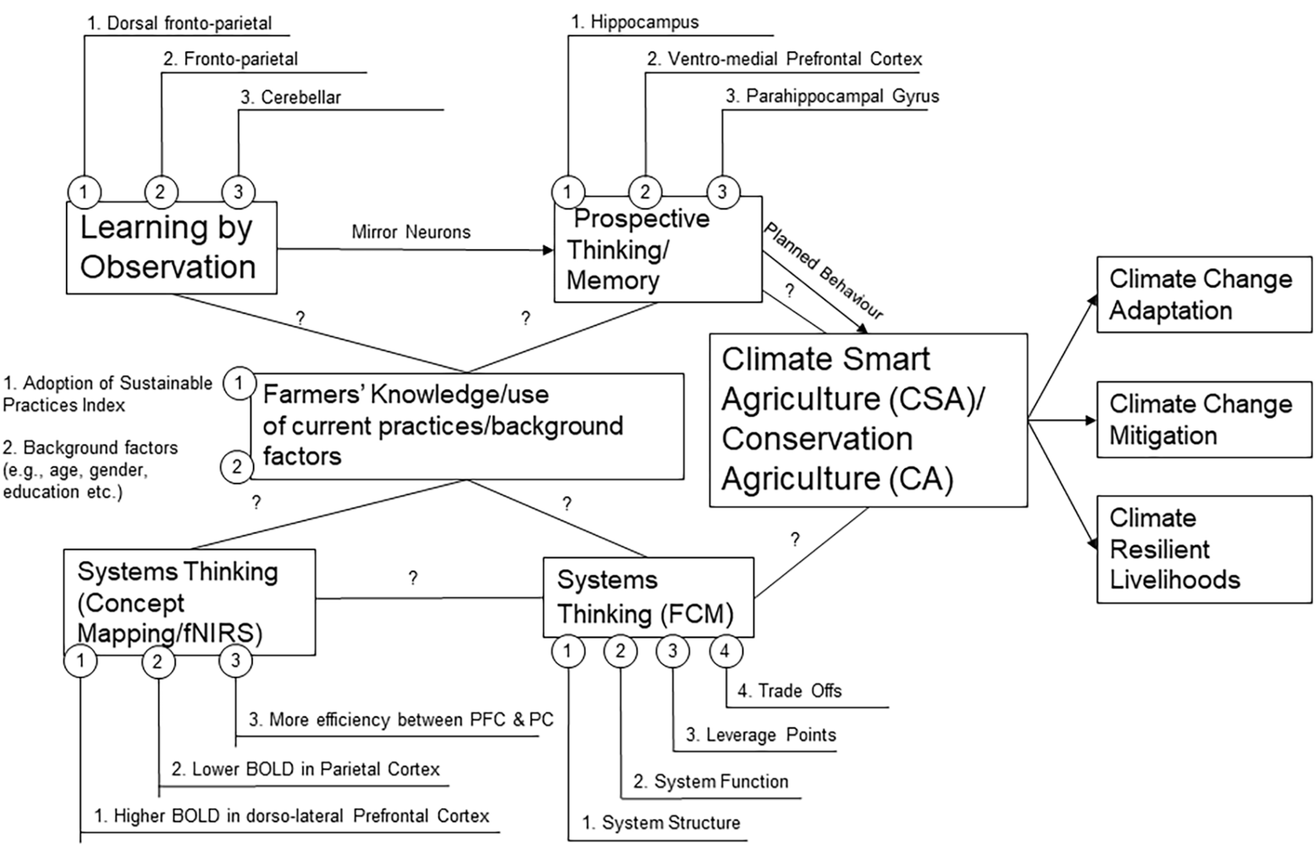

FIGURE 2
Theory of change. Please note some of the indicators/brain regions highlighted in Figure 2 are based on a scan of the literature and/or the use of fNIRS (e.g., under concept mapping). This might be slightly different with the use of NIRS (focus on the prefrontal cortex).

We propose that higher forms of ST are associated with an enhanced ability to respond to observational learning (e.g., Zonca et al., 2021[8]) and further posit that this correlates positively with prospective thinking/memory; attitude, subjective norm, perceived behavioural control and thereby intention to perform the behaviour (theory of planned behaviour constructs referred to as planned behaviour in **Figure 2**). Whilst the observational task designs mentioned in the previous section have utilised fMRI we envisage that it would be possible to adapt methodologies by Burke et al. (2010) and Monfardini et al. (2008, 2013) whilst participants are monitored by NIRS and performing tasks using a tablet. For example, observational task designs (e.g., Burke et al., 2010) could be adapted to ask farmers to choose the "best" set of practices to achieve a reward (positive harvest) and avoid a punishment (crop failure) in anticipation of a dry season/drought (with stimuli showing certain CSA practices if employed providing a much higher probability of avoiding crop failure) compared to another set of stimuli with a set of practices less likely to achieve a positive outcome. Another option could be to adapt the approach taken by Monfardini et al. (2008) who compared brain responses in relation to the retrieval of visuomotor associations learned by observation or by trial and error (individual learning). It may also be possible to adapt current visuomotor associations to show farmers a video of a farmer/actor performing a set of agriculture practices (motor responses) and gather post-response feedback (e.g., binary response based on whether the farmer made the "right" choice or not).

Equally, it could be possible to adapt cue-exposure paradigms (e.g., Brevers et al., 2021) to study prospective thinking and context-response associations (e.g., Neal et al., 2012) or speed of response switching (e.g., Luque et al., 2020) for exploration of prospective memory/habit. Cue-exposure paradigms have explored brain activity patterns in response to different cues on "doing more" sustainable behaviours or on "doing less" unsustainable behaviours and the perceived feasibility of performing these practices (Brevers et al., 2021). Likewise, one can imagine a similar cue-exposure paradigm exploring CSA practices and perceived feasibility. For example, more sustainable practices such as minimising soil disturbance, planting a diversity of crops, application of soil cover ("do more"), and unsustainable practices such as crop burning, tillage, and leaving the land bare ("do less").

Although perceptions of climate change/vulnerability provide useful background factors to include; affective/emotional reactivity is considered an important consideration in providing a better understanding of observational learning in the context of pro-environmental behaviours (e.g., Doell et al., 2021) and

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[8] Although Zonca et al. (2021) did not look at ST abilities they found that individuals with a low initial level of strategic sophistication did not succeed in learning from observation compared to those with a higher level of strategic sophistication.

the theory of planned behaviour (e.g., Brosch et al., 2014) thus could be incorporated/tested more explicitly using self-reports/questionnaires which can be done in tandem/repeated measurements. We acknowledge the literature on habit (action regularly performed) (e.g., Verplanken and Orbell, 2022) and thus propose a possible feedback from the use of CSA practices to prospective thinking/memory (**Figure 2**; for a more detailed description of the proposed indicators see **Supplementary Table A1**, Explanation of key themes and respective indicators).

One of the major challenges in studying environmental decision making more broadly relates to the fact that behavioural changes (e.g., sustainable behaviours/use of certain agriculture practices) are often those which take place in the long-term (Leeuwis et al., 2022). Thus, there are limitations to "one-shot" neuroimaging studies (Sawe, 2017). Whilst the lack of longitudinal is cited as a common limitation of pro-environmental behaviour studies (e.g., Leeuwis et al., 2022), short-term studies may provide a proof of concept such as identifying potential brain regions/networks involved in specific pro-environmental behaviours (e.g., certain agricultural practices) and lead to longer-term studies.

Though some of the studies may be challenging to administer in practice (e.g., observational learning tasks and/or cue/exposure paradigms to study prospective thinking) another option would be to utilise the approach by Baumgartner et al. (2019). The authors use the neural trait approach which explores task-independent, brain-based differences between people and links these differences to a behaviour of interest. The study involved recording task independent EEG at resting before measuring participants' attitudes regarding environmental behaviour several days later and participants' everyday pro-environmental behaviour over five days (*via* Smartphone) conducted several weeks later to reduce any carry-over effect (*via* Smartphone). A similar study could be used prior to land preparation and several weeks into the agricultural season, for instance. Similar predictive modelling studies have been done with fNIRS (e.g., see Burns et al., 2018).

Thus, the use of field-based experiments (e.g., Doell et al., 2021) and other trait-based approaches (e.g., Baumgartner et al., 2019) may be more feasible to implement. This would allow for a more nuanced understanding of the indicators that reflect neural and behaviour change at the respective individual level that could support wider population-level studies (Sawe, 2019; Leeuwis et al., 2022). Moreover, nudge theory/choice architecture could also be utilised to investigate the specific "behavioural nudges" that can influence decision making and whether this is associated with higher degrees of ST and exploration of what might be predictive of national behaviour (e.g., Sawe, 2019)[9]. Recent research has found farmers that watched Edutainment TV programmes (e.g., Shamba Shape-up in Kenya) on sustainable agriculture practices had a higher probability of implementing these practices (Areal et al., 2020). The authors concluded that Edutainment TV can effectively "nudge farmers" to implement sustainable agriculture practices and that this highlights a viable approach to addressing challenges such as adaptation/mitigation to climate change (Areal et al., 2020).

6. Concluding remarks

The majority of the world's poorest people reside in rural areas, primarily engaged in agriculture and located in the Global South. Future climate change scenarios have highlighted the negative effects on agricultural productivity worldwide, particularly for LICs in the Global South, highlighting the need for climate change adaptation (e.g., CSA practices) that will contribute to more resilient livelihoods dependent on agriculture. ST has been associated with "better" environmental decision making in a number of environmental and cultural settings, however, to what extent does ST correlate with other important aspects of environmental decision making and improve human adaptive behaviour? Current measures of ST (e.g., cognitive mapping methods such as Fuzzy Cognitive Mapping) are limited in scope (e.g., reliance on recall on participants' meta-cognition) highlighting the need for triangulation and integration of other approaches to elucidate previously hidden forms of cognition.

Using CSA, as an example case study (with a focus on SSA where the majority of the world's poorest live[10]) in this perspective essay, we have explored: (i) ST from a social science perspective; (ii) cognitive neuroscience tools that could be used to explore ST abilities in the context of LICs; (iii) an exploration of the possible correlates of systems thinking: observational learning, prospective thinking/memory and the theory of planned behaviour and (iv) a proposed theory of change highlighting the integration of social science frameworks and a cognitive neuroscience perspective that can be used to enhance our understanding of ST and farmers' decision making. We find, recent advancements in the field of cognitive neuroscience such as Near-Infrared Spectroscopy (NIRS) provide exciting potential to explore previously hidden forms of cognition, especially in a low-income country/field setting; improving our understanding of environmental decision making and the ability to more accurately test more complex hypotheses where access to laboratory studies is severely limited. We posit that it would be important to engage farmers *via* specific brain networks to: (a) enhance understanding of CSA practices (e.g., *via* the frontoparietal network extending from the DLPFC to the parietal cortex (PC) a control hub involved in ST and observational learning) such as tailoring training towards developing ST (e.g., Gray et al., 2019) among farmers and involving observational learning explicitly and (b) motivate farmers to use such practices (*via* the network between the DLPFC and NAc which mediates reward processing and motivation) by focussing on a reward/emotion to engage farmers.[11]

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[9] Nudging aims to increase the attractiveness of the behaviour whilst freedom of choice still exists by alteration of the choice architecture (i.e. presenting choices in different ways that will impact decision making) and has been shown to positively influence pro-environmental behaviours (Leeuwis et al., 2022; Mertens et al., 2022).

[10] See World Bank (2022).

[11] Although we have focussed on specific CSA practices we feel that this approach could also be used to explore environmental-decision making in similar/related domains and in different regions/countries.

A more nuanced exploration of how contextual factors such as gender and educational efforts such as TV programs might affect these mechanisms would be fruitful. For example, different stimuli (e.g., farmer demonstrations, Farmer Field Schools) combined with different modes of information communication/ social referents) and "behavioural levers" (e.g., nudging) can be important in this regard and warrant further research, particularly from a cognitive neuroscience perspective.

Data availability statement

The original contributions presented in the study are included in the article/**Supplementary materials**, further inquiries can be directed to the corresponding author.

Author contributions

BL, SG, and TM-G conceptualised the study, wrote and approved the final version of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/fnint.2023.1145744/full#supplementary-material.

References

Abdulai, A. N. (2016). Impact of conservation agriculture technology on household welfare in Zambia. *Agric. Econ.* 47, 729–741. doi: 10.1111/agec.12269

Ajzen, I. (1991). The theory of planned behaviour. *Organ. Behav. Hum. Decis.* 50, 179–211.

Ajzen, I. (2006). Constructing a theory of planned behavior questionnaire. Available online at: https://people.umass.edu/aizen/pdf/tpb.measurement.pdf.

Ajzen, I. (2019). Behavioral interventions based on the theory of planned behavior. Available online at: https://people.umass.edu/aizen/pdf/tpb.intervention.pdf.

Aminpour, P., Gray, S. A., and Beck, M. W.. (2022). Urbanized knowledge syndrome—erosion of diversity and systems thinking in urbanites' mental models. *NPJ Urban Sustain.* 2:11. doi: 10.1038/s42949-022-00054-0

Aminpour, P., Gray, S. A., Jetter, A. J., Introne, J. E., Singer, A., Arlinghaus, R. (2020). Wisdom of stakeholder crowds in complex social-ecological systems. *Nat. Sustain.* 3, 191–199. doi: 10.1038/s41893-019-0467-z

Areal, F. J., Clarkson, G., Garforth, C., Barahona, C., Dove, M., and Dorward, P. (2020). Does TV edutainment lead to farmers changing their agricultural practices aiming at increasing productivity? *J. Rural Stud.* 76, 213–229. doi: 10.1016/j.jrurstud.2020.03.001

Arnold, R., and Wade, J. (2015). A definition of systems thinking: a systems approach. *Procedia Comput. Sci.* 44, 669–678. doi: 10.1016/j.procs.2015.03.050

Baker, J. M., Rojas-Valverde, D., Gutiérrez, R., Winkler, M., Fuhrimann, S., Eskenazi, B., et al. (2017). Portable functional neuroimaging as an environmental epidemiology tool: a how-to guide for the use of fNIRS in field studies. *Environ. Health Perspect.* 125:094502. doi: 10.1289/EHP2049

Bardenhagen, C. J., Howard, P. H., and Gray, S. A. (2020). Farmer mental models of biological pest control: associations with adoption of conservation practices in blueberry and cherry orchards. *Front. Sustain. Food Syst.* 4:54. doi: 10.3389/fsufs.2020.00054

Barron, H. C., Dolan, R. J., and Behrens, T. E. (2013). Online evaluation of novel choices by simultaneous representation of multiple memories. *Nat. Neurosci.* 16, 1492–1498. doi: 10.1038/nn.3515

Baumgartner, T., Langenbach, B. P., Gianotti, L. R. R., Müri, R. M., and Knoch, D. (2019). Frequency of everyday pro-environmental behaviour is explained by baseline activation in lateral prefrontal cortex. *Sci. Rep.* 9:9. doi: 10.1038/s41598-018-36956-2

Bembich, S., Clarici, A., Vecchiet, C., Baldassi, G., Cont, G., and Demarini, S. (2014). Differences in time course activation of dorsolateral prefrontal cortex associated with low or high risk choices in a gambling task. *Front. Hum. Neurosci.* 8:464. doi: 10.3389/fnhum.2014.00464

Benhangi, S. M., Bagheri, A., Abolhassani, L., and Razi, H. H. (2020). Assessing the learning capacity of water users-Adoption a social learning framework. *J. Hydrol.* 590:125496. doi: 10.1016/j.jhydrol.2020.125496

Benoit, C.-E., Bella, S. D., Farrugia, N., Obrig, H., Mainka, S., and Kotz, S. A. (2014). Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. *Front. Hum. Neurosci* 8:494. doi: 10.3389/fnhum.2014.00494

Berthelin, J., Laba, M., Lemaire, G., Powlson, D., Tessier, D., Wander, M., et al. (2022). Soil carbon sequestration for climate change mitigation: mineralization kinetics of organic inputs as an overlooked limitation. *Eur. J. Soil Sci.* 73:e13221. doi: 10.1111/ejss.13221

Bhavnani, S., Parameshwaran, D., Sharma, K. K., Mukherjee, D., Divan, G., Patel, V., et al. (2022). The acceptability, feasibility and utility of portable electroencephalography to study resting-state neurophysiology in rural communities. *Front. Hum. Neurosci.* 16:802764. doi: 10.3389/fnhum.2022.802764

Binder, C. R., Hinkel, J., Bots, P. W. G., and Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. *Ecol. Soc.* 18:26. doi: 10.5751/es-05551-180426

Brandstädter, K., Harms, U., and Großschedl, J. (2012). Assessing system thinking through different concept-mapping practices. *Int. J. Sci. Educ.* 14, 2147–2170. doi: 10.1080/09500693.2012.716549

Brevers, D., Baeken, C., Maurage, P., Sescousse, G., Vögele, C., and Billieux, J. (2021). Brain mechanisms underlying prospective thinking of sustainable behaviours. *Nat. Sustain.* 4, 433–439. doi: 10.1038/s41893-020-00658-3

Brosch, T., Patel, M. K., and Sander, D. (2014). Affective influences on energy-related decisions and behaviors. *Front. Energy Res.* 2:11. doi: 10.3389/fenrg.2014.00011

Buccino, G., Vogt, S., Ritzl, A., Fink, G. R., Zilles, K., Freund, H. J. et al. (2004). Neural circuits underlying imitation learning of hand actions: an event-related fMRI study. *Neuron* 42, 323–334. doi: 10.1016/s0896-6273(04)00181-3

Buchanan, J. (1885). *The Shire Highlands (east and central Africa) as Colony and Mission*. Edinburgh and London: William Blackwood and Sons.

Burke, C. J., Tobler, P. N., Baddeley, M., and Schultz, W. (2010). Neural mechanisms of observational learning. *Proc. Natl. Acad. Sci. U S A* 107, 14431–14436. doi: 10.1073/pnas.1003111107

Burns, S. M., Barnes, L. N., Katzman, P. L., Ames, D. L., Falk, E. B., Lieberman, M. D., et al. (2018). A functional near infrared spectroscopy (fNIRS) replication of the sunscreen persuasion paradigm. *Soc. Cogn. Affect. Neurosci.* 13, 628–636. doi: 10.1093/scan/nsy030

Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., and Haggard, P. (2006). Seeing or doing? influence of visual and motor familiarity in action observation. *Curr. Biol.* 16, 1905–1910. doi: 10.1016/j.cub.2006.07.065

Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., and Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proc. Nat. Acad. Sci.* 100, 5497–5502. doi: 10.1073/pnas.0935845100

Caspers, S., Zilles, K., Laird, A. R., and Eickhoff, S. B. (2010). ALE meta-analysis of action observation and imitation in the human brain. *Neuroimage* 50, 1148–1167. doi: 10.1016/j.neuroimage.2009.12.112

Cazzell, M., Li, L., Lin, Z.-J., Patel, S. J., and Liu, H. (2012). Comparison of neural correlates ofrisk decision making between genders: an exploratory fNIRS study of the Balloon Analogue Risk Task (BART). *Neuroimage* 62, 1896–1911. doi: 10.1016/j.neuroimage.2012.05.030

Cholewicki, J., Popovich, J. M., Jr., Aminpour, P., Gray, S. A., Lee, A. S., Hodges, P. W.et al. (2019). Development of a collaborative model of low back pain: report from the 2017 NASS consensus meeting. *Spine J.* 19, 1029–1040. doi: 10.1016/j.spinee.2018.11.014

Church, S. P., Lu, J., Ranjan, P., Reimer, A. P., and Prokopy, L. S. (2020). The role of systems thinking in cover crop adoption: implications for conservation communication. *Land Use Policy* 94:104508. doi: 10.1016/j.landusepol.2020.104508

Craik, K. J. W. (1943). *The Nature of Explanation*. Cambridge: Cambridge University Press.

Cross, E. S., Kraemer, D. J., Hamilton, A. F., Kelley, W. M., and Grafton, S. T. (2009). Sensitivity of the action observation network to physical and observational learning. *Cereb. Cortex* 19, 315–326. doi: 10.1093/cercor/bhn083

D'Argembeau, A., and Demblon, J. (2012). On the representational systems underlying prospection: evidence from the event-cueing paradigm. *Cognition* 125, 160–167. doi: 10.1016/j.cognition.2012.07.008

D'Argembeau, A., Renaud, O., and Van der Linden, M. (2011). Frequency, characteristics and functions of future-oriented thoughts in daily life. *Appl. Cogn. Psychol.* 25:96. doi: 10.1002/acp.1647

Davis, L. E., Ajzen, I., Saunders, J., and Williams, T. (2002). The decision of African American students to complete high school: an application of the theory of planned behavior. *J. Educ. Psychol.* 94, 810–819. doi: 10.1037/0022-0663.94.4.810

De Pinto, A., Cenacchi, N., Kwon, H.-Y., Koo, J., and Dunston, S. (2020). Climate smart agriculture and global food-crop production. *PLoS One* 15:e0231764. doi: 10.1371/journal.pone.0231764

Dingman, M. (2019). *Your Brain, Explained: What Neuroscience Reveals About Your Brain and Its Quirks*. UK: Hachette

Doell, K. C., Conte, B., and Brosch, T. (2021). Interindividual differences in environmentally relevant positive trait affect impacts sustainable behavior in everyday life. *Sci. Rep.* 11:20. doi: 10.1038/s41598-021-99438-y

Dugan, K. E., Mosyjowski, E. A., Daly, S. R., and Lattuca, L. R. (2022). Systems thinking assessments in engineering: a systematic literature review. *Systems Res. Behav. Sci.* 39, 840–866. doi: 10.1002/sres.2808

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour. *Trends Cogn. Sci.* 14, 172–179. doi: 10.1016/j.tics.2010.01.004

Duncan, J. (2013). The structure of cognition: attentional episodes in mind and brain. *Neuron* 80, 35–50. doi: 10.1016/j.neuron.2013.09.015

Dunlap, R. E. (2008). The new environmental paradigm scale: from marginality to worldwide use. *J. Environ. Educ.* 40, 3–18. doi: 10.3200/joee.40.1.3-18

Fabbri-Destro, M., and Rizzolatti, G. (2008). Mirror neurons and mirror systems inmonkeys and humans. *Physiology (Bethesda)* 23, 171–179. doi: 10.1152/physiol.00004.2008

FAO (2020). *Global Forest Resources Assessment 2020*. Rome: FAO. Available online at: https://doi.org/10.4060/ca8753en.

FAO (2022a). Available online at: https://www.fao.org/climate-smart-agriculture/en/.

FAO (2022b). Available online at: https://www.fao.org/conservation-agriculture/en/.

FAO (2021). IFAD, UNICEF, WFP and WHO. The state of food security and nutrition in the world 2021. *Transforming Food Systems for Food Security, Improved Nutrition and Affordable Healthy Diets for All.* Rome: FAO.

Fryling, M. J., Johnston, C., and Hayes, L. J. (2011). Understanding observational learning: an interbehavioral approach. *Anal. Verbal Behav.* 27, 191–203. doi: 10.1007/BF03393102

Galla, B., O'Reilly, G., Kitil, M., Smalley, S., and Black, D. (2015). Community-based mindfulness program for disease prevention and health promotion: targeting stress reduction. *Am. J. Health Promot.* 30, 36–41. doi: 10.4278/ajhp.131107-QUAN-567

Gallese, V. (2003). The roots of empathy: the shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology* 36, 171–180. doi: 10.1159/000072786

Gardner, B., Arden, M. A., Brown, D., Eves, F. F., Green, J., Hamilton, K., et al. (2021). Developing habit-based health behavior change interventions: twenty-one questions to guide future research. *Psychol. Health* 14, 1–23. doi: 10.1080/08870446.2021.2003362

Gazzola, V., and Keysers, C. (2009). The observation and execution of actions share motor and somatosensory voxels in all tested subjects: single-subject analyses of unsmoothed fMRI data. *Cereb. Cortex* 1239–1255. doi: 10.1093/cercor/bhn181

Goldman, A. I., and Sripada, C. S. (2005). Simulationist models of face-based emotion recognition. *Cognition* 94, 193–213. doi: 10.1016/j.cognition.2004.01.005

Gonzalez-Sanchez, E. J., Veroz-Gonzalez, O., Conway, G., Moreno-Garcia, M., Kassam, A., Mkomwa, S., et al. (2019). Meta-analysis on carbon sequestration through conservation agriculture in africa. *Soil Tillage Res.* 190, 22–30. doi: 10.1016/j.still.2019.02.020

Gray, S., McFall, A., Hilsberg, J., and Arlinghaus, R. (2015). The impact of specialization and target species choice on the structure of mental models about fish population dynamics. *J. Outdoor Recreation Tourism* 12, 1–13. doi: 10.1016/j.jort.2015.09.001

Gray, S. (2018). Measuring systems thinking. *Nature Sustain.* 1, 388–389. doi: 10.1038/s41893-018-0121-1

Gray, S. E., Sterling, W. C., Akabas, S., Singer, A., Giabbanelli, P., Jordan, R., et al. (2019). Assessing (social-ecological) systems thinking using concept mapping techniques. *Sustainability* 11:5753. doi: 10.3390/su11205753

Green, K. H., Van De Groep, I. H., Te Brinke, L. W., van der Cruijsen, R., van Rossenberg, F., and El Marroun, H. (2022). A perspective on enhancing representative samples in developmental human neuroscience: connecting science to society. *Front. Integr. Neurosci.* 16:981657. doi: 10.3389/fnint.2022.981657

Grohs, J., Kirk, G., Soledad, M., and Knight, D. (2018). Assessing systems thinking: a tool to measure complex reasoning through Ill-structured problems. *Thinking Skills and Creativity* 28, 110–130. doi: 10.1016/j.tsc.2018.03.003

Halbrendt, J., Gray, S., Radovich, T., Crow, S., and Kimura, A. (2014). Differences in farmer and expert beliefs about the perceived impacts of conservation agriculture. *Glob. Environ. Change* 28, 50–62. doi: 10.1016/j.gloenvcha.2014.05.001

Heyes, C. (2009). Where do mirror neurons come from. *Neurosci. Biobehav. Rev.* 34, 575–583. doi: 10.1016/j.neubiorev.2009.11.007

Hu, M., Shealy, T., Grohs, J., Panneton, R. (2019). Empirical evidence that concept mapping reduces neurocognitive effort during concept generation for sustainability. *J. Cleaner Product.* 238:117815. doi: 10.1016/j.jclepro.2019.117815

Hu, M., and Shealy, T. (2018). "*Systems versus Linear Thinking: Measuring Cognitive Networks for Engineering Sustainability*," in *Construction Research Congress 2018* (American Society of Civil Engineers), 726–736. doi: 10.1061/9780784481301.072

IFAD (2020). Available online at: https://www.ifad.org/en/web/latest/-/blog/to-move-the-needle-on-ending-extreme-poverty-focus-on-rural-areas.

Inzlicht, M., and Schmeichel, B. J. (2012). What is ego depletion? Toward a mechanistic revision of the resource model of self-control. *Perspect. Psychol. Sci.* 7, 450–463. doi: 10.1177/1745691612454134

Inzlicht, M., Schmeichel, B. J., Macrae, C. N. (2014). Why self-control seems (but may not be) limited. *Trends Cogn. Sci.* 18, 127–133. doi: 10.1016/j.tics.2013.12.009

Irani, F., Platek, S. M., Bunce, S., Ruocco, A. C., and Chute, D. (2007). Functional near infraredspectroscopy (fNIRS): an emerging neuroimaging technology with important applications for the study of brain disorders. *Clin. Neuropsychol.* 21:9e37. doi: 10.1080/13854040600910018

Jacob, P., and Jeannerod, M. (2005). The motor theory of social cognition: a critique. *Trends Cogn. Sci.* 209, 21–55. doi: 10.1016/j.tics.2004.11.003

Jasińska, K. K., and Guei, S. (2018). Neuroimaging field methods using functional near infrared spectroscopy (NIRS) neuroimaging to study global child development: rural sub-saharan africa. *J. Vis. Exp.* 21:57165. doi: 10.3791/57165

Jones, N., Ross, H., Lynam, T., Perez, P., and Leitch, A. (2011). Mental models: an nterdisciplinary synthesis of theory and methods. *Ecol. Soc.* 16:46. Available online at: http://www.ecologyandsociety.org/vol16/iss1/art46/.

Kang, W., Pineda, H. S., and Mei, J. (2021). Neural mechanisms of observational learning: a neural working model. *Front. Hum. Neurosci.* 14:609312. doi: 10.3389/fnhum.2020.609312

Kassam, A. H., Mkomwa, S., and Friedrich, T. (2017). *Conservation Agriculture for Africa*. Wallingford, United Kingdom: CABI.

Kay, J., and Foster, J. (1999). "About teaching systems thinking," in *Proceedings of the HKK Conference*, Eds. G. Savage, and P. Roe (Waterloo, Ontario, Canada: University of Waterloo), 165–172

Keifer, J., and Summers, C. H. (2021). The neuroscience community has a role in environmental conservation. *eNeuro* 8:ENEURO.0454-20.2021. doi: 10.1523/ENEURO.0454-20.2021

Kerr, R. B., Young, S. L., Young, C., Santoso, M. V., Magalasi, M., Entz, M., et al. (2022). "Farming for change: developing a participatory curriculum on agroecology, nutrition, climate change and social equity in Malawi and Tanzania," in *Critical Adult Education in Food Movements* (Cham: Springer Nature Switzerland). 29–46.

Keysers, C., and Gazzola, V. (2006). Towards a unifying neural theory of social cognition. *Prog. Brain Res.* 156, 379–401. doi: 10.1016/S0079-6123(06)56021-2

Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P., and & Linkov, I. (2005). Application of multicriteria decision analysis in environmental decision making. *Integr. Environ. Assess. Manage.* 1, 95–108. doi: 10.1897/IEAM_2004a-015.1

Köhler, S., Kapur, S., Moscovitch, M., Winocur, G., and Houle, S. (1995). Dissociation of pathways for object and spatial vision: a PET study in humans. *Neuroreport* 6, 1865–1868. doi: 10.1186/s40545-023-00547-y

Kondylis, F., Mueller, V., Sheriff, G., and Zhu, S. (2016). Do female instructors reduce gender bias in diffusion of sustainable land management techniques? Experimental evidence from Mozambique. *World Dev.* 78, 436–449. doi: 10.1016/j.worlddev.2015.10.036

Kopton, I. M., and Kenning, P. (2014). Near-infrared spectroscopy (NIRS) as a new tool for neuroeconomic research. *Front. Hum. Neurosci.* 8:549. doi: 10.3389/fnhum.2014.00549

Kosko, B. (1986). Fuzzy cognitive maps. *Int. J. Man-Mach. Stud.* 24, 65–75. doi: 10.1016/S0020-7373(86)80040-2

Lalani, B., Aminpour, P., Gray, S., Williams, M., Büchi, L., Haggar, J., et al. (2021). Mapping farmer perceptions, conservation agriculture practices and on-farm measurements: the role of systems thinking in the process of adoption. *Agric. Syst.* 191:103171. doi: 10.1016/j.agsy.2021.103171

Lalani, B., Dorward, P., Holloway, G., and Wauters, E. (2016). Smallholder farmers' motivations for using conservation agriculture and the roles of yield, labour and soil fertility in decision making. *Agric. Syst.* 146, 80–90. doi: 10.1016/j.agsy.2016.04.002

Lamarque, P., Meyfroidt, P., Nettier, B., and Lavorel, S. (2014). How ecosystem services knowledge and values influence farmers' decision-making. *PLoS One* 9:e107572. doi: 10.1371/journal.pone.0107572

Lau-Zhu, A., Lau, M. P. H., and McLoughlin, G. (2019). Mobile EEG in research on neurodevelopmental disorders: opportunities and challenges. *Dev. Cogn. Neurosci.* 36:100635. doi: 10.1016/j.dcn.2019.100635

Leeuwis, N., van Bommel, T., and Alimardani, M. (2022). A framework for application of consumer neuroscience in pro-environmental behavior change interventions. *Front. Hum. Neurosci.* 16:886600. doi: 10.3389/fnhum.2022.886600

Leff, D. R., Orihuela-Espina, F., Karimyan, V., Darzi, A., and Yang, G. Z. (2009). Comparingprefrontal responses evoked by a visuomotor task and a cognitive problem solving task: a longitudinal fNIRS evaluation in surgical trainees. *Neuroimage* 47:S190. doi: 10.1016/S1053-8119(09)72127-5

Levy, M. A., Lubell, M. N., and McRoberts, N. (2018). The structure of mental models of sustainable agriculture. *Nat. Sustain.* 1, 413–420. doi: 10.1038/s41893-018-0116-y

Lloyd-Fox, S., Blasi, A., and Elwell, C. E. (2010). Illuminating the developing brain: the past, present and future of functional near infrared spectroscopy. *Neurosci. Biobehav. Rev.* 34, 269–284. doi: 10.1016/j.neubiorev.2009.07.008

Luque, D., Molinero, S., Watson, P., López, F. J., and Le Pelley, M. E. (2020). Measuring habit formation through goal-directed response switching. *J. Exp. Psychol. Gen.* 149, 1449–1459. doi: 10.1037/xge0000722

Maertens, A., Michelson, H., and Nourani, V. (2020). How do farmers learn from extension services? Evidence from Malawi. *Am. J. Agric. Econ.* 103, 569–595. doi: 10.1111/ajae.12135

Makate, C. (2019). Effective scaling of climate smart agriculture innovations in African smallholder agriculture: a review of approaches, policy and institutional strategy needs. *Environ. Sci. Policy* 96, 37–51. doi: 10.1016/j.envsci.2019.01.014

Mann, C., Parkins, J. R., Isaac, M. E., and Sherren, K. (2019). Do practitioners of holistic management exhibit systems thinking? *Ecol. Soc.* 24:19. doi: 10.5751/ES-11092-240319

Meadows, D. H. (2008). *Thinking in Systems: A Primer*. Chelsea Green Publishing.

Mertens, S., Herberz, M., Hahnel, U. J., and Brosch, T. (2022). The effectiveness of nudging: a meta-analysis of choice architecture interventions across behavioral domains. *Proc. Natl. Acad. Sci. U S A* 119:e2107346118. doi: 10.1073/pnas.2107346118

Mkomwa, S. K., and Kassam, A. (2022). *Conservation Agriculture in Africa: Climate Smart Agricultural Development*. Wallingford, United Kingdom: CABI.

Monfardini, E., Brovelli, A., Boussaoud, D., Takerkart, S., and Wicker, B. (2008). I learned from what you did: retrieving visuomotor associations learned by observation. *Neuroimage* 42, 1207–1213. doi: 10.1016/j.neuroimage.2008.05.043

Monfardini, E., Gazzola, V., Boussaoud, D., Brovelli, A., Keysers, C., and Wicker, B. (2013). Vicarious neural processing of outcomes during observational learning. *PLoS One* 8:e73879. doi: 10.1371/journal.pone.0073879

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci. U S A* 104, 19680–19685. doi: 10.1073/pnas.0701855104

Moyo, B. H. Z. (2010). The use and role of indigenous knowledge in small-scale agricultural systems in Africa: the case of farmers in northern Malawi. Available online at: http://theses.gla.ac.uk/2022/.

Moyo, B., Pullanikkatil, D., Phiri, J. P., and Gerow, D. (2022). "Unravelling indigenous knowledge using the msangu (Faidherbia albida) tree in Malawi: through the voice of farmers," in *Socio-Ecological Systems and Decoloniality*, Eds. D. Pullanikkatil, and K. Hughes (Cham: Springer), 107–127. doi: 10.1007/978-3-031-15097-5_6

Nayaki, A., Gray, S., Lepczyk, C., Skibins, J., and Rentsch, D. (2014). Understanding the hidden drivers and local-scale dynamics of the bushmeat trade through participatory modeling. *Conserv. Biol.* 28, 1403–1414.

Neal, D. T., Wood, W., Labrecque, J. S., and Lally, P. (2012). How do habits guide behavior? Perceived and actual triggers of habits in daily life. *J. Exp. Soc. Psychol.* 48, 492–498. doi: 10.1016/j.jesp.2011.10.011

Nelson, G. C., van der Mensbrugghe, D., Ahammad, H., Blanc, E., Calvin, K., Hasegawa, T., et al. (2014). Agriculture and climate change in global scenarios: why don't the models agree. *Agric. Econ.* 45, 85–101. doi: 10.1111/AGEC.12091

Nkala, P., Mango, N., and Zikhali, P. (2011). Conservation Agriculture and livelihoods of smallholder farmers in central Mozambique. *J. Sustainable Agric.* 35, 757–779. doi: 10.1080/10440046.2011.606492

Novak, J., and Cañas, A. (2006). *The Theory Underlying Concept Maps and How to Construct Them*.

Özesmi, U., and Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecol. Model.* 176, 43–64. doi: 10.1016/j.ecolmodel.2003.10.027

Pike, M. F., Maior, H. A., Porcheron, M., Sharples, S. C., and Wilson, M. L. (2014). "Measuring the effect of think aloud protocols on workload using fNIRS," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (New York: Association for Computing Machinery (ACM)), 3807–3816. doi: 10.1145/2556288.2556974

Poeplau, C., and Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops—a meta-analysis. *Agric. Ecosyst. Environ.* 200, 33–41. doi: 10.1016/j.agee.2014.10.024

Ramsey, R., Kaplan, D. M., and Cross, E. S. (2021). Watch and learn: the cognitive neuroscience of learning from others' actions. *Trends Neurosci.* 44, 478–491. doi: 10.1016/j.tins.2021.01.007

Rizzolatti, G., and Craighero, L. (2004). The mirror-neuron system. *Annu. Rev. Neurosci.* 27, 169–192. doi: 10.1146/annurev.neuro.27.070203.144230

Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nat. Rev. Neurosci.* 2, 661–670. doi: 10.1038/35090060

Rogé, P., Snapp, S., Kakwera, M. N., Mungai, L., Jambo, I., and Peter, B. (2016). Ratooning and perennial staple crops in Malawi. A review. *Agronomy Sustainable Dev.* 36:50. doi: 10.1007/s13593-016-0384-8

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., et al. (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil Tillage Res.* 103, 23–32. doi: 10.1016/j.still.2008.09.013

Sanga, U., and Koli, U. (2023). Mental models of sustainable groundwater management among farmers in semi-arid regions of Maharashtra, India. *Groundwater Sustainable Dev.* 21:100904. doi: 10.1016/j.gsd.2023.100904

Saran, A., Singh, S., Gupta, N., Walke, S. C., Rao, R., Simiyu, C., et al. (2022). PROTOCOL: Interventions promoting resilience through climate-smart agricultural practices for women farmers: a systematic review. *Campbell Syst. Rev.* 18:e1274. doi: 10.1002/cl2.1274

Sawe, N. (2017). Using neuroeconomics to understand environmental valuation. *Ecol. Econ.* 122, 1–9. doi: 10.1016/j.neuroimage.2015.08.010

Sawe, N. (2019). Adapting neuroeconomics for environmental and energy policy. *Behav. Pub. Pol.* 3, 17–36. doi: 10.1017/bpp.2018.2

Schacter, D. L., Addis, D. R., Hassabis, D., Martin, V. C., Spreng, R. N., and Szpunar, K. K. (2012). The future of memory: remembering, imagining and the brain. *Neuron* 76, 677–694. doi: 10.1016/j.neuron.2012.11.001

Schacter, D. L., Benoit, R. G., and Szpunar, K. K. (2017). Episodic future thinking: mechanisms and functions. *Curr. Opin. Behav. Sci.* 17, 41–50. doi: 10.1016/j.cobeha.2017.06.002

Senge, P., and Sterman, J. D. (1992). Systems thinking and organizational learning: acting locally and thinking globally in the organization of the future. *Eur. J. Operational Res.* 59, 137–150. doi: 10.1016/0377-2217(92)90011-W

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., and Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science* 303, 1157–1162. doi: 10.1126/science.1093535

Skaza, H., and Krystyna, S. (2009). "A test of the relative effectiveness of using systems simulations to increase student understanding of environmental issues," in *The 27th International Conference of the Systems Dynamics Society* (Albuquerque, New Mexico).

Stave, K. A., and Hopper, M. (2007). "What constitutes systems thinking: a proposed taxonomy," in *25th International Conference of the System Dynamics Society* (System Dynamics Society). Available online at: https://digitalscholarship.unlv.edu/sea_fac_articles/201/.

Steinkuehler, C., and Duncan, S. (2008). Scientific habits of mind in virtual worlds. *J. Sci. Educ. Technol.* 17, 530–543. doi: 10.1007/S10956-008-9120-8

Sterling, E. J., Filardi, C., Toomey, A., Sigouin, A., Betley, E., Gazit, N., et al. (2010). Episodic future thought: an emerging concept. *Perspect. Psychol. Sci.* 5, 142–162. doi: 10.1177/1745691610362350

Stier, A., Samhouri, J., Gray, S., Martone, R., Mach, R. M., Halpern, B., et al. (2017). Integrating expert opinion into food web conservation and management. *Conserv. Lett.* 10, 67–76. doi: 10.1111/conl.12245

Stoewer, S., Ku, S. P., Goense, J., Steudel, T., Logothetis, N. K., Duncan, J., et al. (2010). Frontoparietal activity with minimal decision and control in the awake macaque at 7 T. *Magn. Reson. Imaging* 28, 1120–1128. doi: 10.1016/j.mri.2009.12.024

Streefkerk, I. N., de Bruijn, J., Haer, T., Van Loon, A. F., Quichimbo, E. A., Wens, M., et al. (2023). A coupled agent-based model to analyse human-drought feedbacks for agropastoralists in dryland regions. *Front. Water* 4:1037971. doi: 10.3389/frwa.2022.1037971

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., des Ios Rios, I., et al. (2018). Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *J. Rural Stud.* 59, 232–241. doi: 10.1016/j.jrurstud.2017.01.020

Szpunar, K. K. (2010). Episodic future thought: an emerging concept. *Perspect. Psychol. Sci.* 5, 142–162. doi: 10.1177/1745691610362350

Tabacaru, M., Kopainsky, B., Stave, K., and Heather, S. (2009). "How can we assess whether our simulation models improve system understanding for the ones interacting with them?," in *The 27th International Conference of the Systems Dynamics Society* (Albuquerque, New Mexico)

Taura, T., and Nagai, Y. (2013). *Concept Generation For Design Creativity: A Systematized Theory and Methodology*. London: Springer.

Valdes-Sosa, P. A., Galan-Garcia, L., Bosch-Bayard, J., Bringas-Vega, M. L., Aubert-Vazquez, E., Rodriguez-Gil, I., et al. (2021). The cuban human brain mapping project, a young and middle age population-based EEG, MRI and cognition dataset. *Sci. Data* 8:45. doi: 10.1038/s41597-021-00829-7

Vanwindekens, F. M., Stilmant, D., and Baret, P. V. (2013). Development of a broadened cognitive mapping approach for analysing systems of practices in social-ecological systems. *Ecol. Model.* 250, 252–362. doi: 10.1016/j.ecolmodel.2012.11.023

Verplanken, B., and Orbell, S. (2003). Reflections on past behavior: a self-report index of habit strength. *J. Appl. Soc. Psychol.* 33, 1313–1330. doi: 10.1111/j.1559-1816.2003.tb01951.x

Verplanken, B., and Orbell, S. (2022). Attitudes, habits and behavior change. *Ann. Rev. Psychol.* 73, 327–352. doi: 10.1146/annurev-psych-020821-011744

Vogt, P., Riitters, K., Estreguil, C., Kozak, J., and Wickham, J. (2007). Mapping spatial patterns with morphological image processing. *Landscape Ecol.* 22, 171–177. doi: 10.1007/s10980-006-9013-2

Vuillot, C., Coron, N., Calatayud, F., Sirami, C., Mathevet, R., and Gibon, A. (2016). Ways of farming and ways of thinking: do farmers' mental models of the landscape relate to their land management practices? *Ecol. Soc.* 21:35. doi: 10.5751/ES-08281-210135

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., and Rizzolatti, G. (2003). Both of us disgusted in My insula: the common neural basis of seeing and feeling disgust. *Neuron* 40, 655–664. doi: 10.1016/s0896-6273(03)00679-2

Wood, W. (2019). *Good Habits, Bad Habits*. MacMillan Publishers. Available online at: https://us.macmillan.com/books/9781250159076/goodhabitsbadhabits.

Woods, T. (1993). 'Why not persuade them to grow tobacco?' Planters, tenants and political economy of central Malawi, 1920–1940. *African Econ. Hist.* 21, 131–150. doi: 10.2307/3601813

World Bank (2014). Available online at: https://www.worldbank.org/en/news/feature/2014/11/12/for-up-to-800-million-rural-poor-a-strong-world-bank-commitment-to-agriculture.

World Bank (2022). *Poverty and Shared Prosperity 2022: Correcting Course*. Washington, DC: World Bank.

Wu, J. Q., Szpunar, K. K., Godovich, S. A., Schacter, D. L., and Hofmann, S. G. (2015). Episodic future thinking in generalized anxiety disorder. *J. Anxiety Disord.* 36, 1–8. doi: 10.1016/j.janxdis.2015.09.005

Zolfagharipoor, M. A., and Ahmadi, A. (2021). Agent-based modeling of participants' behaviors in an inter-sectoral groundwater market. *J. Environ. Manage.* 299:113560. doi: 10.1016/j.jenvman.2021.113560

Zonca, J., Vostroknutov, A., Coricelli, G., and Polonio, L. (2021). Timing of social feedback shapes observational learning in strategic interaction. *Sci. Rep.* 11:21972. doi: 10.1038/s41598-021-01466-1

Zvacek, S. M., Restivo, M. T., and Chouzal, M. F. (2012). "Visualizing understanding with concept maps," in *2012 15th International Conference on Interactive Collaborative Learning (ICL)* (Villach, Austria). doi: 10.1109/ICL.2012.6402184

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Demographic reporting and phenotypic exclusion in fNIRS

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Functional near-infrared spectroscopy (fNIRS) promises to be a leading non-invasive neuroimaging method due to its portability and low cost. However, concerns are rising over its inclusivity of all skin tones and hair types (Parker and Ricard, 2022, Webb et al., 2022). Functional NIRS relies on direct contact of light-emitting optodes to the scalp, which can be blocked more by longer, darker, and especially curlier hair. Additionally, NIR light can be attenuated by melanin, which is accounted for in neither fNIRS hardware nor analysis methods. Recent work has shown that overlooking these considerations in other modalities like EEG leads to the disproportionate exclusion of individuals with these phenotypes—especially Black people—in both clinical and research literature (Choy, 2020; Bradford et al., 2022; Louis et al., 2023). In this article, we sought to determine if (Jöbsis, 1977) biomedical optics developers and researchers report fNIRS performance variability between skin tones and hair textures, (2a) fNIRS neuroscience practitioners report phenotypic and demographic details in their articles, and thus, (2b) is a similar pattern of participant exclusion found in EEG also present in the fNIRS literature. We present a literature review of top Biomedical Optics and Human Neuroscience journals, showing that demographic and phenotypic reporting is unpopular in both fNIRS development and neuroscience applications. We conclude with a list of recommendations to the fNIRS community including examples of Black researchers addressing these issues head-on, inclusive best practices for fNIRS researchers, and recommendations to funding and regulatory bodies to achieve an inclusive neuroscience enterprise in fNIRS and beyond.

KEYWORDS

fNIRS (functional near-infrared spectroscopy), inclusion, neuroimaging, melanin, biomedical optics

1. Introduction

Functional near-infrared spectroscopy (fNIRS) promises to be the leading non-invasive human neuroimaging method of the next few decades due to its portability, low cost, motion tolerance, and usability in special populations. This light-based modality was first ideated for blood-oxygenation estimation and has grown in its popularity, with publication counts doubling every 3.5 years (Jöbsis, 1977; Boas et al., 2014). fNIRS is indispensable in many cognitive and psychological science settings, but especially in child development, hyperscanning, brain-computer interfacing, and other areas where movement and portability are challenges and which preclude EEG and fMRI as the leading non-invasive modalities (Crosson et al., 2010; Yücel et al., 2017; Girolamo et al., 2022).

As fNIRS increases in popularity, concerns over its inclusion of all skin tones and hair types are rising (Parker and Ricard, 2022; Webb et al., 2022). While it has long been established that the physics of hair color, hair thickness, and skin pigmentation affect the detection of a NIRS signal (Pringle et al., 1999), a systematic study is still missing that directly addresses the limitations of modern-day NIRS for different phenotypes. With these limitations, we are in danger of perpetuating bias against the darker skinned and thicker haired people of the world—individuals who already face racism and oppression worldwide. Here, we are careful to distinguish between phenotype and race: while phenotype refers to heritable physical characteristics such as hair and skin color, race is a social construct based on a collection of phenotypic, cultural, and regional indicators that hold power in society and affect the lived experiences of individuals who are minoritized and marginalized based on these indicators.

In this article, we briefly define technical limitations in biomedical optics for marginalized *phenotypes* and explore how they lead to disproportionate exclusion of people of marginalized *races* through a literature review. We sought to examine racial and phenotypic reporting specifically as compared to gender reporting, an established reporting category over the last few decades due to NIH mandated reporting. Although most guidelines combine "women and minorities," we hypothesized that gender is reported at much higher rates than racial/ethnic demographics and treat it is a reporting exemplar.

2. Bias in fNIRS

2.1. Phenotypic bias

fNIRS is used to measure real-time hemodynamics in the brain and is a proxy for brain activity. Red and near-infrared light is illuminated onto the scalp by a source optode and undergoes scattering and absorption throughout the underlying brain tissue until the attenuated light is detected at another optode some distance away from the source (see Figure 1). Two phenotypic "challenges" have emerged from this. The first is in *accessing the scalp* on individuals with coarse, dense, and curly hair; present-day optodes do not ensure that light sufficiently reaches the brain when thick hair occludes the scalp. The second challenge is in acquiring quality NIRS signals once the scalp is reached. Accurate measures of hemodynamics are impacted by the light absorption and scattering properties of the layers of tissue between the scalp and the brain, namely the dermis, skull, and blood vessels, and their particular tissue chromophores, including melanin (Kharin et al., 2009; Jacques, 2013). Because darker, i.e., more melanated, skin is not accounted for in fNIRS techniques, phenotypic bias is perpetuated against darker skin, darker hair, and curlier hair as discussed below.

2.1.1. Hair type

One source of bias in fNIRS is its easier usability with short, straight, thin, and lighter-colored hair. Optodes must be as flush to the scalp's surface as possible to get an optimal signal, and securely in place. Any optical obstruction between the fiber and the scalp, especially hair, can dramatically reduce the number of photons penetrating the scalp and ultimately the surface of the brain. Conventional NIRS systems cause concern for those with coarse, curly hair because the density and thickness of the hair may obstruct the fiber and because the caps may not accommodate the larger hair volume. Even thoughtful researchers who are knowledgeable about coarse and dense hair types may struggle with maintaining participants' optode-scalp contacts over time; for example, coarse hair tends to revert or "turn back" to its normal, unmanipulated state over time, which can move the optodes or occlude them in experiments longer than a few minutes. Or, in special populations such as children or neurodivergent people, movement and stimming may easily shift hair to suboptimal positions with respect to the optodes. Additionally, dark colored hair (of any texture) is another contributor to varying absorption properties; dark colored and thicker hair can reduce the light intensity from 20 to 50% (Koizumi et al., 1999) while light attenuation improves with lighter hair. Etienne et al. (2020) found that traditional electrodes fail to maintain low impedance on individuals with coarse, curly, and dense hair leading to exclusion of Black participants (Choy et al., 2022), so too might fNIRS optodes fail to maintain physical contact with the scalp, since they are attached in the same fashion. Even with spring-loaded grommets and tension tops on fNIRS caps, anecdotally, the signal quality for participants with coarse and/or curly hair is poor. As a result, individuals with coarse, curly, and dark hair—often people of African, African-American, and Caribbean descent—are excluded from fNIRS studies (Loussouarn et al., 2007; Takahashi, 2019; Bradford et al., 2022). Therefore, fNIRS datasets tend to underrepresent Black and Brown individuals, which supports the need for our review, as well as other individuals with this hair type. As a field we must ask: does the density, length, texture, or even the color of hair impact signal-to-noise ratio of the hemodynamics response inferred from fNIRS?

2.1.2. Skin pigmentation

Another source of bias in fNIRS is its better usability with lighter skin tones. Three key underlying assumptions in using the Beer Lambert Law are that: (1) hemoglobin is the main absorber in the dermis, (2) that the tissue is optically homogeneous, and (3) that the differential pathlength is invariable across skin tones. In reality, several layers of the skin are optically heterogeneous, with melanin the dominating absorber of NIR light in the epidermis, and hemoglobin in the dermis. Functional NIRS devices assume that given a constant source-detector distance, there is a fixed light pathlength through the brain for all users. However, since melanin is a highly absorbing chromophore, higher concentrations render more absorption, thus decreasing the differential pathlength of the light, which is unaccounted for in current devices' estimations of absolute hemoglobin. Even though fNIRS measures *relative* changes in hemoglobin, a systematic, nonlinear attenuation of the signal due to higher melanin concentrations may lead to inaccurate estimations (likely underestimations) of relative changes in oxygenation. These oversimplifying assumptions particularly bias against data from individuals with skin pigmentation darker than a two on the Fitzpatrick scale, a spectrum of skin tones ranging from 1 (lightest) to 6 (darkest).

The field has not done enough investigation into the effects of melanin on NIRS broadly. We do know that in both

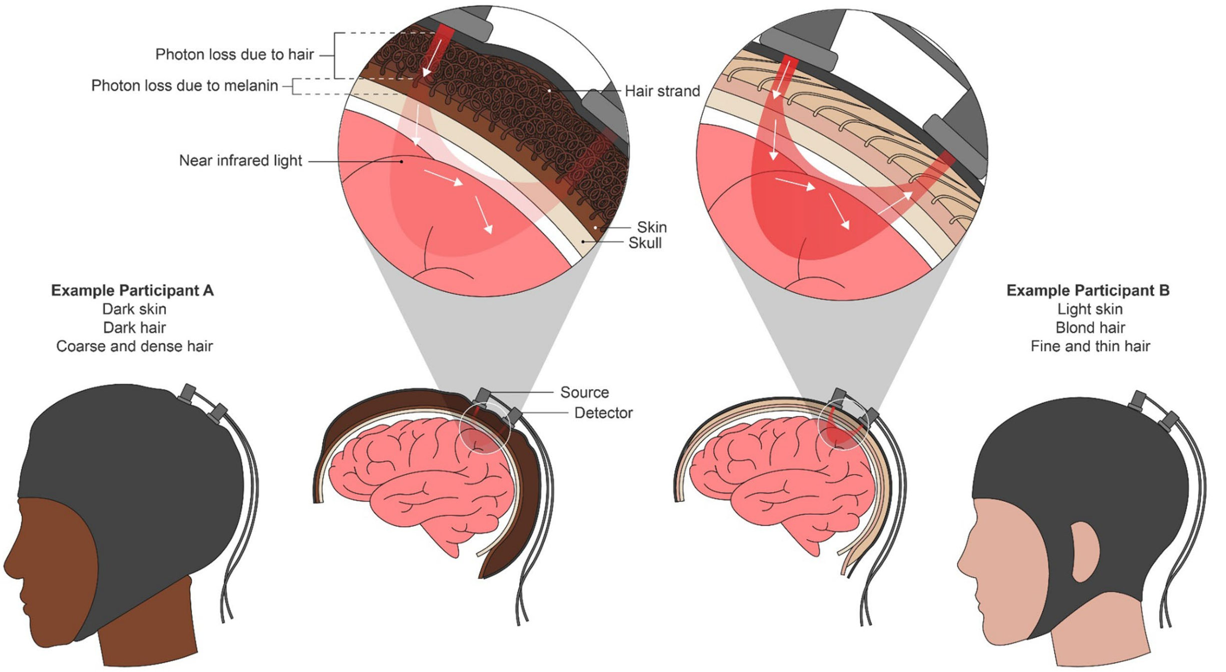

FIGURE 1
A combination of red and near-infrared (NIR) light at an optical source is shone into the brain non-invasively. From the source, light travels through the skin and into the brain surface before resurfacing at a detector or array of detectors elsewhere on the scalp. Using the scattering and absorption properties of NIR light in brain tissue, the relative amounts of oxygenated and deoxygenated hemoglobin present in the underlying brain region are calculated using the modified Beer-Lambert Law. We depict an individual with both dark skin and curly hair (left) and an individual with light skin and straight, blond hair as two extremes of phenotypic disparity. In the left individual, both mechanical blocking due to hair texture and increased light absorption due to melanin attenuates the NIR signal, potentially leading to bias in the oxygenation estimation.

transmission-based NIRS such as pulse oximetry and reflectance-based NIRS like cerebral oximetry, there is evidence of larger oxygen saturation estimation error for darker skin overall and increasing error with darker pigmentation (Sun et al., 2015). Further, reflectance-based NIRS, which requires light to interact with larger bulk tissue areas, results in larger error (8% compared to transmission-based error of 2–3%) (Jubran and Tobin, 1990; Bickler et al., 2013). Simulation work for cerebral oximetry, which uses the same reflectance-based setup as fNIRS, shows that at low oxygen saturation levels—levels when patients need the most attention—the error can be up to 15% (Afshari et al., 2022). Additionally, depending on the source-detector distances, melanin might have a larger effect on data quality: larger distances would allow light to penetrate larger brain tissue volumes, decreasing the relative amount of "noise" introduced by the melanin layers in the light path. However, the influence of the amount of bulk tissue traversed has yet to be investigated with respect to skin pigmentation.

While pulse oximetry and cerebral oximetry are similar to fNIRS, one key difference is that they measure absolute hemoglobin rather than relative changes in hemoglobin. We do expect less error type in estimates of relative hemoglobin concentration changes, like those measured in continuous wave fNIRS setups. However, systematic bias in the spectroscopy technique may still exist as a function of melanin in ways that have yet to be quantified, for example, due to nonlinearities in the absorption estimations that render the relative changes in hemoglobin unreliable. Therefore, in functional NIRS, there is likely inaccuracies in calculating the hemodynamic response due to similar reasoning.

This inaccurate estimation of optically derived measures in different skin pigmentation levels is not new. The first clinically adopted NIRS device was the pulse oximeter, or pulse ox, used for non-invasive measurements of arterial oxygen saturation through the finger (Severinghaus and Honda, 1987). Developed during WWII in the racially homogeneous Japan (Millikan, 1942; Bickler and Tremper, 2022), the first pulse oximeter was adopted into clinical anesthesiology workflows in the 1980s (Severinghaus and Honda, 1987). While it has been long established that its accuracy is dependent on the calibration population (Ralston et al., 1991), its design has not been reconsidered for darker skin. Recently, COVID-19 increased hospital and home-based pulse ox monitoring (Greenhalgh et al., 2021) leading to reporting that suggest skin tone may negatively affect accuracy (Sjoding et al., 2020; Keller et al., 2022). These limitations are currently under review by the FDA (Food and Drug Administration, 2022).

2.2. Exploring exclusion

Methodological, experimental, and cultural limitations in current fNIRS practices contribute to what is called "convenience sampling" in brain imaging research. To accurately pinpoint convenience sampling in neuroscience research, we must assess the current phenotypic reporting practices in the theoretical and empirical neuroscience literature (Girolamo et al., 2022). In the following section, we present a literature review to determine current phenotypic and demographic reporting practices in fNIRS literature and conclude with a list of solutions to achieve an inclusive neuroscience enterprise.

3. Literature review

3.1. Methods

In May and June 2022, we conducted a literature review of demographic and phenotypic reporting from articles in top English-language Biomedical Optics and Human Neuroscience journals. The three optics and two neuroscience journals were chosen to represent a range of articles covering fNIRS hardware and algorithm development and fNIRS as a tool in basic or clinical neuroscience research, respectively. Using PubMed, we saved a catalog of all articles in the given time range, selected journal name, and the keyword "fNIRS." For the biomedical optics articles, we selected a 15-year time range; for the human neuroscience articles, we selected a 5-year time range. This time difference is because fNIRS' adoption into basic research has understandably lagged fNIRS development; in all, both time ranges include the present day. Articles were retrieved on the open web or via subscription at the authors' institution. For each article, we documented the number of participants, country of testing, any quantitative or qualitative reports of data exclusion, and participant demographics including: mention of sex or gender; mention of race, ethnicity, or nationality; mention of melanin, pigmentation, or Fitzpatrick scale; and mention of hair type. Animal and *in silico* studies were reported as "N/A." We intentionally included sex/gender reporting in the analyses to compare as a baseline exemplar of "good" demographic reporting, since the NIH and many publishing bodies have encouraged or mandated reporting increasingly in the past 3 decades (National Academies of Sciences, Engineering, and Medicine, 2022).

4. Results

From three top optics journals, we identified 110 articles from 2007 to 2022. We excluded *in silico* studies or those using animals, leaving a total of 90 articles with human volunteer participants (Figure 2A). While most studies reported gender (84.4%) as we predicted, nearly all articles failed to report phenotypic characteristics about participants being race/ethnicity (98.9%), skin pigmentation (96.7%), or hair type (93.3%). Over time, this trend does not seem to be improving (see Supplementary Figure 1).

We then repeated this analysis for two top human neuroscience journals that together publish a large proportion of basic science fNIRS articles. We identified 87 papers from 2017 to 2022 that used fNIRS as a tool (Figure 2B). Again, the vast majority of studies report gender (90.8%), but do not report race/ethnicity (97.7%), skin pigmentation (100%), or hair type (96.6%).

Lastly, we looked at the types of exclusion that were reported from all five journals. Only 69 of the 177 total articles (39.0%) mentioned if any participants were excluded *for any reason*. Of these 69, eight (11.6%) explicitly mention hair and four (5.80%) cite it as the main reason for the exclusion or withdrawal. The majority of the articles shared general reasons for dismissing a participant like "noisy data across channels," "poor light shielding," "technical issues… or low quality fNIRS data…," "Bad fNIRS signal and technical issues," and "poor cap fit." The four articles cited thick or dark hair as being the reason for why a participant may have been excluded saying "poor data quality resulting from the subject's relatively thick, black hair," "unable to collect effective signals from fNIRS due to the participant's thick, strong hair," "had a lot of hair to obstruct light," and "presumably due to dense and/or dark-colored hair." No articles mention skin tone as being the primary source of signal noise. Race/ethnicity was the second least reported demographic and was typically reported by country of origin (e.g., "All participants were Chinese."). A list of all the reasons for exclusion from the 69 articles are provided in Supplementary Table 1.

Unfortunately, because of the low level of demographic reporting, we were not able to present data comparing the relative exclusion of marginalized and majority phenotypes.

5. Discussion

Our results point to two distinct issues: the under-reporting of exclusion and the potential, but unconfirmed, disproportionate exclusion of marginalized phenotypes. While recruiting diverse participants can prove challenging, simply reporting the participant makeup should be straightforward (see section 5 for more discussion and recommendations). It is hard to disentangle the contributing factors toward exclusion of marginalized groups in neuroimaging: there is phenotypic bias, but also less access, lower interest and response rates (due to perceived racial bias), claims that data is "unusable," and health disparities (Rad et al., 2018; Louis et al., 2022; Webb et al., 2022; Ricard et al., 2023). There is a long literature about these issues, especially medical mistrust among African-Americans, as well as how to alleviate these issues (see introduction in Otado et al., 2015). However, when comparing to the representation of Black/African-American identifying individuals in the United states (13%) and that of NIH-funded neuroimaging studies generally (7%), the anecdotal indications that there are not nearly *any* Black participants in fNIRS is alarming and points to phenotypic bias contributions beyond the typical exclusion factors that lead to underrepresentation of Black participants (NIH stats from public access database).

In surveying biomedical optics journals, we sought to target work by the engineers who design fNIRS systems, those responsible for inclusive design practices. In surveying human neuroscience journals, we targeted work by end users. In both pursuits, we found that gender was reported in the vast majority of articles. This is likely due to the widespread adoption of gender reporting from NIH mandates that touched the animal research world as well as human research (and to our knowledge, other animals do not observe the social construct of race).

While four articles did report hair type and should be commended, there was only one article that explicitly mentioned hair type, hair color, *and* Fitzpatrick skin color. We especially commend that group for being transparent about the influences on their results and believe it should be the standard.

6. Recommendations

In the absence of adequate reporting of demographic data to determine exclusion trends in fNIRS literature, we think its important to highlight ways that the community—both developers and practitioners—can be more inclusive and more upfront about the

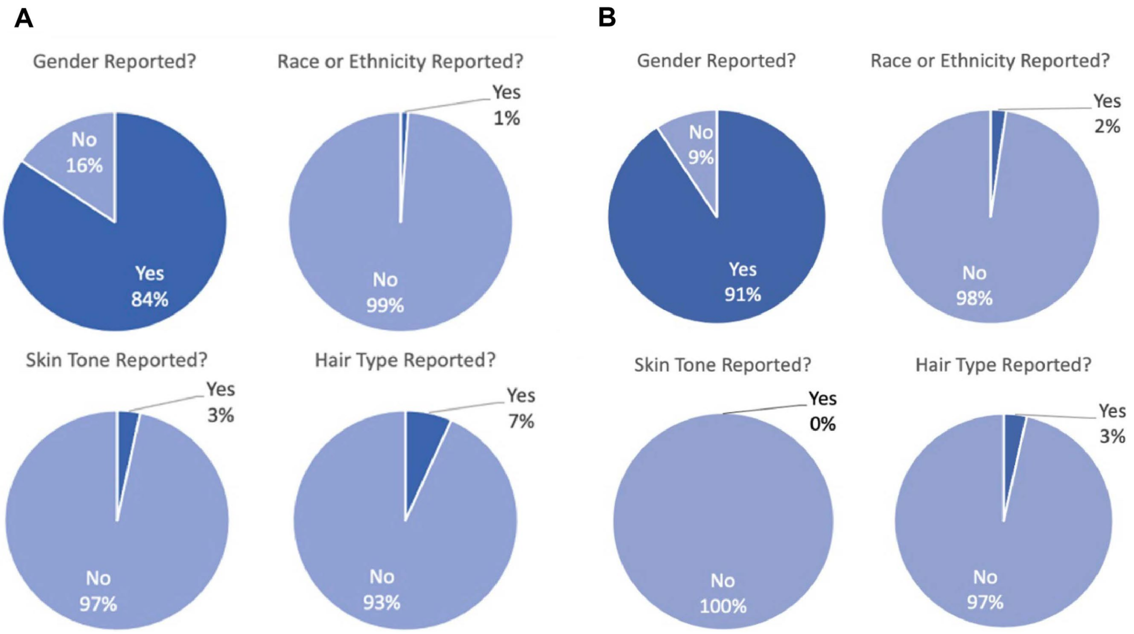

FIGURE 2
(A) Demographic reporting for 90 articles with empirical human fNIRS data in three top biomedical optics journals. Overwhelmingly, gender is reported ("yes") whereas race/ethnicity, skin pigmentation, and hair type are overwhelmingly not reported ("no"). **(B)** Demographic reporting for 87 articles with empirical human fNIRS data in two top human neuroscience journals. Overwhelmingly, gender is reported ("yes") whereas race/ethnicity, skin pigmentation, and hair type are overwhelmingly not reported ("no").

inclusivity of their data. Based on our results, there is unequivocally exclusion based on, at minimum, the curliness and darkness of hair. To address this embedded bias, fNIRS tools and practices must change to accurately represent a heterogeneous population. The transition of fNIRS technology to more inclusive methodologies will require concerted efforts from engineers, scientists, clinicians, and imaging professionals following the example of groups already developing creative solutions.

6.1. Engineering solutions

Some groups are actively addressing phenotypic bias limitations of fNIRS while maintaining other design requirements such as direct and prolonged contact with the scalp, maintenance of good signal-to-noise ratios, and increasingly higher spatial resolutions:

- A Texas-based group designed brush-type optodes to improve photon transmission and demonstrated its applicability with dark hair colors and high hair density by estimating power attenuation through a derived analytical model (Khan et al., 2012).
- More recently, a team led by Sossena Wood began developing both novel inclusive optodes for curly hair and better algorithms to account for skin pigmentation (see award announcement here). The novel optode adapters anchor onto the scalp using the strength of strategically placed braids and improve the optical contact onto the scalp compared to commercially available flat optodes. An alternative to strategic braiding is to have the hair pre-braided before the visit into very small braids (which allow for more scalp contact options) or to have the hair fully washed, detangled, and dried while in a "stretched" state (via a loose ponytail, braids, twists, etc.). To achieve these specifications, volunteers must be given reasonably advanced notice, just as fMRI volunteers are given notice about piercings that need healing or larger hairstyles that might not fit into head coils. The team, which includes some authors from the aforementioned EEG work (Etienne et al., 2020), has recently expanded to create novel pulse ox as well.
- A few studies mention personalized approaches to inclusive fNIRS setup, especially cap interfacing and design, a critical element to achieve quality optical contact. Sun et al. mounts light sources and detectors on a custom silicone cap to maintain contact (see Supplementary Figure 2; Sun et al., 2022). The same group at the University of Michigan uses crochet hooks with LED lights to gently move hair during the optimization process before inserting optodes. While cap customization improves optode contact for different hair lengths and some hair types, the design may not be universal. For example, using crochet hooks can be painful for black hair as it tangles, and research assistants must be trained to do it.

6.2. Best inclusive practices for fNIRS researchers

There are feasible approaches that researchers may consider to curb phenotypic exclusion and increase equity in the field. We also point to other work specific to recruitment practices outlined in our supplement section 1 (Dancy et al., 2004; Auksztulewicz and Friston, 2015; Habibi et al., 2015; Otado et al., 2015; Garavan et al., 2018; Wieland et al., 2021).

6.2.1. Report demographics and phenotypes

We commend the one group in our sample that provided all demographic information upfront as well as the other groups that were honest about their exclusion of thick and coarse hair. Researchers involved in neuroimaging should explicitly report the racial and gender breakdown of their sample and, especially when there is exclusion of certain participants, describe the phenotypes such as hair color, hair type, and skin tone (Yücel et al., 2021). Data about hair type and skin tone can be surveyed or judged by an experimenter familiar with the Fitzpatrick scales and hair typing scales such as the Andre Walker System or the L'Oreal system (Loussouarn et al., 2007). Researchers should also consider the benefit of systematically quantifying the association of hair type, density, and melanin content of the scalp with fNIRS measurements. Formally defining these limitations through a systematic review will enable engineers to approach future advancements driven by these factors.

6.2.2. Adopt inclusive methodologies and hire a diverse research team

Although fNIRS systems need improvements, there are other reasons why darker skinned and curlier haired individuals are excluded from psychological research and design solutions. Many standard procedures foster an unpleasant environment and result in voluntary participant withdrawal from marginalized backgrounds especially for special populations in which fNIRS is beneficial. For example, children with darker pigmented skin and curlier hair textures (and their parents) may get frustrated and lose trust in the researchers because of the complex setup process, which involves repeatedly moving the cap and hair. Moreover, individuals with intellectual disabilities—a large proportion due to fNIRS' portability and motion tolerance—may not be able to handle the inconvenience.

To improve participant experience, researchers should train to work with a range of hair types as standard practice. Adverse outcomes of unpreparedness include longer setup times, microaggressions, participant discomfort, and participant dropout. fNIRS researchers should consider developing guidelines for preparation that will serve as standard operating procedure. Given some similarities in configuration and setup between EEG systems and fNIRS equipment, following Etienne et al.'s suggestion for adopting braiding techniques to separate hair might be a good solution. For higher spatial resolution setups, labs can consider application of (or development of) suggestions as outlined in *A Guide to Hair Preparation for EEG Studies,* available online (Richardson et al., 2021).

Aside from building trust with marginalized communities, hiring and training a research team with diversity in mind can bring in practitioners who can effectively relate to marginalized participants before, during, and after laboratory visits. With better familiarity of marginalized communities, researchers can identify and prevent barriers to participation, making their studies more accessible. Similarly, allocating grant money to hire a hair consultant while considering custom setups is ideal.

6.3. IRBs, journals, governing, and foundations: mandated reporting

The responsibility of race and gender reporting does not simply fall on individual researchers, but also on the funding, publishing, and ethics bodies to which they are beholden. Each of these entities have a responsibility to mandate reporting of demographics and question any researchers who include race- or phenotype-based exclusion criteria in their studies. As highlighted in Webb et al. (2022), IRBs are in place to ensure that institutional research is both rigorous and ethical. IRB personnel should receive ongoing training on the presence of racial bias in research devices and offer institutionally mandated inclusive best practices to researchers.

Similarly, funding bodies and journals should require demographic reporting and data demographic disaggregation. Foundations should invite research proposals explicitly asking the questions of the present article: who is being excluded and why, both technologically and culturally? Finally, foundations should fund innovative and equitable technologies, like the work of the team led by Sossena Wood at Carnegie Mellon University and the team led by Meryem Yücel at Boston University, both funded by Meta Reality Labs.

Pressure for change will mount with the help of concerted action-based efforts. More scientific organizations and foundations should provide support for neuroscientists and engineers via resources like the Neuroethics Framework formed by IEEE. At the Federal level, passing the Diverse and Equitable Participation in Clinical Trials (DEPICT) Act and similar legislature would help, provide the FDA with the authority to require diverse representation in clinical trials.

Though the onus of progress is collective, the authors herein embolden the entire fNIRS community to assume individual responsibility for conducting inclusive work within their own realms of influence, including as researchers, journal editors, manuscript and grant reviewers, IRB members, and leaders in their own scientific and social circles.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JK and KK: conceptualization. JK and HP: methodology, data curation, and visualization. JK, HP, TP, and NN: investigation. JK, HP, KK, TP, and NN: writing (original draft). JK and SW: writing (review and editing) and supervision. SW: funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

JK was employed by Precision Neuroscopics, Inc., a designer of inclusive EEG electrodes.

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Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnins.2023.1086208/full#supplementary-material

References

Afshari, A., Saager, R. B., Burgos, D., Vogt, W. C., Wang, J., Mendoza, G., et al. (2022). Evaluation of the robustness of cerebral oximetry to variations in skin pigmentation using a tissue-simulating phantom. *Biomed. Opt. Express* 13, 2909–2928. doi: 10.1364/BOE.454020

Auksztulewicz, R., and Friston, K. (2015). Attentional enhancement of auditory mismatch responses: a DCM/MEG study. *Cereb. Cortex* 25, 4273–4283. doi: 10.1093/cercor/bhu323

Bickler, P. E., Feiner, J. R., and Rollins, M. D. (2013). Factors affecting the performance of 5 cerebral oximeters during hypoxia in healthy volunteers. *Anesth. Analg.* 117, 813–823. doi: 10.1213/ANE.0b013e318297d763

Bickler, P., and Tremper, K. K. (2022). The pulse oximeter is amazing, but not perfect. *Anesthesiology* 136, 670–671. doi: 10.1097/aln.0000000000004171

Boas, D. A., Elwell, C. E., Ferrari, M., and Taga, G. (2014). Twenty years of functional near-infrared spectroscopy: introduction for the special issue. *Neuroimage* 85, 1–5. doi: 10.1016/j.neuroimage.2013.11.033

Bradford, D. E., DeFalco, A., Perkins, E., Carbajal, I., Kwasa, J., Goodman, F., et al. *Whose signals are we amplifying? Towards a more equitable clinical psychophysiology*. (2022).

Choy, T., Baker, E., and Stavropoulos, K. (2022). Systemic racism in EEG research: considerations and potential solutions. *Affect Sci.* 3, 14–20. doi: 10.1007/s42761-021-00050-0

Crosson, B., Ford, A., McGregor, K. M., Meinzer, M., Cheshkov, S., Xiufeng, L., et al. (2010). Functional imaging and related techniques: an introduction for rehabilitation researchers. *J. Rehabil. Res. Dev.* 47, vii–xxxiv. doi: 10.1682/JRRD.2010.02.0017

Dancy, B. L., Wilbur, J., Talashek, M., Bonner, G., and Barnes-Boyd, C. (2004). Community-based research: barriers to recruitment of African Americans. *Nurs. Outlook* 52, 234–240. doi: 10.1016/j.outlook.2004.04.012

Etienne, A., Laroia, T., Weigle, H., Afelin, A., Kelly, S. K., Krishnan, A., et al. Novel electrodes for reliable EEG recordings on coarse and curly hair. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS. (2020).

Food and Drug Administration. Pulse oximeter accuracy and limitations: FDA safety communication. (2022).

Garavan, H., Bartsch, H., Conway, K., Decastro, A., Goldstein, R. Z., Heeringa, S., et al. (2018). Recruiting the ABCD sample: design considerations and procedures. *Dev. Cogn. Neurosci.* 32, 16–22. doi: 10.1016/j.dcn.2018.04.004

Girolamo, T., Parker, T. C., and Eigsti, I.-M. (2022). Incorporating dis/ability studies and critical race theory to combat systematic exclusion of black, indigenous, and people of color in clinical neuroscience. *Front. Neurosci.* 16:988092. doi: 10.3389/fnins.2022.988092

Greenhalgh, T., Knight, M., Inada-Kim, M., Fulop, N. J., Leach, J., and Vindrola-Padros, C. (2021). Remote management of covid-19 using home pulse oximetry and virtual ward support. *BMJ*:n677:372. doi: 10.1136/bmj.n677

Habibi, A., Der, S. A., Gomez, M., and Ilari, B. (2015). Developmental brain research with participants from underprivileged communities: strategies for recruitment, participation, and retention. *Mind Brain Educ* 9, 179–186. doi: 10.1111/mbe.12087

Jacques, S. L. (2013). Optical properties of biological tissues: a review. *Phys. Med. Biol.* 58, 5007–5008. doi: 10.1088/0031-9155/58/14/5007

Jöbsis, F. F. (1977). Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science* 198, 1264–1267. doi: 10.1126/science.929199

Jubran, A., and Tobin, M. J. (1990). Reliability of pulse oximetry in titrating supplemental oxygen therapy in ventilator-dependent patients. *Chest* 97, 1420–1425. doi: 10.1378/chest.97.6.1420

Keller, M. D., Harrison-Smith, B., Patil, C., and Arefin, M. S. (2022). Skin colour affects the accuracy of medical oxygen sensors. *Nature* 610, 449–451. doi: 10.1038/d41586-022-03161-1

Khan, B., Wildey, C., Francis, R., Tian, F., Delgado, M. R., Liu, H., et al. (2012). Improving optical contact for functional near-infrared brain spectroscopy and imaging with brush optodes. *Biomed. Opt. Express* 3, 878–898. doi: 10.1364/BOE.3.000878

Kharin, A., Varghese, B., Verhagen, R., and Uzunbajakava, N. (2009). Optical properties of the medulla and the cortex of human scalp hair. *J. Biomed. Opt.* 14:024035. doi: 10.1117/1.3116712

Koizumi, H., Yamashita, Y., Maki, A., Yamamoto, T., Ito, Y., Itagaki, H., et al. (1999). Higher-order brain function analysis by trans-cranial dynamic near-infrared spectroscopy imaging. *J. Biomed. Opt.* 4, 403–413. doi: 10.1117/1.429959

Louis, C. C., Webster, C. T., Gloe, L. M., and Moser, J. S. (2022). Hair me out: highlighting systematic exclusion in psychophysiological methods and recommendations to increase inclusion. *Front. Hum. Neurosci.* 16:1058953. doi: 10.3389/fnhum.2022.1058953

Loussouarn, G., Garcel, A. L., Lozano, I., Collaudin, C., Porter, C., Panhard, S., et al. (2007). Worldwide diversity of hair curliness: a new method of assessment. *Int. J. Dermatol.* 46, 2–6. doi: 10.1111/j.1365-4632.2007.03453.x

Millikan, G. A. (1942). The oximeter, an instrument for measuring continuously the oxygen saturation of arterial blood in man. *Rev. Sci. Instrum.* 13, 434–444. doi: 10.1063/1.1769941

National Academies of Sciences, Engineering, and Medicine. *Improving representation in clinical trials and research*. Washington, DC: The National Academies Press (2022).

Otado, J., Kwagyan, J., Edwards, D., Ukaegbu, A., Rockcliffe, F., and Osafo, N. (2015). Culturally competent strategies for recruitment and retention of African American populations into clinical trials. *Clin. Transl. Sci.* 8, 460–466. doi: 10.1111/cts.12285

Parker, T. C., and Ricard, J. A. (2022). Structural racism in neuroimaging: perspectives and solutions. *Lancet Psychiatry* 9:e22. doi: 10.1016/S2215-0366(22)00079-7

Pringle, J., Roberts, C., Kohl, M., and Lekeux, P. (1999). Near infrared spectroscopy in large animals: optical pathlength and influence of hair covering and epidermal pigmentation. *Vet. J.* 158, 48–52. doi: 10.1053/tvjl.1998.0306

Rad, M. S., Martingano, A. J., and Ginges, J. (2018). Toward a psychology of Homo sapiens: making psychological science more representative of the human population. *Proc. Natl. Acad. Sci. U. S. A.* 115, 11401–11405. doi: 10.1073/pnas.1721165115

Ralston, A. C., Webb, R. K., and Runciman, W. B. (1991). Potential errors in pulse oximetry III: effects of interference, dyes, dyshaemoglobins and other pigments. *Anaesthesia* 46, 291–295. doi: 10.1111/j.1365-2044.1991.tb11501.x

Ricard, J. A., Parker, T. C., Dhalama, E., Kwasa, J., Allsop, A., and Holmes, A. J. (2023). Confronting racially exclusionary practices in the acquisition and analyses of neuroimaging data. *Nat. Neurosci.* 26, 4–11. doi: 10.1038/s41593-022-01218-y

Richardson, L., Woodley, N., Neuberger, L., Sandoval, J., and Huang, H. J.. *A guide to hair preparation for EEG studies.* (2021). Available at: https://hellobrainlab.com/research/eeg-hair-project/

Severinghaus, J. W., and Honda, Y. (1987). History of blood gas analysis. VII. Pulse oximetry. *J. Clin. Monit.* 3, 135–138. doi: 10.1007/BF00858362

Sjoding, M. W., Dickson, R. P., Iwashyna, T. J., Gay, S. E., and Valley, T. S. (2020). Racial bias in pulse oximetry measurement. *N. Engl. J. Med.* 383, 2477–2478. doi: 10.1056/NEJMc2029240

Sun, X., Ellis, J., Corso, P. J., Hill, P. C., Chen, F., and Lindsay, J. (2015). Skin pigmentation interferes with the clinical measurement of regional cerebral oxygen saturation. *Br. J. Anaesth.* 114, 276–280. doi: 10.1093/bja/aeu335

Sun, X., Zhang, K., Marks, R., Karas, Z., Eggleston, R., Nickerson, N., et al. (2022). Morphological and phonological processing in English monolingual, Chinese-English bilingual, and Spanish-English bilingual children: An fNIRS neuroimaging dataset. *Data Brief* 42:108048. doi: 10.1016/j.dib.2022.108048

Takahashi, T. (2019). Unique hair properties that emerge from combinations of multiple races. *Cosmetics* 6:36. doi: 10.3390/cosmetics6020036

Webb, E. K., Etter, J. A., and Kwasa, J. A. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Wieland, M. L., Njeru, J. W., Alahdab, F., Doubeni, C. A., and Sia, I. G. (2021). Community-engaged approaches for minority recruitment into clinical research: a scoping review of the literature. *Mayo Clin. Proc.* 96, 733–743. doi: 10.1016/j.mayocp.2020.03.028

Yücel, M. A., Lühmann, A. V., Scholkmann, F., Gervain, J., Dan, I., Ayaz, H., et al. (2021). Best practices for fNIRS publications. *Neurophotonics* 8:012101. doi: 10.1117/1.NPh.8.1.012101

Yücel, M. A., Selb, J. J., Huppert, T. J., Franceschini, M. A., and Boas, D. A. (2017). Functional near infrared spectroscopy: enabling routine functional brain imaging. *Curr. Opin. Biomed. Eng.* 4, 78–86. doi: 10.1016/j.cobme.2017.09.011

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Corrigendum: Demographic reporting and phenotypic exclusion in fNIRS

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The authors apologize for this error and state that this does not change the scientific conclusions of the article in any way. The original article has been updated.

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The implications of socioeconomic factors on salivary bioscience methodological variables in a large pediatric multi-site study

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Introduction: Salivary bioscience has found increased utilization within pediatric research, given the non-invasive nature of self-collecting saliva for measuring biological markers. With this growth in pediatric utility, more understanding is needed of how social-contextual factors, such as socioeconomic factors or status (SES), influence salivary bioscience in large multi-site studies. Socioeconomic factors have been shown to influence non-salivary analyte levels across childhood and adolescent development. However, less is understood about relationships between these socioeconomic factors and salivary collection methodological variables (e.g., time of saliva collection from waking, time of day of saliva collection, physical activity prior to saliva collection, and caffeine intake prior to saliva collection). Variability in salivary methodological variables between participants may impact the levels of analytes measured in a salivary sample, thus serving as a potential mechanism for non-random systematic biases in analytes.

Methods: Our objective is to examine relationships between socioeconomic factors and salivary bioscience methodological variables within the Adolescent Brain Cognitive Development Study© cohort of children aged 9–10 years old (n=10,567 participants with saliva samples).

Results: We observed significant associations between household socioeconomic factors (poverty status, education) and salivary collection methodological variables (time since waking, time of day of sampling, physical activity, and caffeine intake). Moreover, lower levels of household poverty and education were significantly associated with more sources of potential bias in salivary collection methodological variables (e.g., longer times since waking, collections later in the day, higher odds of caffeine consumption, and lower odds of physical activity). Consistent associations were not observed with neighborhood socioeconomic factors and salivary methodological variables.

Discussion: Previous literature demonstrates associations between collection methodological variables and measurements of salivary analyte levels, particularly with analytes that are more sensitive to circadian rhythms, pH levels, or rigorous physical activity. Our novel findings suggest that unintended distortions in measured salivary analyte values, potentially resulting from the non-random systematic biases in salivary methodology, need to be intentionally incorporated into analyses and interpretation of results. This is particularly salient for future studies interested in examining underlying mechanisms of childhood socioeconomic health inequities in future analyses.

KEYWORDS

socioeconomic status, salivary bioscience, child and adolescent development, methodology, health inequities

1. Introduction

Socioeconomic factors or status (SES) that drive health inequities are well established (1–3). However, a thorough understanding of SES-driven health inequities is needed within pediatric populations to elucidate early-life biological antecedents of adult health inequities. Previous studies among pediatric populations demonstrate multiple salivary biomarkers implicated in associations between the broader social environment and physiology, including neuroendocrine markers (e.g., alpha-amylase, cortisol, DHEA), metabolic markers (e.g., insulin, glucose), and immune markers (e.g., c-reactive protein, cytokines) (4–7). However, a number of these biomarkers rely on invasive sampling techniques, particularly blood draws, risking harm to participant-researcher rapport and overall willingness of communities to participate in biomedical research, particularly among pediatric populations. One approach to address this research gap in biological measures among pediatric studies is the use of salivary biosciences.

Salivary biospecimen technologies have grown in popularity over the last decade within research studies and clinical testing to non-invasively measure levels of analytes within diverse human populations (8). This utility is primarily due to its contextual practicality, allowing for sample collection outside of laboratory or clinical settings, as well as the non-invasiveness and feasibility of saliva sampling relative to more invasive techniques, such as phlebotomy (9–11). The many advantages of collecting salivary samples over other types of biospecimens in research include (1) being a low-cost option particularly for studies requiring multiple samples, (2) the ability for a participant to self-sample, and (3) adaptability to various field settings (10, 12–14). This method offers increased feasibility to measure physiological correlates of SES and related factors given the non-invasive nature, ease of collection of salivary samples, and reduced cost of sampling (10). These cost-saving benefits afford strengthening of study design such as sampling from more participants, increased number of collections within participants, or increased number of biomarkers assayed from each saliva sample. Further, salivary bioscience demonstrates great potential for diagnostic capability including pediatric endocrine dysfunction, cardiometabolic disease (15), monitoring lithium levels for psychiatric disorders (16), and diagnosing COVID-19 at home (17).

Additional methodological strengths of salivary sampling allow for the inclusion of communities that have been traditionally underrepresented in research and eases the burden of participation for families, improving adherence (13, 18). Certainly, a history of scientific injustices exists, disproportionately affecting low socioeconomic status and racially/ethnically minoritized communities, and driving historical and current-day underrepresentation in biomedical research that has often resulted in varying degrees of distrust of researchers (19–21). These historical and current injustices often occur when the cultural appropriateness of biological sample collection is not adequately considered (19, 22). Salivary collection is a tool that can minimize cultural insensitivities inherent in the collection of biological data, given its acceptance among diverse adolescent communities (23, 24). However, it is important to note that any biological collection can be precarious and warrants culturally and equity guided investigations. Some potential examples include: (a) some cultures or communities may feel averse to producing a saliva sample, particularly when observed by an experimenter, and may prefer other biological methods over saliva; (b) age of study sample matters, with children generally exhibiting aversion to blood sampling but willingness to produce saliva; and (c) certain cultures may perceive discarding unused saliva into waste as disrespectful. It is our recommendation that the community preferences for or against saliva collection be well understood before leveraging salivary biosciences.

Given these advantages, feasibility, and promising diagnostic future of salivary biosciences it is essential to first understand how the experimental design and saliva collection methodology should be standardized to ensure precision of measured analyte levels, particularly for the investigation of health inequities, and for increased application within pediatric research or clinical utility. Without this deeper methodological understanding, spurious differences in experimental design and methodological implementation of salivary biosciences may undermine the interpretability, accuracy, and utility of salivary analytes.

Several decisions in the experimental design can directly influence the methodology of salivary sample collections. For example, a design that rigorously standardizes collection of salivary samples can reduce or eliminate unintentional biases due to variations in collection methodological variables. These methodological decisions include how much time should be allowed between a participant's waking time to their saliva collection time, the time of day the saliva sample is collected, the amount of physical activity allowed prior to sampling, if caffeine is consumed prior to sampling, or other oral considerations that can impact measured analyte levels (5, 8, 12, 25, 26). Standardized collection practices help eliminate unintended experimental noise, where non-biological factors may influence the composition or volume of whole unstimulated saliva (27). Without stringent standardized collection practices of how and when saliva samples are collected, leveraging salivary biosciences on a large scale may result in unintended methodological variations, which can impact the analyte levels measured in the collected saliva sample and thus take a detour from true biological levels, warranting caution (28).

Many adrenal steroid analytes demonstrate diurnal/circadian or seasonal rhythms, marked by patterns of varying levels over an extended period of time. For example, cortisol, a marker of psychological stress, fluctuates throughout the day, peaking approximately 30–45 min after waking followed by tapering levels in the evening (e.g., 3–12 h after waking) (11, 29). In addition, the amount of sunlight at various points of the day drives circadian rhythms (30). Waking later in the day when sunlight is different than morning light may shift circadian phases and thus alter typical patterns of analytes.

Not only is the time since waking important, the time of day when the sample is collected is also a source of experimental variation. For example, salivary dehydroepiandrosterone (DHEA) and testosterone levels are typically highest in morning samples and drop continuously throughout the day to produce lower levels in evening samples (31–34). In addition, DHEA is implicated in physiological responses to acute stress (35, 36). Thus, saliva sampled later in the day may represent different hormonal profiles compared to morning collections given fluctuating levels with circadian patterns, or greater opportunity to experience acute stressors as the day goes on. Given these considerations, minimizing variations in collection practices or pre-collection exposures are important for making accurate conclusions about the source of differences in analyte levels. Variations in methodological factors may become increasingly problematic for obtaining precise measured analyte levels in maturing adolescent populations, especially where pubertal maturation is underlying the biological systems producing the analytes of interest.

Further, methodological variables related to lifestyle such as rigorous physical activity and caffeine intake prior to salivary sample collection may introduce bias in analyte levels by altering physiological states or the integrity of the saliva sample. Rigorous (>20 min) physical activity can alter levels of DHEA or testosterone (37), particularly in saliva samples taken during early stages of pubertal maturation when hormone levels are very low (38). Salivary DHEA levels among adolescent males have been documented to increase post-exercise, yet with varying slopes according to pubertal development (35). Caffeine intake prior to saliva sampling can impact analyte levels through a few different mechanisms, including shifting the salivary pH, increasing sample acidity, and therefore impacting the performance of certain pH-sensitive assays (5, 39), or promote bacterial growth, thereby compromising the integrity of salivary fluid (40). In addition, caffeine intake may risk dehydration in the participant that would reduce salivary flow rate, and/or activation of physiological pathways that overlap with origins of the analyte of interest, such as caffeine activating the adrenergic pathway and increasing urine concentrations of metanephrine (41–43). Although these observations are in serum or urine samples, unclear evidence on correlations of serum/urine metanephrine with salivary levels as a function of caffeine intake warrants consideration of caffeine exposure in salivary collections.

Standardized collection practices can minimize differences between and within participants in these methodological variables by regulating time of day when the saliva sample is collected, prohibiting participants from consuming caffeine or performing rigorous exercise beforehand, and standardizing the duration of saliva sampling between and within participant sampling (25). Analytes closely connected to circadian patterns may be particularly sensitive to variability in sampling times, or alterations in pH levels due to caffeine consumption. The present analysis examined relationships with several salivary methodological collection variables in a large US-based, representative pediatric cohort participating in the Adolescent Brain Cognitive Development Study© (44). In the ABCD Study, detailed data was collected on methodological variables mentioned above, but was not standardized in the collection protocol allowing for our evaluation of potential non-random methodological variation relating to saliva collection and key socioeconomic factors.

Socioeconomic factors have been of central focus for understanding health inequities. Socioeconomic factors reflect access to economic or social resources and are often represented by individual or composite measures of household income level, poverty status, parental education attainment, or occupation (45). These factors have been described in the literature to influence child developmental outcomes. Low SES has been associated with poor school readiness and academic achievement, more frequent adverse experiences, structural brain differences, and altered executive functioning (46–50). Studies investigating the relationship with SES using salivary samples among children from low SES households have noted higher baseline neuroendocrine profiles and steeper neuroendocrine trajectories over time relative to children from high SES households (51, 52).

SES has been purported to operate as a function of resource availability for a study participant (53). If collected at the home, participants may have limited access to freezers to store salivary samples, mailing resources to mail collected saliva, technology, such as text messages or phone, that would facilitate reminders to collect samples at consistent timings or more accurate collection time records without the aid of digital tools (25). Possible limited availability and access to social and economic resources may influence salivary sample collection variables when participants self-schedule throughout the day when to come into the laboratory for sampling. Thus, collections performed at a laboratory or at a study site issue the question whether collection methods differ as a function of participant resource availability.

Relationships between SES and other variables important in salivary collection, namely physical activity and caffeine consumption, have been demonstrated. Positive relationships between SES and the amount of physical activity performed among adolescents have been reported, such that low SES tends to be associated with less physical activity compared to those with a high SES (3, 54, 55). However, variations in the measurement of both SES (e.g., income-to-needs ratio, household income, parental occupation, parental education) and amount of physical activity (e.g., time or duration, frequency, school-based or extracurricular) may contribute to some null findings (55). Despite overall reductions in the amount of caffeine consumption among children and adolescents since 2000, those living at 0–99% and 100–199% of the federal poverty level have consistently consumed caffeine at higher rates compared to those living at greater than 200% of the federal poverty level (56). Particularly among children ages 6–11 years old, rates of caffeine consumption in households with low or very low food security and income-to-poverty ratios below 2.0 are significantly higher compared to households with income-to-poverty ratios above 2.0 (57). Thus, child/adolescent physical activity and caffeine consumption are a possible source of methodological variation in saliva collection when not standardized in the collection design.

Given that many analyte levels fluctuate on a circadian rhythm, patterns of saliva collections earlier or later in the day among one socioeconomic context relative to others in the study sample would suggest potential non-random systematic errors in salivary analyte values due to broader social determinants. Similarly, socioeconomic-related differences in physical activity or caffeine consumption prior to salivary sampling may serve as another mechanism for non-random systematic errors in salivary analyte levels. Without disentangling these contributors, the inclusion of these salivary analyte values in analyses would bias conclusions regarding differences in biological outcomes. Thus, it remains important to capture a greater understanding of socioeconomic influences on salivary bioscience methodology before leveraging salivary data for accurate investigation of health inequities. The present analyses will inform how special considerations need to be made when leveraging salivary analyte levels from large multi-site studies in childhood, a critical period of development when inequities during early life developmental periods, "get under the skin."

Investigations of the relationship between salivary collection methodological variables and socioeconomic factors among child populations are limited. However, with the emergence of salivary technology we are observing widespread utilization of salivary biosciences in large cohort studies. The objective of this study was to examine the association between key socioeconomic factors (e.g., poverty status, household education, neighborhood deprivation) and key salivary sample collection methodological variables (e.g., time since waking, collection time of day, and caffeine intake and physical activity within 24 h of sampling) among a diverse and large sample of US-based children aged 9–10 years old.

2. Materials and methods

2.1. Background on study sample and sample characteristics

This analysis was performed using a sample of children aged 9–10 years at enrollment participating in a 21-site study in the United States from the Adolescent Brain Cognitive Development (ABCD) Study© Release 3.0. This dataset was selected given that it is a large-scale longitudinal (e.g., annually over the course of 10 years) pediatric collection of whole saliva via passive drool for analysis of several hormonal analytes (e.g., estradiol among females only, DHEA and testosterone among males and females). Although there have been three collection timepoints to-date in this dataset (e.g., enrollment/baseline, year 1, and year 2), this current analysis focuses on baseline measures collected in 2016–2018 only. Longitudinal change was not the focus of the *a priori* aims, and any existing methodological variation observed at baseline are most likely repeated and similar in future waves of saliva collection in this cohort.

Participants reported to the study site for salivary sample collection, where one salivary sample was collected via passive drool from each participant at each annual timepoint (58). Participants and their guardian/parent did not receive prior instruction to prepare for the saliva collection during the study visit (e.g., participants were not instructed to abstain from eating, caffeine, or vigorous exercise prior to study visit). Upon arrival at the study site, a minimum of 30 min time passed between participants' arrival and starting the saliva collection. During this time, participants were instructed to not eat or drink anything other than water (including no mints/gum), then asked to rinse their mouth out with water 10 min prior to providing the saliva sample. If participants were given a lunch break, or arrived immediately after lunch, the protocol allowed for minimum of 60 min before sampling. Thus, the majority of saliva samples occurred ~ 60 min after a large meal (38, 58). Participants and their guardian/parent arrived at the study site for collection based on when the study site and participant schedules aligned. Current guidelines for optimal utilization of salivary bioscience recommend the notation of time of recent meal, oral health or injuries, braces, or recent loss of deciduous teeth (5). However, many of these variables were not controlled or collected in the ABCD Study given considerations for reducing participant burden, and experimentally prioritize the central aims of the ABCD study including multi-modal MRI, comprehensive profiles of adolescent substance use, and mental health assessments.

When present at the study site, a research assistant (RA) documented the arrival time of the participant, presence of parent or guardian, and the time the participant reported waking. After the RA instructed the participant to passively drool into a sample collection tube, the RA then documented the timing of the salivary sample, duration of sample collection, discoloration, or visible imperfections, as well as duration from collection to placement into a −20°C to −80°C freezer. Guardians/parents were compensated for their participation in the ABCD study, with the level of compensation being varied between study sites to account for differences in cost of living (44). Salivary samples were then shipped from study sites on dry ice, confirmed for frozen state upon arrival, and assayed by an external laboratory (59).

To reduce statistical noise within the analytic sample unrelated to sampling methodological variables, we removed participants whose biological sex at birth was not collected ($n = 7$), reported unable to complete ($n = 59$), and refused ($n = 19$) from analyses. We further cross-referenced each participant's biological sex at birth with the biological sex reported at the time of salivary sample collection and removed those with mismatched sex ($n = 23$). We adopted this decision to cross-reference reported sex at birth with biological sex reported at Baseline collections because early ABCD protocol indicated that a participant's sex at birth would determine which hormone panel (e.g., being inclusive or exclusive of estradiol) would be analyzed at the study visit. Only 2 participants were marked as male at birth but had missing entries at salivary sample collection. Those 2 participants were reclassified as male for analyses. We also reclassified the 4 participants reported as intersex (I) at birth (Figure 1) with the sex reported at salivary sample collection. In addition, participants with a gestational age less than 28 weeks and a reported birthweight less than 1,200 grams were removed from the analytic sample. These participants were erroneously included in the study given that the exclusion criteria required gestational age to be 28 weeks or greater. The final analytic sample consisted of $n = 10{,}567$, of which 5,534 were male and 5,033 were female at baseline (Figure 1).

2.2. Measures

2.2.1. Demographic and socioeconomic variables

The inclusion of child age in statistical analyses (in months) was informed by evidence of differential sleep habits, caffeine intake, and physical activity habits between children ages 7 to 10 years old. Sleep habits including sleep duration, which may inform waking time before salivary collection, is significantly associated with child age around 9-and 10-year-olds (e.g., sleep duration decreases as child age increases) (60, 61). Further, documented significant declines in physical activity with increases in child age between ages 9 and 15 years (62–64) demonstrates a need to control for child age as a precision variable due to independent relationships with the outcome in these analyses. Regarding caffeine intake, inconsistent relationships in the literature warrant investigation in our analyses. While previous evidence demonstrates general increases in caffeine intake with increases in age, several studies (65) observed lower caffeine intake between 9- and 10-year-olds, while other studies observed similar caffeine intake among 9–10-year-olds (66). Given these existing associations, bivariate relationships were examined between child age and salivary methodological variables. After observing significant bivariate relationships (Table 1), multivariate models were adjusted for child age as a precision variable to isolate effects due to independent relationships between each predictor and the outcomes.

To examine relationships between salivary collection methods with socioeconomic factors, we constructed the following measures.

Poverty status represents the household's socioeconomic position relative to the federal poverty level (FPL). This was indexed according

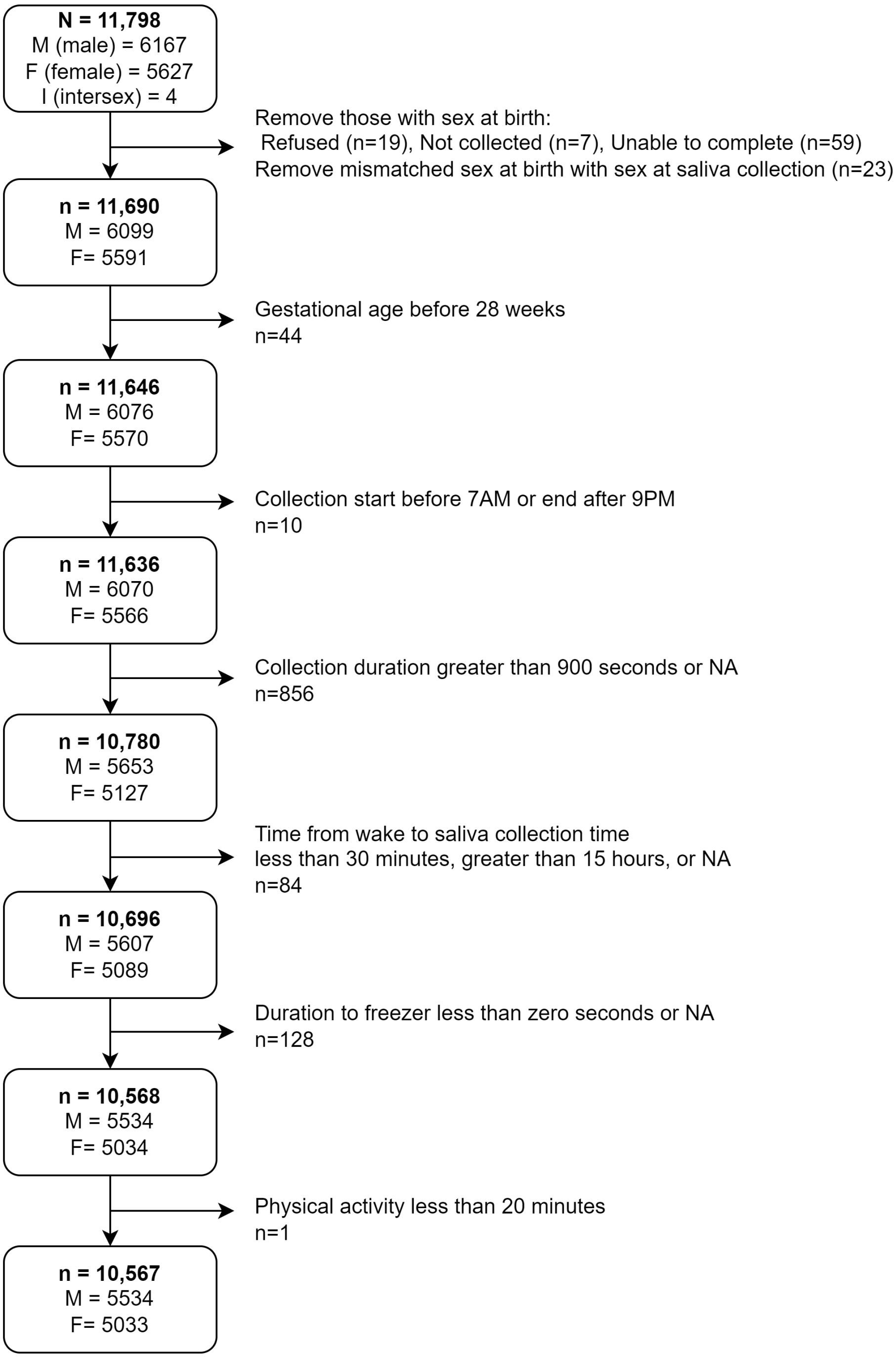

FIGURE 1
Depiction of decision tree to obtain final analytical sample. M, Male; F, Female; I, Intersex.

to the reported combined household income and the reported number of family members living from that combined income in the household. Poverty status was categorized relative to the FPL according to the following: Deep Poverty (<50%), Poverty (50–<100%), Near Poverty (100– <200%), Mid Income (200– <400%), High Income (≥400%). Although group membership across poverty status levels is imbalanced (Table 1), we made an evidence-informed decision to distinguish Deep Poverty from Poverty. From 1996 to 2011 the percentage of households living in Deep Poverty has grown 129.6% while the percentage of households in Poverty has grown 80.4% (67). Children living in Deep Poverty are at greater risk of adverse physical health and intellectual outcomes compared to children in poverty but who are not deeply poor, and children not living in poverty (68–70). Therefore, Deep Poverty is an important, unique construct of experienced poverty.

The participant's guardian/parent self-reported their level of education, and if partnered, also reported the partner's level of education. Household education in our analyses represents the highest level of education in the household reported by the parent. If the parent reported having a partner, then the highest level of education

TABLE 1 Descriptive statistics between socioeconomic variables and salivary methodological variables.

		Time since waking (hours)		Collection time of day (hours since midnight)		Physical activity			Caffeine intake		
		Range: 0.60–14.63		Range: 7.02–20.70							
	Mean (SD)	r_s	P^{A}	r_s	P^{A}	<20	>20	P^{B}	Yes	No	P^{B}
						Mean (SD)	Mean (SD)		Mean (SD)	Mean (SD)	
Child age (months)	118.9 (7.5)	−0.047	<0.001	−0.041	<0.001	119 (7.5)	118.8 (7.7)	ns	119.3 (7.5)	118.9 (7.5)	ns

		Time since waking (hours)		Collection time of day (hours since midnight)		Physical activity			Caffeine intake		
Household poverty status	N	Mean (SE)	P^{B}	Mean (SE)	P^{B}	<20	>20	P^{C}	Yes	No	P^{C}
						N (%)	*N* (%)		*N* (%)	*N* (%)	
Deep poverty	798	5.98 (0.11)	0.01	13.05 (0.11)	<0.001	732 (7.8)	64 (5.4)	0.03	84 (12.1)	713 (7.3)	<0.001
Poverty	616	5.89 (0.13)		13.04 (0.13)		545 (5.8)	69 (5.8)		57 (8.2)	557 (5.7)	
Near poverty	1,541	5.89 (0.08)		12.99 (0.08)		1,369 (14.7)	169 (14.2)		127 (18.4)	1,413 (14.4)	
Mid income	2,358	5.84 (0.06)		12.96 (0.06)		2083 (22.3)	270 (22.8)		163 (23.6)	2,192 (22.3)	
High income	4,165	5.62 (0.05)		12.69 (0.04)		3,654 (39.1)	499 (42.0)		185 (26.7)	3,973 (40.4)	
Household education											
Less than HS	523	6.05 (0.13)	0.28	13.26 (0.13)	0.02	473 (5.1)	47 (4.0)	<0.001	59 (5.8)	461 (4.7)	<0.001
HS graduate	1,004	5.78 (0.10)		12.96 (0.10)		897 (9.6)	105 (8.8)		111 (16.0)	891 (9.1)	
Some college or associate	2,748	5.78 (0.06)		12.88 (0.06)		2,466 (26.4)	273 (23.0)		241 (34.8)	2,503 (25.5)	
College graduate	2,660	5.78 (0.06)		12.87 (0.06)		2,364 (25.3)	293 (24.7)		144 (20.8)	2,514 (25.6)	
Graduate or professional	3,596	5.76 (0.05)		12.85 (0.05)		3,118 (33.4)	469 (39.5)		137 (19.8)	3,454 (35.1)	
Household marital status											
Yes	7,082	5.87 (0.04)	0.78	12.86 (0.03)	0.05	6,216 (66.6)	848 (71.4)	0.001	392 (56.7)	6,680 (68.0)	<0.001
No	3,377	5.81 (0.05)		12.96 (0.05)		3,037 (32.6)	332 (28.0)		292 (42.2)	3,079 (31.3)	
Area deprivation index											
Quartile 1 (least deprived)	2,488	5.57 (0.06)	0.003	12.73 (0.06)	0.10	2,190 (23.5)	292 (24.6)	0.004	117 (16.9)	2,368 (24.1)	<0.001
Quartile 2	2,484	5.87 (0.06)		12.96 (0.06)		2,147 (23.0)	328 (27.6)		131 (18.9)	2,347 (23.9)	
Quartile 3	2,482	5.87 (0.06)		12.97 (0.06)		2,215 (23.7)	260 (21.9)		177 (25.6)	2,303 (23.4)	
Quartile 4 (most deprived)	2,485	5.83 (0.06)		12.87 (0.06)		2,225 (23.9)	257 (21.7)		223 (32.2)	2,258 (23.0)	

Bivariate relationships between salivary collection variables and socioeconomic variables are represented in Table 2.

^{A}*P*-values of Spearman Correlation tests reflect correlations between continuous salivary collection variables and continuous child age. ^{B}*P*-values of Kruskal-Wallis tests reflect associations between child age and categorical physical activity and caffeine intake. value of ps of Kruskal-Wallis tests also reflect associations between continuous salivary collection variables and categorical household poverty status, household education, household marital status, and Area Deprivation Index (ADI). ^{C}*P*-values of Chi-Square test of independent reflect associations between categorical salivary collection variables and categorical socioeconomic variables. r_s, Spearman correlation coefficient; SD, standard deviation; *P*, *p*-value; ns, non-significant.

TABLE 2 Bivariate correlations between socioeconomic variables.

	Household poverty status	Household education	Household marital status	ADI
Household poverty status	–	–	–	–
Household education	0.63**	–	–	–
Household marital status	0.46**	0.42**	–	–
ADI	−0.46**	−0.39**	−0.26**	–

Spearman rank correlations coefficients (r_s) between ordinal categorical socioeconomic variables are represented below. Values range from −1 to +1 reflecting strong negative to strong positive correlations, respectively. ADI, Area Deprivation Index.

**$p < 0.001$.

by either the reporting parent or the partner was included in the analyses. Otherwise, if the reporting parent did not have a partner, the single-caregiver's reported education level was used. Previous evidence demonstrates strong positive correlations between reports of maternal education, paternal education, and the highest education level of either parent in household (71, 72). Thus, to leverage a single operationalization of household education and to reflect inclusivity in gender-neutral terminology (73), we used the highest level of education in the household reported by the parent.

Household marital status was categorized as, "yes," if the parent reported being married. Otherwise, marital status was categorized as, "no," if the parent reported being widowed, divorced, separated, never married, or living with partner.

Area deprivation index (ADI) was calculated as the scaled weighted sum of 17 neighborhood-level characteristics within the participant's reported census block group. A detailed list of census variables has been summarized in Kind et al. and adapted for use in ABCD (74, 75). This includes proportion of population aged ≥25 years with <9 years of education; proportion of population aged ≥25 years with less than high school diploma; proportion of employed persons age 16+ in a "white collar" occupation; median household income; income disparity; median home value; median gross rent; median monthly mortgage; percent owner-occupied housing; percent of population age 16+ unemployed; percent of families below poverty line; percent of population below 138% of poverty line; percent of single-parent households with children <18 years; percent occupied housing units without vehicle; percent occupied units without telephone; percent occupied units without complete plumbing; percent occupied units with more than 1 person per room (74). Higher ADI scores, and thus upper quartile categorization, refer to higher levels of area deprivation, while lower quartile categorization refers to lower levels of area deprivation. Similar assessments of ADI have been widely applied in pediatric developmental research and support the validity of ADI for predicting child and family well-being (76–78). Specifically, within the ABCD cohort, many childhood outcomes such as brain structure and function, as well as body mass index, are associated with the ADI measure used in this analysis (79–81).

2.2.2. Methodological variables for salivary collection

The following salivary collection variables were analyzed.

Time since waking reflects the duration of time from the participant's self-reported time of waking to the start of the salivary sample collection documented by the RA. If a participant's time since waking was calculated to be less than 30 min, greater than 15 h, or was missing, values were assumed to be erroneous data, and therefore were excluded from the analyses ($n = 84$). Samples with time since waking less than 30 min were removed because due to ABCD protocol, it is highly unlikely that saliva sampling occurred within this time frame. Specifically, after participants arrived at the study site, the research assistant preformed a series of pre-collection assessments, including obtaining consent/assent, explanation of saliva sampling, and conducting demographic and pubertal questionnaires before soliciting a saliva sample (82). Given that the estimated time to complete these steps was at least 30 min, samples documented to be collected within 30 min of waking are likely erroneous.

Collection time of day refers to the time of day the salivary sample collection took place at the local study site laboratory. Collections that were reported before 06:00 a.m. and after 9:00 p.m. were assumed to be erroneous data, and therefore excluded from the analyses ($n = 10$).

Physical activity was categorized dichotomously, reflecting whether the participant was vigorously physically active (sweating, breathing heavy) for at least 20 min within the 12 h prior to sampling. Participants were classified into less than 20 min of physical activity, or greater than 20 min of physical activity.

Caffeine intake was categorized dichotomously as a yes or no response, referring to whether the participant reported consuming caffeine from drink within the 12 h prior to sampling. We categorized affirmative responses coinciding with reports of non-zero milligrams of caffeine as, "yes," and denial responses coinciding with reports of zero milligrams of caffeine as, "no," for these analyses.

2.3. Statistical analyses

Associations between socioeconomic variables and salivary collection variables were examined through a series of bivariate tests. A Spearman test of correlation (r_s) was performed to examine correlations between ordinally coded socioeconomic variables (Table 2). Given that neither the participant's age in months nor the continuous salivary collection variables were normally distributed, a Spearman test of correlation (r_s) was performed to examine the strength and direction of their relationship (Table 1). A Kruskal-Wallis non-parametric test of equality (H test statistic) was performed to identify differences in continuous salivary collection variables between levels of categorical socioeconomic variables (Table 1). A Chi-square test of independence (X^2) was performed to identify associations between categorical salivary collection variables and categorical socioeconomic variables (Table 1).

A series of univariate and multivariate multi-level linear or logistic mixed effects models were performed to examine potential confounding effects among socioeconomic factors determining salivary collection outcomes. To account for clustering effects by study site, random intercepts were specified according to study site as level 2 and subject ID as level 1 random intercepts. Time since waking (skew = 0.5, kurtosis = −0.81) and collection time of day (skew = 0.40, kurtosis = −0.92) were log-transformed due to non-normality prior to analyses. Post-transformation skew and kurtosis for time since waking (skew = −0.30 and kurtosis = −0.76) and collection time of day (skew = 0.08, kurtosis = −1.05) were improved. Due to log transformation of continuous outcomes, beta coefficients in regression models were exponentiated to improve interpretability. The Bonferroni-corrected significance level was set to alpha = 0.0125 for 4 outcomes. Bonferroni corrected *p*-values are reported.

All tests were performed in R Statistical Software Studio version 1.3.1073 utilizing the following packages: nlme (83), car (84), piecewiseSEM (85), lubridate (86), Hmisc (87).

3. Results

3.1. Descriptive statistics

Within the entire sample, the mean number of hours between participant waking and time of collection was 5.79 h, and the average time of collection was approximately 12 h and 53 min after midnight local time (not pictured). Time since waking and collection time of day were significantly strongly positively correlated ($r_s = 0.93$, $p < 0.05$). No significant associations were observed between physical activity and caffeine intake ($X^2 = 0.25$, df = 1, $p = 0.61$). A descriptive summary of salivary collection methods for the entire analytical sample, according to income group, is presented in Figure 2. Correlations between socioeconomic variables for the entire analytic sample are reflected in Table 2. All socioeconomic variables were significantly correlated with each other, albeit with ranging direction and strengths (*p*-values < 0.05, Table 2). Household poverty status was strongly positively correlated with household education ($r_s = 0.63$, $p < 0.05$), yet moderately positively correlated with household marital status ($r_s = 0.46$, p < 0.05). Household education was also moderately positively correlated with household marital status ($r_s = 0.42$, p < 0.05). ADI was negatively correlated with household poverty status ($r_s = -0.46$, p < 0.05), education ($r_s = -0.39$, p < 0.05), and marital status ($r_s = -0.26$, p < 0.05).

Child age (mean ± SD = 118.9 ± 7.5 months) was significantly negatively correlated with time since waking and collection time of day, albeit weakly (*p*s < 0.05, Table 1). No significant bivariate associations were observed between child age in months and physical activity nor caffeine intake.

Significant bivariate associations were observed between household poverty status and all salivary collection measures, but varying relationships between other SES factors and salivary collection measures. Mean time since waking was significantly different between levels of household poverty status (Table 1; $H = 12.4$, df = 4, $p = 0.01$), yet it was not significantly associated with household education (Table 1; $H = 5.04$, df = 4, $p = 0.28$). Household marital status was also not significantly associated with time since waking (Table 1; $H = 0.08$, df = 1, $p = 0.78$). Regarding bivariate associations at the neighborhood-level with ADI, mean time since waking ($H = 13.9$, df = 3, $p = 0.003$) was significantly different between quartiles of neighborhood deprivation (Table 1).

Additionally, while mean collection time of day was significantly different between levels of household poverty status (Table 1; $H = 25.8$, df = 4, $p < 0.001$) and household education (Table 1; $H = 11.6$, df = 4, $p = 0.02$), it was not significantly associated with household marital status (Table 1; $H = 3.8$, df = 1, $p = 0.05$) nor ADI (Table 1; $H = 6.2$, df = 3, $p = 0.10$).

Lastly, categories of physical activity and caffeine intake were not significantly independent (e.g., reject null hypothesis) of household

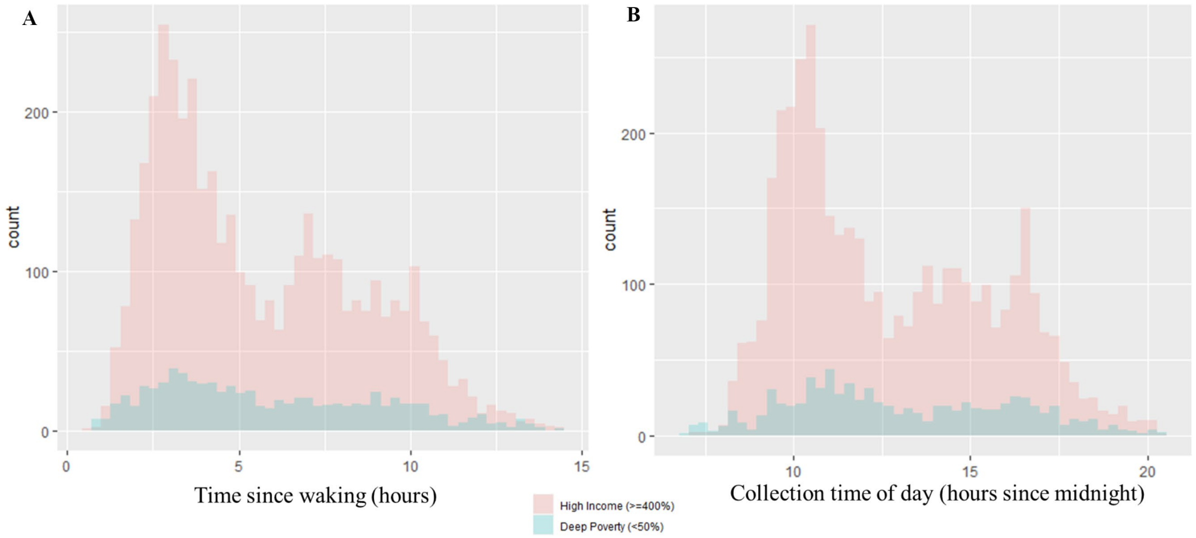

FIGURE 2
Distributions of salivary collection variables. **(A)** The distribution of time since waking in hours is represented by **(A)**. The distributions are further depicted according to poverty status (Deep Poverty versus High Income groups). Within the Deep Poverty group, the range of time since waking is 0.77–14.38h and the median is 5.32h. Within the High Income group, the range of time since waking is 0.60–14.33h and the median is 4.85h. **(B)** The distribution of collection time of day in hours since midnight is represented by **(B)**. The distributions are further depicted according to poverty status (Deep Poverty versus High Income groups). Within the Deep Poverty group, the range of collection time of day is 7.02–20.42h and the median is 12.46h. Within the High Income group, the range of collection time of day is 7.27–20.53h and the median is 11.92h.

poverty status, household education, marital status, nor ADI (Table 1). Whether or not a participant engaged in physical activity prior to sampling appeared to be significantly associated with household poverty status ($X^2 = 10.8$, df = 4, $p = 0.03$), household education ($X^2 = 19.7$, df = 4, $p < 0.001$), marital status ($X^2 = 10.3$, df = 1, $p = 0.001$) and ADI ($X^2 = 13.3$, df = 3, $p = 0.004$). In addition, caffeine consumption prior to sampling was significantly associated with household poverty status ($X^2 = 66.6$, df = 4, $p < 0.001$), household education ($X^2 = 124.3$, df = 4, $p < 0.001$), marital status ($X^2 = 35.8$, df = 1, $p < 0.001$), and ADI ($X^2 = 45.8$, df = 3, $p < 0.001$).

3.2. Child age

In univariate models, no significant independent relationships were observed between child age in months and time since waking and collection time of day. However, because of significant bivariate associations between child age and these salivary collection methods (Table 1), child age (months) was adjusted for in multivariate models predicting the outcomes described below.

3.3. Time since waking

Time since waking refers to the timeframe between the participant's waking time and subsequent start of saliva collection. Univariate analyses demonstrated a significant 5.34% longer time since waking among deep poverty households compared to high income households (Table 3; beta = 0.05; $p < 0.0125$). ADI was not significantly associated with time since waking (Table 3).

3.3.1. Multivariate

When adjusting for child age or ADI in multivariate analyses, significant relationships were observed between household poverty status and a longer time since waking (Table 3; Model 1 and Model 2). Deep poverty households demonstrated a significant 2.06% longer time since waking compared to high income households, adjusting for only child age (Table 3; $\beta = 0.02$; $p < 0.0125$). Moreover, when adjusting for both child age and ADI, time since waking was significantly 5.88% longer among deep poverty households compared to high income households (Table 3; $\beta = 0.057$; $p < 0.0125$).

3.4. Collection time of day

Collection time of day refers to the local time of day of the salivary sample collection. In univariate analyses, deep poverty households significantly demonstrated collection start times 2.43% later in the day compared to high income households (Table 4; $\beta = 0.024$; $p < 0.0125$). No significant differences were observed between marital status, levels

TABLE 3 Univariate and multivariate multilevel linear models of log transformed time since waking.

	Time since waking (log)								
	Univariate			Multivariate					
				Model 1			Model 2		
	% inc or dec	Beta (SE)	*P*	% inc or dec	Beta (SE)	*P*	% inc or dec	Beta (SE)	*P*
Intercept					1.684 (0.104)	<0.001		1.684 (0.107)	<0.001
Household poverty status									
(Intercept)	374.85	1.558 (0.062)	<0.001						
Deep poverty	5.34	0.052 (0.02)	0.011	2.06	0.020 (0.020)	0.012	5.88	0.057 (0.022)	0.011
Poverty	−2.07	−0.021 (0.022)	0.352	2.27	0.022 (0.022)	0.349	−1.12	−0.011 (0.024)	0.645
Near poverty	0.36	0.004 (0.016)	0.820	1.58	0.016 (0.016)	0.823	0.60	0.006 (0.017)	0.725
Mid income	0.42	0.004 (0.013)	0.750	1.34	0.013 (0.013)	0.780	0.52	0.005 (0.014)	0.713
High income	Ref			Ref			Ref		
Area deprivation index									
Quartile 1 (least deprived)	Ref			Ref			Ref		
(Intercept)	377.10	1.563 (0.062)	<0.001						
Quartile 2	1.35	0.013 (0.015)	0.385	–	–	–	1.30	0.013 (0.016)	0.431
Quartile 3	−0.40	−0.004 (0.016)	0.796	–	–	–	−1.06	−0.011 (0.017)	0.542
Quartile 4 (most deprived)	0.55	0.005 (0.017)	0.755	–	–	–	−1.28	−0.013 (0.02)	0.530

All models adjusted for child age (months). % inc or dec refers to exponentiated beta coefficient and reflect percent increase or decrease from reference group. Due to log transformation of the outcome, beta coefficients were log transformed to improve interpretability. SE, standard error; *P*, *p*-value.

TABLE 4 Univariate and multivariate multilevel linear models of log transformed collection time of day.

	Collection time of day (log)								
	Univariate			Multivariate					
				Model 3			Model 4		
	% inc or dec	Beta (SE)	*P*	% inc or dec	Beta (SE)	*P*	% inc or dec	Beta (SE)	*P*
Intercept				1,143	2.52 (0.042)	<0.001	1,143	2.52 (0.042)	<0.001
Household marital status									
Intercept	1134.60	2.5133 (0.0259)	<0.001						
No	0.77	0.0076 (0.0043)	0.073	0.28	0.0028 (0.0052)	0.582	0.28	0.0028 (0.0053)	0.600
Yes		Ref			Ref			Ref	
Household poverty status									
(Intercept)	1129.54	2.509 (0.026)	<0.001						
Deep poverty	2.43	0.024 (0.008)	0.003	2.41	0.024 (0.01)	0.016	2.60	0.026 (0.01)	0.013
Poverty	0.02	0.0002 (0.009)	0.985	0.08	0.001 (0.01)	0.940	0.50	0.005 (0.011)	0.633
Near poverty	0.54	0.005 (0.006)	0.375	0.77	0.008 (0.007)	0.274	0.90	0.009 (0.007)	0.222
Mid income	0.66	0.007 (0.005)	0.202	0.75	0.008 (0.006)	0.173	0.89	0.009 (0.006)	0.125
High income		Ref			Ref			Ref	
Household education									
(Intercept)	1133.21	2.512 (0.026)	<0.001						
Less than HS	0.39	0.004 (0.01)	0.685	−1.07	−0.011 (0.013)	0.409	−1.42	−0.014 (0.014)	0.299
HS graduate	1.23	0.012 (0.007)	0.090	0.64	0.006 (0.009)	0.493	0.77	0.008 (0.01)	0.434
Some college or associate	0.37	0.004 (0.005)	0.465	−0.75	−0.007 (0.006)	0.236	−0.79	−0.008 (0.007)	0.229
College graduate	0.39	0.004 (0.005)	0.438	0.23	0.002 (0.005)	0.664	0.19	0.002 (0.006)	0.729
Graduate or professional		Ref			Ref			Ref	
Area deprivation index									
Quartile 1 (least deprived)		Ref			Ref			Ref	
(Intercept)	1134.21	2.513 (0.026)	<0.001						
Quartile 2	0.75	0.008 (0.006)	0.210		–	–	0.64	0.015 (0.016)	0.320
Quartile 3	0.00	0.00002 (0.006)	0.997		–	–	−0.52	−0.007 (0.018)	0.446
Quartile 4 (most deprived)	0.14	0.001 (0.007)	0.831		–	–	−0.88	−0.01 (0.021)	0.277

All models adjusted for child age (months). % inc or dec refers to exponentiated beta coefficient and reflect percent increase or decrease from reference group. Due to log transformation of the outcome, beta coefficients were exponentiated to improve interpretability. SE, standard error; *P*, *p*-value.

of household education, nor ADI and collection time of day in univariate analyses.

3.4.1. Multivariate

In multivariate analyses adjusting for child age, marital status, and household education, significant relationships between household poverty status and collection time of day were maintained (Table 4; Model 3). Collection start times among deep poverty households were 2.41% significantly (marginal) later in the day compared to high income households (Table 4; $\beta = 0.024$; $p = 0.016$). When including ADI in multivariate analyses, marginal significant relationships between household poverty status and collection time of day were still maintained (Table 4; Model 4).

3.5. Physical activity

Physical activity refers to any rigorous physical activity for 20 or more minutes in the 12 h prior to providing a saliva sample. In univariate analyses, significant increases were observed in the odds of physical activity with decreasing levels of poverty. Deep poverty households demonstrated 42% lower odds of physical activity within 12 h of salivary sampling compared to high income households (Table 5; OR = 0.58, 95% CI [0.44–0.77]; $p < 0.0125$). Despite a stepwise increase in odds of physical activity with lesser impoverished households, these households were still less likely to engage in physical activity relative to high income households, albeit not significantly.

In univariate analyses, lower levels of household education demonstrated a significantly lower odds of physical activity compared to households with Graduate/Professional educations (Table 5; $p < 0.05$). To note, univariate relationships between household education (e.g., HS graduate and College Graduate) and physical activity were not significant after Bonferroni correction. There was a pattern of increasing odds of physical activity with higher education levels. Households with a less than HS education demonstrated a 43% reduced odds of physical activity 12 h prior to salivary sampling compared to Graduate/professional households (OR = 0.57, 95% CI [0.41–0.79]; $p < 0.0125$). Households with a HS graduate, Some College/Associate, or College education demonstrated a respective 26, 27, and 16% reduced odds of physical activity compared to the reference group (Table 5).

ADI was not significantly associated with physical activity in univariate analyses (Table 5).

TABLE 5 Univariate and multivariate multilevel logistic models of physical activity.

	Physical activity								
	Univariate			Multivariate					
				Model 5			Model 6		
	OR	95% CI	*P*	OR	95% CI	*P*	OR	95% CI	*P*
Intercept				0.13	[0.09, 0.18]	<0.001	0.12	[0.09, 0.18]	<0.001
Household marital status									
Intercept	0.12	[0.08, 0.16]	<0.001						
No	0.78	[0.68, 0.90]	0.001	0.88	[0.75, 1.04]	0.140	0.85	[0.72, 1.01]	0.073
Yes	Ref			Ref			Ref		
Household poverty status									
(Intercept)	0.12	[0.09, 0.17]	<0.001						
Deep poverty	0.58	[0.44, 0.77]	<0.001	0.71	[0.50, 0.99]	0.046	0.76	[0.54, 1.09]	0.134
Poverty	0.82	[0.62, 1.08]	0.156	0.95	[0.69, 1.30]	0.735	0.97	[0.70, 1.36]	0.876
Near poverty	0.83	[0.69, 1.01]	0.066	0.96	[0.77, 1.20]	0.711	0.98	[0.77, 1.23]	0.848
Mid income	0.89	[0.76, 1.05]	0.175	0.98	[0.82, 1.16]	0.793	0.99	[0.83, 1.19]	0.943
High income	Ref			Ref			Ref		
Household education									
(Intercept)	0.13	[0.09, 0.17]	<0.001						
Less than HS	0.57	[0.41, 0.79]	0.001	0.66	[0.42, 1.04]	0.075	0.65	[0.40, 1.04]	0.074
HS graduate	0.74	[0.59, 0.94]	0.013	1.01	[0.75, 1.35]	0.969	1.01	[0.75, 1.38]	0.927
Some college or associate	0.73	[0.62, 0.86]	<0.001	0.79	[0.64, 0.97]	0.022	0.78	[0.63, 0.97]	0.024
College graduate	0.84	[0.72, 0.99]	0.034	0.87	[0.73, 1.03]	0.096	0.88	[0.74, 1.04]	0.131
Graduate or professional	Ref			Ref			Ref		
Area deprivation index									
Quartile 1 (least deprived)	Ref			Ref			Ref		
(Intercept)	0.11	[0.08, 0.16]	<0.001	–	–	–			
Quartile 2	1.12	[0.93, 1.35]	0.227	–	–	–	1.23	[1.00, 1.50]	0.045
Quartile 3	0.83	[0.68, 1.01]	0.060	–	–	–	0.92	[0.73, 1.15]	0.443
Quartile 4 (most deprived)	0.84	[0.67, 1.04]	0.111	–	–	–	1.04	[0.80, 1.35]	0.779

OR, odds ratio; CI, confidence interval; *P*, *p*-value.

3.5.1. Multivariate

In multivariate analyses adjusting for household socioeconomic factors and ADI, relationships between household poverty status and odds of physical activity became fully attenuated (Table 5; Model 5 and Model 6).

Relationships between household education and odds of physical activity became partially attenuated. Only households with Some college/Associate education demonstrated 21% lower odds of physical activity (OR = 0.79, 95% CI [0.64–0.97]; $p < 0.05$) within 12 h of salivary sampling compared to households with Graduate/Professional educations (Table 5). This result however is not significant after Bonferroni correction.

Despite univariate non-significance between ADI and physical activity, a marginally significant relationship between ADI and physical activity emerged in multivariate analyses adjusting for household marital status, household poverty status, and household education. An ADI in quartile 2 (e.g., moderately deprived neighborhood) was significantly associated with 1.23 higher odds of physical activity compared to an ADI in quartile 1 (least deprived) (OR = 1.23, 95% CI [1.00–1.50]; $p < 0.05$). These results are not significant after Bonferroni correction.

3.6. Caffeine intake

Caffeine intake refers to the child's self-report of any caffeinated beverage during the 12 h prior to providing a saliva sample. In univariate analyses, significantly higher odds of caffeine intake was observed among lower levels of household poverty compared to high income households (Table 6; $p < 0.0125$). Deep poverty households

TABLE 6 Univariate and multivariate multilevel logistic models of caffeine Intake.

	Caffeine intake								
	Univariate			Multivariate					
				Model 7			Model 8		
	OR	95% CI	*P*	OR	95% CI	*P*	OR	95% CI	*P*
Intercept				0.04	[0.03, 0.05]	<0.001	0.04	[0.03, 0.05]	<0.001
Household marital status									
Intercept	1.10	[1.10, 1.10]	<0.001						
No	1.09	[1.09, 1.09]	<0.001	1.01	[0.83, 1.23]	0.908	1.00	[0.82, 1.23]	0.984
Yes	Ref			Ref			Ref		
Household poverty status									
(Intercept)	0.05	[0.04, 0.06]	<0.001						
Deep poverty	2.15	[1.62, 2.85]	<0.001	1.14	[0.80, 1.64]	0.466	1.15	[0.78, 1.67]	0.483
Poverty	1.95	[1.42, 2.68]	<0.001	1.05	[0.72, 1.53]	0.799	1.00	[0.67, 1.48]	0.990
Near poverty	1.86	[1.46, 2.36]	<0.001	1.20	[0.90, 1.58]	0.213	1.15	[0.86, 1.55]	0.348
Mid income	1.57	[1.26, 1.96]	<0.001	1.21	[0.95, 1.53]	0.119	1.18	[0.92, 1.51]	0.197
High income	Ref			Ref			Ref		
Household education									
(Intercept)	0.04	[0.03, 0.05]	<0.001						
Less than HS	2.88	[2.07, 4.01]	<0.001	2.49	[1.58, 3.91]	<0.001	2.21	[1.36, 3.57]	0.001
HS graduate	2.79	[2.14, 3.64]	<0.001	2.78	[1.98, 3.90]	<0.001	2.61	[1.83, 3.73]	<0.001
Some college or associate	2.33	[1.87, 2.90]	<0.001	2.11	[1.62, 2.75]	<0.001	1.94	[1.47, 2.55]	<0.001
College graduate	1.50	[1.18, 1.90]	<0.001	1.39	[1.08, 1.79]	0.010	1.40	[1.09, 1.81]	0.010
Graduate or professional	Ref			Ref			Ref		
Area deprivation index									
Quartile 1 (least deprived)	Ref			Ref			Ref		
(Intercept)	0.05	[0.04, 0.06]	<0.001	–	–	–			
Quartile 2	1.23	[0.94, 1.60]	0.129	–	–	–	0.99	[0.75, 1.31]	0.929
Quartile 3	1.59	[1.23, 2.05]	<0.001	–	–	–	1.09	[0.82, 1.45]	0.549
Quartile 4 (most deprived)	1.89	[1.45, 2.46]	<0.001	–	–	–	1.18	[0.87, 1.62]	0.293

OR, odds ratio; CI, confidence interval; *P*, *p*-value.

had a 2.15 higher odds of caffeine intake 12 h prior to sampling compared to high income households (Table 6; OR = 2.15, 95% CI [1.62–2.85]; $p < 0.0125$). This same pattern was observed among poverty (OR = 1.95, 95%, CI [1.42–2.68]; $p < 0.05$), near poverty (OR = 1.86, 95% CI [1.46–2.36]; $p < 0.0125$), and mid income households (OR = 1.57, 95% CI [1.26–1.96]; $p < 0.0125$) (Table 6).

Lower levels of household education demonstrated a significantly higher odds of caffeine intake compared to households with Graduate/Professional educations (Table 6; $p < 0.0125$). Households with a less than HS education demonstrated a 2.88 higher odds of caffeine intake 12 h prior to salivary sampling compared to Graduate/professional households (OR = 2.88, 95% CI [2.07–4.01]; $p < 0.0125$). There was a pattern of decreasing odds of caffeine intake with higher education levels. Households with a HS graduate or Some College/Associate education demonstrated a respective 2.79, 2.33, 1.50 higher odds of caffeine intake compared to the reference group (Table 6).

ADI was only significantly associated with caffeine intake in univariate analyses (Table 6). Residing in highly deprived neighborhoods (e.g., quartile 3 and 4) was significantly associated with a 1.59–1.89 ($p < 0.0125$) higher odds of caffeine intake compared to participants residing in the least deprived neighborhoods (quartile 1).

3.6.1. Multivariate

In multivariate analyses adjusting for household marital status, education, and ADI, relationships between household poverty status and odds of caffeine intake, as well as ADI and caffeine intake became fully attenuated (Model 7 and Model 8). However, significant relationships between household education and caffeine intake were maintained (Model 7 and Model 8).

4. Discussion

The findings from this study demonstrate significant associations between several key salivary methodological variables (time since waking, collection time of day, physical activity, and caffeine intake) with key socioeconomic factors (poverty status, household education, neighborhood deprivation). In general, lower levels of household poverty and education were significantly associated with salivary collection methodological variables (e.g., longer times since waking, collections later in the day, higher odds of caffeine consumption, and lower odds of physical activity). Furthermore, household socioeconomic context and neighborhood socioeconomic context were differentially associated with these variables. This indicates multiple sources of socioeconomic factors can independently introduce methodological biases when not fully standardized across data collection sites and individual participants. Together, present findings ultimately suggest that analyte levels measured from these samples may be impacted by non-random systematic methodological biases, particularly among analytes sensitive to variability in pH levels (e.g., caffeine in sample), physical activity/exercise, or circadian patterns. Leveraging this large salivary data set will require additional care when leveraging salivary analytes in future examination of early life antecedents of health inequities. Finally, only a subset of key socioeconomic factors and salivary sampling methodological variables were assessed in the present analyses, therefore other factors that drive health inequities may impact additional salivary methodological variables in addition to those examined in this current study.

Household poverty status was consistently significantly associated with salivary methodological variables in univariate analyses, often when comparing highly impoverished households with lesser impoverished households. These relationships were maintained in multivariate analyses when specifically predicting time since waking and collection time of day. Significant relationships between household poverty status and physical activity and caffeine intake were attenuated in multivariate analyses when adjusting for household marital status, household education, or ADI. To our knowledge, no study has examined direct relationships between household poverty status and salivary collection variables among pediatric populations. Our measure of poverty status (e.g., household income as a function of household size) may reflect more proximal measures of material or economic goods that, when scarce in impoverished households, facilitate longer durations between waking and arriving to the laboratory to provide a saliva sample, as well as sampling later in the day. With this, it may be that a reduction in economic goods associated with an impoverished household leads to unique barriers preventing an early arrival to the study site shortly after waking and earlier in the day, thereby performing salivary collections in the "tail" of diurnal rhythms when levels are low. Also, later sampling times among participants from impoverished households may have been partially or fully driven by site-specific differences in access (e.g., differences in travel time and distance). Alternatively, given the semi-flexible experimental design of the cohort study, it is possible households in poverty self-selected for a later study start time over an earlier start time in anticipation of additional barriers, such as prioritizing employment responsibilities, geographical or transportation barriers, or responsibilities of other children without funds for additional childcare. Differential preferences to come into the laboratory on a weekday versus a weekend may be another contributing source to this variability and not investigated in the present analysis. Additionally, attenuated relationships with household poverty status predicting physical activity and caffeine intake after accounting for additional socioeconomic factors, such as household education or ADI, suggest that differences in likelihood of physical activity or caffeine intake may be partially attributed to a complex interaction between several socioeconomic constructs. It is possible that individual measures of SES may be less apt to capture differences compared to composite forms of SES that include income, education, and neighborhood characteristics (53, 88). While these are only some explanations, these differences in salivary sampling methodological variables may partially, yet falsely, drive future SES-related health inequities, or null findings, in observed salivary analyte levels that are sensitive to variability in sampling methodological variables.

Household education was not significantly associated with time since waking nor collection time of day but was significantly associated with physical activity and caffeine intake in univariate and multivariate analyses. Again, to our knowledge, no study has examined direct relationships between household education and on-site salivary collection methodological variables among adolescent populations. Even with this, Krieger et al. reported weak associations between education level and physical health status however only among those living below the poverty line (89). While this study was performed among adults and examined health status, this partially supports our non-significant findings between household education and time since waking or collection time of day. In addition, relationships in our study between household education and physical activity were only significant when comparing households with Some College/Associate education to households with a Graduate/Professional education and adjusting for household poverty status. These findings are also in line with those of Krieger et al. where level of education operates on health differentially by poverty status (89). Nonetheless, this evidence may explain why household education was sparsely related to salivary collection variables. The inclusion of both household education and household poverty status in the same statistical models potentiates confounding, given evidence of strong positive correlations between one's education level and income (88). However, we checked variance inflation factor (VIF) values for these models, and all were below 2.09, indicating that these variables were not redundant in predicting the outcomes in this study sample.

When examining neighborhood socioeconomic contexts, significant relationships were observed with ADI when predicting multivariate odds of physical activity and univariate odds of caffeine intake, whereas ADI was not significantly associated with time since waking nor collection time of day. Cerin et al. demonstrated complex relationships between environmental factors and individual-level or household-level factors (e.g., household income and education) that impact participation in physical activity (90). Differences in performing moderate to vigorous physical activity due to area-level socioeconomic factors were significantly mediated by several individual-level factors (e.g., social support from friends and self-efficacy), but not significantly mediated by infrastructure nor area-level crime (90). While ADI is a well-validated measure of neighborhood-level socioeconomic context, there are other ways to assess this construct beyond the current version (91, 92) that may miss key characteristics that are important for understanding childhood origins of health inequities. The measure of ADI used in this study is a composite of multiple forms of area economic and resource deprivation. This indicates that relationships between area-level SES and physical activity may be partially explained by individual-level factors not recorded as part of this study. While limited in the ability to inform individual-level patterns (e.g., due to ecological fallacy), this ADI measure includes factors of basic resources (e.g., plumbing, telephone) that would not be captured by income and education alone.

4.1. Strengths and limitations

Despite evidence for potential non-random systematic bias in salivary sampling methodological variables in the present cohort study, several strengths of the study design were observed. First, the ABCD Study© achieved coordination among 21 sites for the successful self-collection of saliva among a large pediatric cohort repeated annually. This strength adds to both the salience of the observed findings in this nationally representative pediatric study sample and further highlights the utility of salivary bioscience research on large scales and with pediatric populations. Second, the cohort sample of children was successfully recruited from the general population, rather than a convenience sample among those presenting to a clinical site, thus adding to the heterogeneity of the cohort sample, and thereby increasing the external validity of the present findings for future large-scale salivary collections. Additionally, uncovering socioecological relationships using data obtained in a non-invasive way means that salivary biosciences are well-suited to understand public health issues, particularly among children from families underrepresented in research (93). Salivary methodological variables examined in this study are often applicable to other forms of biological sample collection measuring acutely fluctuating levels (e.g., blood, urine) for analytes that vary across time of day yet correlate with salivary levels (94–98). Thus, our results may have increased generalizability beyond saliva in this study and may occur in other large biomedical research studies. Other biological methods measuring chronic levels would not be impacted by these methodological variations (e.g., hair, nails, teeth).

Nonetheless, there are several limitations to the current analyses. First, part of the exclusion criteria for the current analytical sample was a mismatch between parental report of "biological sex at birth" and the participant endorsed a binary "biological sex/gender" at the time of saliva collection from baseline (e.g., current analyses). Unfortunately, given that sex at birth determined the hormone panel for testing prior to Year 3, this protocol misrepresents associations between estradiol and variants of male sex or gender expression by not assaying saliva samples for the assumed "female" hormone. This experimental strategy potentially excludes important dynamics in gender identification throughout pubertal maturation (99) and may limit our ability to fully understand how hormones emerge across a diversity of gender identities in the current data set. In year 3, ABCD protocol solicited the participant's endorsement of any gender identity at saliva collection however this is not part of the Release 3.0 dataset used in these analyses. Additional gender identity specific assessments were added to the study at this Year 3 timepoint as well. After Year 3, biological males at birth endorsing a male gender identity were assessed for testosterone and DHEA only, and all other possible combinations of gender identity endorsement (including neither gender) were assessed for testosterone, DHEA, and estradiol. Future analyses using the ABCD dataset for year 3 and later should leverage the gender identity data that better capture the dynamics of gender identification with salivary hormones. Second, there are many ways to capture socioeconomic status (SES), including measures of employment or unemployment status, wealth, type or status of occupation, or numeric income level (100). The variables used in this study are mostly reflective of household economic resources and household education. Previous evidence indicates that education and poverty status represent just two of many overlapping yet distinct dimensions comprising SES, rather than being entirely reflective of SES (53). Given that SES is a dynamic, multi-dimensional construct, the exclusion of other aspects of SES may only provide a partial understanding of socioecological relationships on salivary collection methodological variables.

Another limitation is the relative difference in smaller sample size among the deep poverty and poverty groups compared to the high-income group, given that larger sample sizes are more statistically powered to detect small effect sizes. Thus, imbalances in sample sizes can bias the findings of smaller effect sizes between groups, especially where the comparison group (e.g., deep poverty or poverty) is a smaller sample size relative to the reference group (e.g., high income). The deep poverty and poverty groups are likely underpowered to detect small effects and are the most at risk for null findings. Null findings between deep poverty and poverty with salivary methodological variables in the present study should be interpreted with caution. However, the deep poverty and poverty sample size were $n = 798$ and $n = 616$, respectively, which is relatively robust for pediatric biomedical research. In addition, for many of the observed findings, the effect sizes of the significant results in this analysis are relatively moderate to small. These results may not be observable within studies with smaller sample sizes, as sample sizes may be underpowered to detect small effect sizes. Without being contextualized to specific analytes of interest, the practical application of current findings is limited.

In addition, an area-level measure such as ADI is subject to an ecological fallacy because aggregate-level patterns may not actually reflect individual-level socioeconomic measures (53, 101). Although we leverage multi-level models accounting for participant clustering by study site, we observed different relationships to salivary collection methodological variables between household income/education and ADI. One potential explanation as to why ADI was not related to time-dependent salivary collection variables is that ADI may not be as proximal to household level factors, and thus would not reflect direct relationships to time since waking or collection time of day.

Another limitation of this analyses is the focus on salivary bioscience methodological variables only. The observed relationships discovered in the present analyses were not examined further in relation to specific salivary analytes that have been assayed in the samples (e.g., DHEA, testosterone, estradiol). Associations of socioeconomic-based differences in salivary collection methodological variables with salivary analyte levels were not directly tested in the present analysis. Further, our examination of baseline relationships may also limit interpretability over time, especially with longitudinal changes in SES for a participant, changes in salivary methodological variables (e.g., sampling at different time of the day or different physical activity/caffeine intake habits as participants age), and even longitudinal changes in analyte levels. Given the breadth of research questions and corresponding analytical approaches with this dataset, associations between methodological biases and analyte levels could vary across independent and longitudinal investigations. There are important considerations for whether these relationships are stable over time. We rely on existing literature that points to interference of accurate analyte measurement due to collection methodological variables (11, 29, 30, 35–37, 39, 40). Rather, this analysis encourages researchers examining health inequities to conduct a thorough examination of salivary collection methods prior to leveraging analyte levels.

While we observed significant relationships between socioeconomic and salivary sampling methodological variables, we cannot make conclusions about magnitude and directionality of relationships to specific analytes. Based on previous literature of neuroendocrine circadian patterns (30–34), we predict that these differences in salivary sampling methodological variables will become more problematic as participants continue to mature, as circadian patterns become more pronounced with maturation, and differences in exercise and caffeine intake may grow with age as a function of key socioeconomic factors. However, not all salivary analytes demonstrate a circadian rhythm or are sensitive to changes in pH of the sample, or physical activity. Thus, some specific analytes may be relatively unaffected by the observations discovered in these analyses. Researchers should evaluate whether their salivary analytes of interest reflect the observed patterns in their own analyses, and if so, intentionally address them in analyses and interpretation of salivary analyte results.

Examination of socioeconomic factors with other salivary sampling methodological variables that were collected in ABCD were out of scope for the current analyses, including cotinine levels from first and/or second-hand tobacco exposure in the children and medications that may alter salivary flow rates. However, future studies of bio-banked salivary samples could measure cotinine directly from the sample to statistically control for these confounders. There are additional salivary sampling methodological considerations that were not fully collected in this large data set, such as participant reported factors of the oral environment (e.g., blood from sores, lost teeth, injury). Research assistants used a 5-point scale to document visible alterations in the saliva sample, including presence of discoloration from food dye or blood, and food particles. A visual inspection of the salivary sample was also conducted by professional laboratory staff during the time of assaying (e.g., Salimetrics, Carlsbad, CA, United States) to note any abnormalities in the sample. Future studies would benefit from a thorough oral health questionnaire at the time of sample collection to account for salivary sample contamination. To achieve the most rigorous use of salivary analytes, all of these methodological factors should be controlled for either through upfront experimental design in future studies, expansion of questionnaires on oral health, or with careful and intentional statistical analyses to fully understand how socioeconomic factors may drive experimental noise and interfere with results. This includes maintaining strict protocols for saliva sampling regarding time since waking, time of day, sample collection duration, abstaining from caffeine, smoking, and rigorous physical activity 12 h prior to sampling.

Lastly, the examination of race/ethnicity differences was outside of the scope of this analysis; however, we encourage investigators to consider intentionally integrating upstream measures when investigating research questions pertaining to racial and ethnic minoritized groups (102–104). For example, structural racism has been identified as an important factor of adverse health among racial and ethnic minoritized groups including adolescents (105–107). Future salivary bioscience research studies must acknowledge root causes of racial/ethnic differences in health, and should be integrated in salivary bioscience research when examining race/ethnicity particularly through collaboration with experts in structural racism.

4.2. Conclusion

Significant associations were observed between socioeconomic factors and salivary collection methodological variables. Specifically, lower levels of household poverty and education were significantly associated with more sources of potential bias in salivary collection methodological variables (e.g., longer times since waking, collections later in the day, higher odds of caffeine consumption, and lower odds of physical activity). These novel findings serve as a thorough cautionary tale for future analyses leveraging analyte levels from these salivary samples to examine early antecedents of health inequities, as results may reflect variations in methodological variables of salivary collections (e.g., time since waking to sampling, time of day of sampling, physical activity, and caffeine intake) and not actual biological mechanisms. Entangled contributions to biological functioning from socioeconomic factors remain a potential source of non-random systematic biases. Conclusions made about biological functioning using saliva while only accounting for salivary collection methodological variables, without the consideration of socioeconomic factors, may erroneously attribute group differences to differences in biological functioning rather than the broader upstream socioeconomic environment.

These results advance salivary bioscience research by applying a health equity perspective in considering socioeconomic factors on standardizing salivary methodology. These findings highlight the importance of developing an experimental design that standardizes salivary collections, to prevent potential unintentional non-random systematic biases in saliva sampling methodology. Specifically, our results suggest that future studies ensure participants self-collect at the same time of day, for the same collection duration, and in the absence of rigorous physical activity or caffeine consumption 12 h prior to providing a sample. If stringent sample collection protocols are not feasible, we recommend that future studies collect information on potentially important salivary methodological variables (e.g., time since waking, collection time of day, physical activity, caffeine intake, oral health, medications), utilize post-hoc statistical techniques (e.g., adjustment) to cautiously disentangle effects, and target analytes that are robust to variability in salivary methodological variables. Nonetheless, salivary samples were collected effectively in participants across 21 sites, demonstrating feasibility of guided self-sampling as a non-invasive biological specimen in a large-scale pediatric study. These samples have strong potential to be leveraged in investigations of biological mechanisms across the entire sample, yet more cautiously when leveraging factors in analyses that drive health inequities.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found: in the NIMH Data Archive (NDA), Adolescent Brain Cognitive Development (ABCD) Study (http://dx.doi.org/10.15154/1519007).

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

HM and KU contributed to the design of the study. HM led analyses and writing. KU contributed to analyses and writing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Publisher's note

References

1. Chen E, Martin AD, Matthews KA. Understanding health disparities: the role of race and socioeconomic status in children's health. *Am J Public Health.* (2006) 96:702–8. doi: 10.2105/AJPH.2004.048124

2. Devenish B, Hooley M, Mellor D. The pathways between socioeconomic status and adolescent outcomes: a systematic review. *Am J Community Psychol.* (2017) 59:219–38. doi: 10.1002/ajcp.12115

3. Hanson MD, Chen E. Socioeconomic status and health behaviors in adolescence: a review of the literature. *J Behav Med.* (2007) 30:263–85. doi: 10.1007/s10865-007-9098-3

4. Condon EM. Chronic stress in children and adolescents: a review of biomarkers for use in pediatric research. *Biol Res Nurs.* (2018) 20:473–96. doi: 10.1177/1099800418779214

5. Granger DA, Fortunato CK, Beltzer EK, Virag M, Bright MA, Out D. Focus on methodology: salivary bioscience and research on adolescence: an integrated perspective. *J Adolesc*. (2012) 35:1081–95. doi: 10.1016/j.adolescence.2012.01.005

6. Granger DA, Kivlighan KT, El-Sheikh M, Gordis EB, Stroud LR. Salivary α-amylase in biobehavioral research. *Annu Rev Public Health*. (2007) 1098:122–44. doi: 10.1196/annals.1384.008

7. Kokka I, Chrousos GP, Darviri C, Bacopoulou F. Measuring adolescent chronic stress: a review of established biomarkers and psychometric instruments. *Horm Res Paediatr*. (2023) 96:74–82. doi: 10.1159/000522387

8. Hoyt MA, Granger DA. Salivary bioscience and the future of behavioral medicine. *Int J Behav Med*. (2020) 27:257–61. doi: 10.1007/s12529-020-09900-w

9. Granger DA, Kivlighan KT, Fortunato C, Harmon AG, Hibel LC, Schwartz EB, et al. Integration of salivary biomarkers into developmental and behaviorally-oriented research: problems and solutions for collecting specimens. *Physiol Behav*. (2007) 92:583–90. doi: 10.1016/j.physbeh.2007.05.004

10. Granger DA, Taylor MK. Foundations of interdisciplinary salivary bioscience: An Introduction In: *Salivary Bioscience: Foundations of Interdisciplinary Saliva Research and Applications* (2020) (Springer), 3–9.

11. Smyth N, Hucklebridge F, Thorn L, Evans P, Clow A. Salivary cortisol as a biomarker in social science research. *Soc Pers Psychol Compass*. (2013) 7:605–25. doi: 10.1111/spc3.12057

12. Granger DA, Johnson SB, Szanton SL, Out D, Schumann LL. Incorporating salivary biomarkers into nursing research: an overview and review of best practices. *Biol Res Nurs*. (2012b) 14:347–56. doi: 10.1177/1099800412443892

13. Ramirez J, Elmofty M, Castillo E, DeRouen M, Shariff-Marco S, Allen L, et al. Evaluation of cortisol and telomere length measurements in ethnically diverse women with breast cancer using culturally sensitive methods. *J Community Genet*. (2017) 8:75–86. doi: 10.1007/s12687-016-0288-y

14. Wilde C, Out D, Johnson S, Granger DA. Sample collection, including participant preparation and sample handling In: *The Immunoassay Handbook* (2013). ed. D. Wild (Elsevier), 427–440.

15. Johnson SB, Voegtline KM. Salivary bioscience and pediatrics In: *Salivary Bioscience: Foundations of Interdisciplinary Saliva Research and Applications* (2020) (Springer), 643–646.

16. Parkin GM, McCarthy MJ, Thein SH, Piccerillo HL, Warikoo N, Granger DA, et al. Saliva testing as a means to monitor therapeutic lithium levels in patients with psychiatric disorders: identification of clinical and environmental covariates, and their incorporation into a prediction model. *Bipolar Disord*. (2021) 23:679–88. doi: 10.1111/bdi.13128

17. Granger D. A., Hamilton K. (2020). Saliva as a biospecimen: then and now in the era of COVID-19. Association for Psychological Science (APS) Observer 33. Available at: https://www.psychologicalscience.org/observer/saliva-as-a-biospecimen-then-and-now-in-the-era-of-covid-19 (Accessed April 19, 2023).

18. Fernandes A, Skinner ML, Woelfel T, Carpenter T, Haggerty KP. Implementing self-collection of biological specimens with a diverse sample. *Field Methods*. (2013) 25:58–73. doi: 10.1177/1525822X12453526

19. Arbour L, Cook D. DNA on loan: issues to consider when carrying Out genetic research with aboriginal families and communities. *Public Health Genom*. (2006) 9:153–60. doi: 10.1159/000092651

20. Rajakumar K, Thomas SB, Musa D, Almario D, Garza MA. Racial differences in parents' distrust of medicine and research. *Arch Pediatr Adolesc Med*. (2009) 163:108–14. doi: 10.1001/archpediatrics.2008.521

21. Scharff DP, Mathews KJ, Jackson P, Hoffsuemmer J, Martin E, Edwards D. More than Tuskegee: understanding mistrust about research participation. *J Health Care Poor Underserved*. (2010) 21:879–97. doi: 10.1353/hpu.0.0323

22. George S, Duran N, Norris K. A systematic review of barriers and facilitators to minority research participation among African Americans, Latinos, Asian Americans, and Pacific islanders. *Am J Public Health*. (2014) 104:e16–31. doi: 10.2105/AJPH.2013.301706

23. Condon EM, Londono Tobon A, Mayes LC, Sadler LS. Acceptability and feasibility of hair and salivary biomarker collection among multiethnic school-age children. *Matern Child Health J*. (2020) 24:865–74. doi: 10.1007/s10995-020-02926-2

24. Ford JL, Boch SJ, McCarthy DO. Feasibility of Hair collection for cortisol measurement in population research on adolescent health. *Nurs Res*. (2016) 65:249–55. doi: 10.1097/NNR.0000000000000154

25. Padilla GA, Calvi JL, Taylor MK, Granger DA. Saliva collection, handling, transport, and storage: special considerations and best practices for interdisciplinary salivary bioscience research In: *Salivary Bioscience: Foundations of Interdisciplinary Saliva Research and Applications* (Springer) (2020). ed. D. Wild (Elsevier), 23–24.

26. Henson BS, Wong DT. Collection, storage, and processing of saliva samples for downstream molecular applications In: editors. *Oral biology: methods in molecular biology.* Eds. GJ Seymour, M Cullinan and N Heng. Totowa, NJ: Humana Press (2010). 21–30.

27. Bellagambi FG, Lomonaco T, Salvo P, Vivaldi F, Hangouët M, Ghimenti S, et al. Saliva sampling: methods and devices. An overview. *TrAC Trends Anal Chem*. (2020) 124:115781. doi: 10.1016/j.trac.2019.115781

28. Riis JL, Bryce CI, Matin MJ, Stebbins JL, Kornienko O, van Huisstede L, et al. The validity, stability, and utility of measuring uric acid in saliva. *Biomark. Med*. (2018) 12:583–96. doi: 10.2217/bmm-2017-0336

29. Navazesh M. Methods for collecting saliva. *Ann N Y Acad Sci*. (1993) 694:72–7. doi: 10.1111/j.1749-6632.1993.tb18343.x

30. Blume C, Garbazza C, Spitschan M. Effects of light on human circadian rhythms, sleep and mood. *Somnologie*. (2019) 23:147–56. doi: 10.1007/s11818-019-00215-x

31. Granger DA, Schwartz EB, Booth A, Curran M, Zakaria D. Assessing dehydroepiandrosterone in saliva: a simple radioimmunoassay for use in studies of children, adolescents and adults. *Psychoneuroendocrinology*. (1999) 24:567–79. doi: 10.1016/S0306-4530(99)00013-X

32. Hucklebridge F, Hussain T, Evans P, Clow A. The diurnal patterns of the adrenal steroids cortisol and dehydroepiandrosterone (DHEA) in relation to awakening. *Psychoneuroendocrinology*. (2005) 30:51–7. doi: 10.1016/j.psyneuen.2004.04.007

33. Matchock RL, Dorn LD, Susman EJ. Diurnal and seasonal cortisol, testosterone, and DHEA rhythms in boys and girls during puberty. *Chronobiol Int*. (2007) 24:969–90. doi: 10.1080/07420520701649471

34. Whetzel CA, Klein LC. Measuring DHEA-S in saliva: time of day differences and positive correlations between two different types of collection methods. *BMC Res Notes*. (2010) 3:1–5. doi: 10.1186/1756-0500-3-204

35. di Luigi L, Guidetti L, Baldari C, Gallotta MC, Sgrò P, Perroni F, et al. Cortisol, dehydroepiandrosterone sulphate and dehydroepiandrosterone sulphate/cortisol ratio responses to physical stress in males are influenced by pubertal development. *J Endocrinol Investig*. (2006) 29:796–804. doi: 10.1007/BF03347373

36. Lennartsson AK, Kushnir MM, Bergquist J, Jonsdottir IH. DHEA and DHEA-S response to acute psychosocial stress in healthy men and women. *Biol Psychol*. (2012) 90:143–9. doi: 10.1016/j.biopsycho.2012.03.003

37. Mastorakos G, Pavlatou M, Diamanti-Kandarakis E, Chrousos GP. Exercise and the stress system. *Hormones*. (2005) 4:73–89.

38. Herting MM, Uban KA, Gonzalez MR, Baker FC, Kan EC, Thompson WK, et al. Correspondence between perceived pubertal development and hormone levels in 9-10 year-olds from the adolescent brain cognitive development study. *Front Endocrinol*. (2021) 11:549928. doi: 10.3389/fendo.2020.549928

39. Schwartz EB, Granger DA, Susman EJ, Gunnar MR, Laird B. Assessing salivary cortisol in studies of child development. *Child Dev*. (1998) 69:1503–13. doi: 10.1111/j.1467-8624.1998.tb06173.x

40. Klein LC, Bennett JM, Whetzel CA, Granger DA, Ritter FE. Caffeine and stress alter salivary α-amylase activity in young men. *Hum Psychopharmacol*. (2010) 25:359–67. doi: 10.1002/hup.1126

41. de Jong WHA, Eisenhofer G, Post WJ, Muskiet FAJ, de Vries EGE, Kema IP. Dietary influences on plasma and urinary metanephrines: implications for diagnosis of catecholamine-producing tumors. *J Clin Endocr Metab*. (2009) 94:2841–9. doi: 10.1210/jc.2009-0303

42. Deutschbein T, Unger N, Jaeger A, Broecker-Preuss M, Mann K, Petersenn S. Influence of various confounding variables and storage conditions on metanephrine and normetanephrine levels in plasma. *Clin Endocrinol*. (2010) 73:153–60. doi: 10.1111/j.1365-2265.2009.03761.x

43. Robertson D, Frölich JC, Carr RK, Watson JT, Hollifield JW, Shand DG, et al. Effects of caffeine on plasma renin activity, catecholamines and blood pressure. *N Engl J Med*. (1978) 298:181–6. doi: 10.1056/NEJM197801262980403

44. Garavan H, Bartsch H, Conway K, Decastro A, Goldstein RZ, Heeringa S, et al. Recruiting the ABCD sample: design considerations and procedures. *Dev Cogn Neurosci*. (2018) 32:16–22. doi: 10.1016/j.dcn.2018.04.004

45. Adler N, Ostrove J. Socioeconomic status and health: what we know and what we don't. *Ann N Y Acad Sci*. (1999) 896:3–15. doi: 10.1111/j.1749-6632.1999.tb08101.x

46. Brito NH, Noble KG. Socioeconomic status and structural brain development. *Front Neurosci*. (2014) 8:276. doi: 10.3389/fnins.2014.00276

47. Chaudry A, Wimer C. Poverty is not just an Indicator: the relationship between income, poverty, and child well-being. *Acad Pediatr*. (2016) 16:S23–9. doi: 10.1016/j.acap.2015.12.010

48. Hair NL, Hanson JL, Wolfe BL, Pollak SD. Association of child poverty, brain development, and academic achievement. *JAMA Pediatr*. (2015) 169:822–9. doi: 10.1001/jamapediatrics.2015.1475

49. Hughes M, Tucker W. Poverty as an adverse childhood experience. *N C Med J*. (2018) 79:124–6. doi: 10.18043/ncm.79.2.124

50. Roos LL, Wall-Wieler E, Lee JB. Poverty and early childhood outcomes. *Pediatrics*. (2019) 143:e20183426. doi: 10.1542/peds.2018-3426

51. Chen E, Cohen S, Miller GE. How low socioeconomic status affects 2-year hormonal trajectories in children. *Psychol Sci*. (2010) 21:31–7. doi: 10.1177/0956797609355566

52. Lupien SJ, King S, Meaney MJ, McEwen BS. Can poverty get under your skin? Basal cortisol levels and cognitive function in children from low and high socioeconomic status. *Dev Psychopathol*. (2001) 13:653–76. doi: 10.1017/S0954579401003133

53. Krieger N, Williams DR, Moss NE. Measuring social class in us public health research: concepts, methodologies, and guidelines. *Annu Rev Public Health*. (1997) 18:341–78. doi: 10.1146/annurev.publhealth.18.1.341

54. Ford ES, Merritt RK, Heath GW, Powell KE, Washburn RA, Kriska A, et al. Physical activity behaviors in lower and higher socioeconomic status populations. *Am J Epidemiol*. (1991) 133:1246–56. doi: 10.1093/oxfordjournals.aje.a115836

55. Stalsberg R, Pedersen AV. Effects of socioeconomic status on the physical activity in adolescents: a systematic review of the evidence. *Scand J Med Sci Sports*. (2010) 20:368–83. doi: 10.1111/j.1600-0838.2009.01047.x

56. Branum AM, Rossen LM, Schoendorf KC. Trends in caffeine intake among US children and adolescents. *Pediatrics*. (2014) 133:386–93. doi: 10.1542/peds.2013-2877

57. Eicher-Miller HA, Boushey CJ, Bailey RL, Yang YJ. Frequently consumed foods and energy contributions among food secure and insecure U.S. children and adolescents. *Nutrients*. (2020) 12:304. doi: 10.3390/nu12020304

58. Uban KA, Horton MK, Jacobus J, Heyser C, Thompson WK, Tapert SF, et al. Biospecimens and the ABCD study: rationale, methods of collection, measurement and early data. *Dev Cogn Neurosci*. (2018) 32:97–106. doi: 10.1016/j.dcn.2018.03.005

59. Salimetrics LLC. *Salimetrics supports adolescent brain cognitive development (ABCD) study with salivary bioscience* Salimetrics (2016) Available at: https://www.prweb.com/releases/abcd_study/salivary_biomarkers/prweb13634957.htm.

60. Spilsbury JC, Storfer-Isser A, Drotar D, Rosen CL, Kirchner LH, Benham H, et al. Sleep behavior in an urban US sample of school-aged children. *Arch Pediatr Adolesc Med*. (2004) 158:988–94. doi: 10.1001/archpedi.158.10.988

61. Thorleifsdottir B, Björnsson JK, Benediktsdottir B, Gislason T, Kristbjarnarson H. Sleep and sleep habits from childhood to young adulthood over a 10-year period. *J Psychosom Res*. (2002) 53:529–37. doi: 10.1016/S0022-3999(02)00444-0

62. Centers for Disease Control and Prevention (CDC) (2003). Physical activity levels among children aged 9–13 years—United States, 2002. *MMWR* 52:785–88.

63. Craggs C, Corder K, van Sluijs EMF, Griffin SJ. Determinants of change in physical activity in children and adolescents: a systematic review. *Am J Prev Med*. (2011) 40:645–58. doi: 10.1016/j.amepre.2011.02.025

64. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA*. (2008) 300:295–305. doi: 10.1001/jama.300.3.295

65. Ellison RC, Singer MR, Moore LL, Nguyen U-SDT, Garrahie EJ, Marmor JK. Current caffeine intake of young children: amount and sources. *J Am Diet Assoc*. (1995) 95:802–4. doi: 10.1016/S0002-8223(95)00222-7

66. Morgan KJ, Stults VJ, Zabik ME. Amount and dietary sources of caffeine and saccharin intake by individuals ages 5 to 18 years. *Regul Toxicol Pharmacol*. (1982) 2:296–307. doi: 10.1016/0273-2300(82)90003-4

67. Shaefer H. L., Edin K. (2012). Extreme poverty in the United States, 1996 to 2011. Available at: https://npc.umich.edu/publications/policy_briefs/brief28/policybrief28.pdf.

68. Davis RP, Williams WR. Bringing psychologists to the fight against deep poverty. *Am Psychol*. (2020) 75:655–67. doi: 10.1037/amp0000650

69. Ekono M, Jiang Y, Smith S. Young children in deep poverty. New York, NY: National Center for Children in Poverty (NCCP) (2016) Available at: https://www.nccp.org/publication/young-children-in-deep-poverty/

70. Nguyen US, Smith S, Granja MR, Street B. Young children in deep poverty: racial/ethnic disparities and child well-being compared to other income groups. New York, NY: National Center for Children in Poverty (NCCP) (2020) Available at: https://www.nccp.org/publication/young-children-in-deep-poverty-racial-ethnic-disparities-and-child-well-being-compared-to-other-income-groups/

71. Goodman E. The role of socioeconomic status gradients in explaining differences in US adolescents' health. *Am J Public Health*. (1999) 89:1522–8. doi: 10.2105/AJPH.89.10.1522

72. Braveman P, Cubbin C, Marchi K, Egerter S, Chavez G. Measuring socioeconomic status/position of in studies racial/ethnic disparities: maternal and infant health. *Public Health Rep*. (2001) 116:449–63.doi: 10.1093/phr/116.5.449

73. Brooks H. (2021). Exploring a nonbinary approach to health. NICHQ - National Institute for Children's Health Quality. Available at: https://www.nichq.org/insight/exploring-nonbinary-approach-health (Accessed April 13, 2023).

74. Kind AJH, Jencks S, Brock J, Yu M, Bartels C, Ehlenbach W, et al. Neighborhood socioeconomic disadvantage and 30-day rehospitalization: a retrospective cohort study. *Ann Intern Med*. (2014) 161:765–74. doi: 10.7326/M13-2946

75. Singh GK. Area deprivation and widening inequalities in US mortality, 1969-1998. *Am J Public Health*. (2003) 93:1137–43. doi: 10.2105/ajph.93.7.1137

76. Hooper A, Hustedt JT, Slicker G, Hallam RA, Gaviria-Loaiza J, Vu JA, et al. Area deprivation index as a predictor of economic risk and social and neighborhood perceptions among families enrolled in early head start. *Child Youth Serv Rev*. (2022) 137:106468. doi: 10.1016/j.childyouth.2022.106468

77. Oates G, Rutland S, Juarez L, Friedman A, Schechter MS. The association of area deprivation and state child health with respiratory outcomes of pediatric patients with cystic fibrosis in the United States. *Pediatr Pulmonol*. (2021) 56:883–90. doi: 10.1002/ppul.25192

78. Wall LB, Wright M, Samora J, Bae DS, Steinman S, Goldfarb CA. Social deprivation and congenital upper extremity differences—an assessment using PROMIS. *J Hand Surg Am*. (2021) 46:114–8. doi: 10.1016/j.jhsa.2020.08.017

79. Adise S, Marshall AT, Kan E, Gonzalez MR, Sowell ER. Relating neighborhood deprivation to childhood obesity in the ABCD study: evidence for theories of neuroinflammation and neuronal stress. *Health Psychol Adv*. (2022). Advance online publication. doi: 10.1037/hea0001250

80. Dennis E, Manza P, Volkow ND. Socioeconomic status, BMI, and brain development in children. *Transl Psychiatry*. (2022) 12:33–10. doi: 10.1038/s41398-022-01779-3

81. Mullins TS, Campbell EM, Hogeveen J. Neighborhood deprivation shapes motivational-neurocircuit recruitment in children. *Psychol Sci*. (2020) 31:881–9. doi: 10.1177/0956797620929299

82. Barch DM, Albaugh MD, Avenevoli S, Chang L, Clark DB, Glantz MD, et al. Demographic, physical and mental health assessments in the adolescent brain and cognitive development study: rationale and description. *Dev Cogn Neurosci*. (2018) 32:55–66. doi: 10.1016/j.dcn.2017.10.010

83. Pinheiro J., Bates D., Deb Roy S., Sarkar D.R Core Team (2022). nlme: linear and nonlinear mixed effects models. R package version 3.1-162. Available at: https://CRAN.R-project.org/package=nlme.

84. Fox J, Weisberg S. *An R companion to applied regression*. *3rd* ed. Thousand Oaks, CA: SAGE Publications Inc. (2019).

85. Lefcheck JS. Piecewise SEM: piecewise structural equation modeling in R for ecology, evolution, and systematics. *Methods Ecol Evol*. (2016) 7:573–9. doi: 10.1111/2041-210X.12512

86. Grolemund G, Wickham H. Dates and times made easy with lubridate. *J Stat Softw*. (2011) 40:1–25. doi: 10.18637/jss.v040.i03

87. Harrell F. E. Jr. (2020). *Hmisc: harrell miscellaneous*. Available at: https://CRAN.R-project.org/package=Hmisc.

88. Liberatos P, Link BG, Kelsey JL. The measurement of social class in epidemiology. *Epidemiol Rev*. (1988) 10:87–121. doi: 10.1093/oxfordjournals.epirev.a036030

89. Krieger N, Fee E. Social class: the missing link in U.S. health data. *Int J Health Serv*. (1994) 24:25–44. doi: 10.2190/2JG7-YMD5-WCP2-XXNT

90. Cerin E, Leslie E. How socio-economic status contributes to participation in leisure-time physical activity. *Soc Sci Med*. (2008) 66:2596–609. doi: 10.1016/j.socscimed.2008.02.012

91. Fu M, Exeter DJ, Anderson A. So, is that your 'relative' or mine? A political-ecological critique of census-based area deprivation indices. *Soc Sci Med*. (2015) 142:27–36. doi: 10.1016/j.socscimed.2015.07.036

92. Trinidad S, Brokamp C, Mor Huertas A, Beck AF, Riley CL, Rasnick E, et al. Use of area-based socioeconomic deprivation indices: a scoping review and qualitative analysis. *Health Aff*. (2022) 41:1804–11. doi: 10.1377/hlthaff.2022.00482

93. Pellecchia M, Nuske HJ, Straiton D, McGhee Hassrick E, Gulsrud A, Iadarola S, et al. Strategies to engage underrepresented parents in child intervention services: a review of effectiveness and co-occurring use. *J Child Fam Stud*. (2018) 27:3141–54. doi: 10.1007/S10826-018-1144-Y/TABLES/6

94. Choe JK, Khan-Dawood FS, Dawood MY. Progesterone and estradiol in the saliva and plasma during the menstrual cycle. *Am J Obstet Gynecol*. (1983) 147:557–62. doi: 10.1016/0002-9378(83)90016-9

95. Ellison PT, Lipson SF. Salivary estradiol--a viable alternative? *Fertil Steril*. (1999) 72:951–2. doi: 10.1016/s0015-0282(99)00344-1

96. Rilling JK, Worthman CM, Campbell BC, Stallings JF, Mbizva M. Ratios of plasma and salivary testosterone throughout puberty: production versus bioavailability. *Steroids*. (1996) 61:374–8. doi: 10.1016/0039-128x(96)00043-8

97. Shirtcliff EA, Granger DA, Schwartz EB, Curran MJ, Booth A, Overman WH. Assessing estradiol in biobehavioral studies using saliva and blood spots: simple radioimmunoassay protocols, reliability, and comparative validity. *Horm Behav*. (2000) 38:137–47. doi: 10.1006/hbeh.2000.1614

98. Vining RF, McGinley RA, Symons RG. Hormones in saliva: mode of entry and consequent implications for clinical interpretation. *Clin Chem*. (1983) 29:1752–6. doi: 10.1093/clinchem/29.10.1752

99. Diamond LM. Gender fluidity and nonbinary gender identities among children and adolescents. *Child Dev Perspect*. (2020) 14:110–5. doi: 10.1111/cdep.12366

100. Shavers VL. Measurement of socioeconomic status in health disparities research. *J Natl Med Assoc*. (2007) 99:1013–23. doi: 10.13016/avw3-9cvx

101. Schwartz S. The fallacy of the ecological fallacy: the potential misuse of a concept and the consequences. *Am J Public Health*. (1994) 84:819–24. doi: 10.2105/AJPH.84.5.819

102. Braveman P, Dominguez TP. Abandon "race." Focus on racism. *Front Public Health*. (2021) 9:689462. doi: 10.3389/fpubh.2021.689462

103. White K, Lawrence JA, Tchangalova N, Huang SJ, Cummings JL. Socially-assigned race and health: a scoping review with global implications for population health equity. *Int J Equity Health*. (2020) 19:25. doi: 10.1186/s12939-020-1137-5

104. Williams DR, Lawrence JA, Davis BA. Racism and health: evidence and needed research. *Annu Rev Public Health*. (2019) 40:105–25. doi: 10.1146/annurev-publhealth-040218-043750

105. Gee GC, Ford CL. Structural racism and health inequities: old issues, New Directions. *Du Bois Rev*. (2011) 8:115–32. doi: 10.1017/S1742058X11000130

106. Heard-Garris N, Boyd R, Kan K, Perez-Cardona L, Heard NJ, Johnson TJ. Structuring poverty: how racism shapes child poverty and child and adolescent health. *Acad Pediatr*. (2021) 21:S108–16. doi: 10.1016/j.acap.2021.05.026

107. Trent M, Dooley DG, Dougé JSection On Adolescent Health, Council on Community Pediatrics, & Committee on Adolescence. The impact of racism on child and adolescent health. *Pediatrics*. (2019) 144:e20191765. doi: 10.1542/peds.2019-1765

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Contextualizing the impact of prenatal alcohol and tobacco exposure on neurodevelopment in a South African birth cohort: an analysis from the socioecological perspective

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Background: Alcohol and tobacco are known teratogens. Historically, more severe prenatal alcohol exposure (PAE) and prenatal tobacco exposure (PTE) have been examined as the principal predictor of neurodevelopmental alterations, with little incorporation of lower doses or ecological contextual factors that can also impact neurodevelopment, such as socioeconomic resources (SER) or adverse childhood experiences (ACEs). Here, a novel analytical approach informed by a socio-ecological perspective was used to examine the associations between SER, PAE and/or PTE, and ACEs, and their effects on neurodevelopment.

Methods: $N = 313$ mother-child dyads were recruited from a prospective birth cohort with maternal report of PAE and PTE, and cross-sectional structural brain neuroimaging of child acquired via 3T scanner at ages 8–11 years. *In utero* SER was measured by maternal education, household income, and home utility availability. The child's ACEs were measured by self-report assisted by the researcher. PAE was grouped into early exposure (<12 weeks), continued exposure (> =12 weeks), and no exposure controls. PTE was grouped into exposed and non-exposed controls.

Results: Greater access to SER during pregnancy was associated with fewer ACEs (maternal education: $\beta = -0.293$, $p = 0.01$; phone access: $\beta = -0.968$, $p = 0.05$). PTE partially mediated the association between SER

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and ACEs, where greater SER reduced the likelihood of PTE, which was positively associated with ACEs (β = 1.110, p = 0.01). SER was associated with alterations in superior frontal (β = −1336.036, q = 0.046), lateral orbitofrontal (β = −513.865, q = 0.046), caudal anterior cingulate volumes (β = −222.982, q = 0.046), with access to phone negatively associated with all three brain volumes. Access to water was positively associated with superior frontal volume (β = 1569.527, q = 0.013). PTE was associated with smaller volumes of lateral orbitofrontal (β = −331.000, q = 0.033) and nucleus accumbens regions (β = −34.800, q = 0.033).

Conclusion: Research on neurodevelopment following community-levels of PAE and PTE should more regularly consider the ecological context to accelerate understanding of teratogenic outcomes. Further research is needed to replicate this novel conceptual approach with varying PAE and PTE patterns, to disentangle the interplay between dose, community-level and individual-level risk factors on neurodevelopment.

KEYWORDS

socioeconomic resources, prenatal substance exposure, neurodevelopment, adverse childhood experiences, prenatal alcohol exposure, prenatal tobacco exposure

1. Introduction

Alcohol and tobacco are established teratogens, as proven in animal models, and consistent with findings in human pediatric samples. Numerous studies have shown that prenatal alcohol exposure (PAE) can lead to alterations in children's physical, cognitive, mental, behavioral and neural development (Glass et al., 2014; Mattson et al., 2019). Since the original recognition of alcohol as a teratogen in humans (Jones and Smith, 1973), the subsequent 50 years of original brain research on FASD has consistently demonstrated structural brain alterations (Riley et al., 1995; Mattson et al., 1996; Archibald et al., 2001; Sowell et al., 2001, 2002, 2008). PAE poses cumulative harm to global health and results in significant economic burdens. PAE can increase demands on health care, special education, justice system, morbidity and mortality, and loss in productivity for both the affected children and their caregivers (Greenmyer et al., 2018; World Health Organization [WHO], 2021). Fetal Alcohol Spectrum Disorders (FASD) refer to a range of diagnoses following PAE. Recent estimates of the collective prevalence of FASD suggest even higher rates than historically reported at 3.1–9.9% in the United States (May et al., 2018). A population-based study conducted in South Africa found a prevalence of Fetal Alcohol Syndrome (FAS), one of 4 diagnoses under the FASD umbrella term, to be between 5.9–9.1%, and a collective FASD prevalence between 13.5–20.7% (May et al., 2013).

Prenatal tobacco exposure (PTE) is a common co-occurring exposure with PAE (Cornelius and Day, 2009), and has been associated with alterations in speech processing, attention, internalizing and externalizing behavior, and brain development (Cornelius and Day, 2009; El Marroun et al., 2014). Despite our understanding of the teratogenic effect of these substances, PAE in conjunction with PTE continue to occur in substance-using societies and pose significant public health challenges.

Existing literature has attributed brain alterations primarily to the teratogenic effect of PAE, with limited consistent examination of other key and often upstream factors that may also shape brain structural development. Likelihood of prenatal substance exposure is closely associated with availability of socioeconomic resources at individual and neighborhood levels (Karriker-Jaffe, 2013; Coleman-Cowger et al., 2017). In general, socioeconomic resources, PAE and PTE are associated with hardships in prenatal and postnatal experiences, which can also alter a child's developmental trajectory (Gibson et al., 2009; Lange et al., 2013; Baglivio et al., 2017; Breen et al., 2018; Kambeitz et al., 2019; Luby et al., 2019). Limited recent research provides initial evidence that PAE may interact with low socioeconomic resources (Coles et al., 2019; Uban et al., 2020) to impact child developmental outcomes. With such limited knowledge, more understanding of upstream factors that contribute to teratogenic outcomes on childhood-adolescent brain outcomes is needed.

Existing literature demonstrates that lack of socioeconomic resources is a childhood adversity on its own that leads to disadvantages in executive functioning, memory, and language development (Noble et al., 2006, 2012; Noble and Farah, 2013), and is reflected in development of brain structure (Gonzalez et al., 2020). The Adverse Childhood Experiences (ACEs) framework incorporates factors such as emotional and physical abuse, domestic violence toward the mother, household substance use and mental illness, and household member with a history of incarceration. Although conceptually limited access to socioeconomic resources may be an ACE in and of itself, socioeconomic resources and ACEs have distinct differences. ACEs have been shown to be associated with greater risk for health challenges in children, including risk for mental health challenges, development of chronic medical conditions, and regional brain development alterations (Teicher et al., 2012, 2016; Kerker et al., 2015; Luby et al., 2019; Mall et al., 2020; Sevenoaks et al., 2022).

Less is known about how poverty may increase the likelihood of other ACEs (Melchior et al., 2007; Finkelhor et al., 2013). The conceptual model developed by Culhane and Elo (2005)

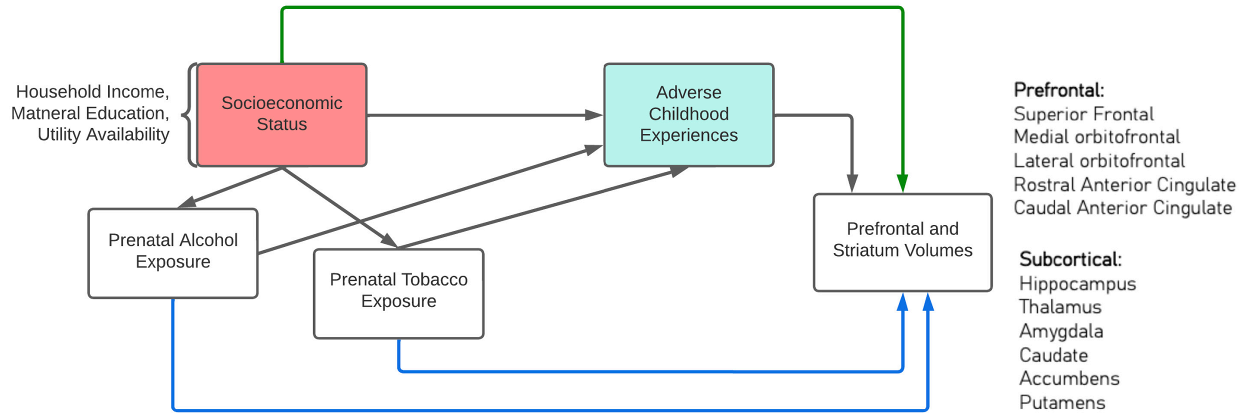

FIGURE 1
Conceptual model.

hypothesized that socioeconomic resources can influence either positive or negative individual health behaviors (including substance use during pregnancy), through the availability of social services, exposure to stress, and social norms. These individual health behaviors may partially explain the association between socioeconomic resources, childhood subsequent ACEs, and child neurodevelopmental outcomes. In other words, low socioeconomic resources, presence of PAE and PTE and more ACEs may tend to cluster together, while each has its own impact on child neurodevelopment.

Some support for the importance of considering socioeconomic resources and ACEs in PAE exists within samples including biological birthing parents. It is established in perinatal literature that socioeconomic resources are associated with PAE, partly via differential patterns and profiles of co-exposures. Lower maternal income is associated with a higher odds ratio of prenatal exposure to marijuana and tobacco (Coleman-Cowger et al., 2017). Women with residence in disadvantaged neighborhoods were more likely to experience substance exposed pregnancies to tobacco and other drugs in comparison to women living in middle-class neighborhoods (Karriker-Jaffe, 2013). Social capital of the country in which women resided was significantly associated with PTE (Shoff and Yang, 2013). Levels of neighborhood assistance accounted for significant variances of type of PAE and PTE after controlling for individual-level characteristics such as race, age, public assistance, and prenatal care (Finch et al., 2001). The potential bidirectionality between upstream socioeconomic resources factors of prevalence of PAE/PTE is not understood well.

In addition to systemic factors, prenatal substance exposure status may serve as indicators of other adverse circumstances within the home environment that shape children's living experiences. For instance, alcohol use for women has been associated with higher risk for experiencing intimate partner violence, which may be associated with an unstable household environment for the children (O'Connor et al., 2006). Literature shows that maternal ACEs is associated with increased risk of PTE as well as adverse experiences of offspring, such as intimate partner violence and child maltreatment (Pear et al., 2017; Buffarini et al., 2022). It is possible that maternal cumulative exposure to adversity, including ACEs and poverty, increases the risk of prenatal tobacco exposure, which links to a subsequent elevated ACEs in children.

Expanding upon current understanding of how socioeconomic resources and ACEs contribute to PAE- and PTE-related structural brain alterations, we applied a novel conceptual model in the present analyses to examine PAE and PTE as mediators of socioeconomic resources and postnatal ACEs, and to examine the effects of socioeconomic resources, PAE/PTE, and ACEs on brain outcomes. Rather than framing prenatal substance exposure as primary predictors of brain alterations, this intentional reframing of prenatal substance exposure as a mediator is warranted, given the commonly co-occurring of between prenatal substance, socioeconomic resources (Bingol et al., 1987; McLachlan et al., 2020) and ACEs (Kambeitz et al., 2019; Andre et al., 2020): all factors known to individually impact brain development (Rivkin et al., 2008; Dannlowski et al., 2012; Noble et al., 2012; Luby et al., 2013; Bick and Nelson, 2016).

For the first aim, we hypothesized that fewer socioeconomic resources would be associated with more ACEs, and presence or absence of PAE or PTE would partially mediate this relationship (**Figure 1**). The second aim examined whether socioeconomic resources-related resources, PAE or PTE, or ACEs altered cortical brain structural development among children and adolescents (**Figure 1**). We hypothesized that lower socioeconomic resources, the presence of PAE or PTE, and higher ACEs would be associated with smaller cortical volumes.

2. Materials and methods

2.1. Study design and participant recruitment

The current study involved a subsample of the existing birth cohort of the Prenatal Alcohol in Sudden Infant Death Syndrome (SIDs) and Stillbirth (PASS) Network recruited from Cape Town, South Africa (Dukes et al., 2014). For the original PASS cohort, pregnant women were recruited during their routine antenatal care at the Belhar antenatal clinic and Bishop Lavis Midwife Obstetric Unit between August 2007 and January 2015. Enrollment of pregnant women started between the 6th week of gestation and delivery day. Pregnant women within this cohort originated from Bishop Lavis and Belhar communities: both low-income urban suburbs that developed as a direct result of apartheid in of Cape Town, South Africa. Historically, both communities have experienced high rates of prenatal alcohol exposure, SIDS and socioeconomic inequalities (May et al., 2000). A detailed report on the recruitment methodology of the original PASS study has been published elsewhere (Dukes et al., 2014).

For the study reported here, birth parent/legal guardian and their child were recruited from the PASS birth cohort among those with surviving children 8–12 years later. This age range was selected for the dynamic pubertal maturation that occurs during the transition from childhood to early adolescence. This period was hypothesized to be more opportunistic for observing lasting brain alternations following prenatal conditions. Further, the neuroimaging protocols were adapted from the Adolescent Brain and Cognitive Development Study, designed for collecting MRI data at this age range. Female birth parents and their children were approached for neuroimaging and other neuropsychological measures in the townships around Cape Town, South Africa. This current analysis includes a sample of 313 birth parent/legal guardian–child participant dyads. The demographics of the study sample is presented in **Table 1**.

Inclusion criteria for the birth parents were (1) at least 16 years of age and (2) spoke either English or Afrikaans. Children were between 8 and 11 years of age at the acquisition of the MRI brain scan. Exclusion criteria were (1) history of traumatic brain injury, (2) presence of major medical or central nervous system disorders, and (3) MRI contraindications, such as orthodontic braces and ferromagnetic metal implants.

2.2. Measurements

2.2.1. Structural magnetic resonance imaging data acquisition

A 3-Tesla Siemens Skyra scanner at the Cape Universities Imaging Center (CUBIC) was used to acquire whole-brain T1-weighted images for all participants. The total acquisition time was around 45 min, and only data from the structural scan was analyzed for the current study. The image was acquired through a multi-echo T_{1w} MPRAGE sequence, with acquisition parameters as following: 1 × 1 × 1 mm voxel size, 176 slices, slice thickness 1.00 mm, FOV 256 × 256, TR = 2,530 ms, TE = (1.61; 3.44, 5.27; 7.1 ms), TI = 1,240 ms, flip angle = 7 degrees.

2.2.2. Image processing

FreeSurfer'S v5.3 recon-all pipeline was utilized as metrics for volumetric segmentation. Briefly, the FreeSurfer pipeline includes motion correction (Reuter et al., 2010), non-uniform intensity normalization (Sled et al., 1998), skull-strip (Ségonne et al., 2004), Talairach transformation and volumetric labeling of cortical and subcortical regions (Fischl et al., 2002; Fischl, 2004), tessellation of gray/white matter boundaries for topology correction and cortical surface construction (Fischl et al., 2002; Fischl, 2004), parcellation of white and gray matter and derivation of cortical and subcortical matrices. A detailed description of all steps can be found elsewhere: https://surfer.nmr.mgh.harvard.edu/fswiki/FreeSurferMethodsCitation. The structural MRI sequence was adapted from the US-based ABCD Study © that was designed to optimize pediatric neuroimaging for similar age ranges (9.0–10.99 years old): covering both late childhood and early adolescence matching the age range and pubertal maturation of participants in the present study.

2.2.3. ROIs

The overlapping cortical and subcortical regions that have been historically shown to be impacted by PAE and PTE, socioeconomic resources, and ACEs were selected as Regions of interests (ROIs) (Cortical: superior frontal, medial and lateral orbitofrontal, rostral, and caudal anterior cingulate regions; Subcortical: hippocampus, thalamus, amygdala, caudate, nucleus accumbens, and putamen). Volumes of ROIs were analyzed bilaterally across left and right hemispheres.

2.2.4. Socioeconomic resources measures

Socioeconomic resources measures included monthly household income in South African rand (ZAR), the number of school grades completed by the birth parent, dichotomous (yes/no) utility variables that recorded the availability of electricity, phone (landline and/or mobile phone), flushing toilet, and running water in the household (Myer et al., 2008). Socioeconomic resources measures were included individually in the analysis (e.g., household income, utility availability, and maternal education).

2.2.5. Prenatal substance exposure measures

The PASS study collected prospective information on PAE and PTE using a modified Timeline Follow-Back (TLFB) during pregnancy. The TLFB measure was modified to be administered in the participant's language of choice (Afrikaans in the current analytical sample), and prompts to the researchers were inserted to facilitate precision of administration among participants and across repeated time points within participants during pregnancy (Dukes et al., 2014).

Data on PAE and PTE was collected up to three times during pregnancy (20–24, 28–32, and 34+ gestational weeks) and 1 month post-delivery using the TLFB. Detailed information to accurately measure the total grams of alcohol consumed on a drinking day were collected. Standard drinks were calculated based on the type of alcohol consumed, whether the drinks contained ice, if drinks were shared amongst others, and the volume potentially consumed as measured by the size of container.

Timing data for PAE was grouped into three PAE categories: (1) early PAE, (2) extended PAE, and (3) no PAE. The no PAE group included children whose birth mothers reported consuming no alcohol in all three trimesters. The early PAE group included children whose mother reported having one or more drinks during the first trimester ($<$12 weeks into pregnancy) but not in the second or the third trimesters, while the extended PAE group included children whose mother reported consuming one or more drinks in two or all trimesters of their pregnancy. Available PTE data was grouped dichotomously into (1) PTE at any time *in utero* or (2) no PTE exposure throughout *in utero* development.

2.2.6. ACEs measure

Because no prior ACE questionnaires existed that were validated for youth in the Cape Town Flats, validated ACEs

TABLE 1 Demographic information.

	NoAlc (N = 98)	EarlyAlc (N = 58)	ContinuedAlc (N = 113)	Total (N = 269)	p-value
PTE					<0.001
NoTob	55 (56.1%)	23 (39.7%)	32 (28.3%)	110 (40.9%)	
Tob	43 (43.9%)	35 (60.3%)	81 (71.7%)	159 (59.1%)	
Sex					0.403
Male	53 (54.1%)	27 (46.6%)	51 (45.1%)	131 (48.7%)	
Female	45 (45.9%)	31 (53.4%)	62 (54.9%)	138 (51.3%)	
Age in years					0.988
Mean (SD)	9.92 (1.27)	9.90 (1.33)	9.93 (1.28)	9.92 (1.28)	
Range	8.00–12.00	8.00–12.00	8.00–12.00	8.00–12.00	
Electricity					0.231
No	0 (0.0%)	0 (0.0%)	2 (2.0%)	2 (0.8%)	
Yes	95 (100.0%)	49 (100.0%)	97 (98.0%)	241 (99.2%)	
Phone					0.022
No	7 (7.4%)	9 (18.4%)	21 (21.2%)	37 (15.2%)	
Yes	88 (92.6%)	40 (81.6%)	78 (78.8%)	206 (84.8%)	
Water					0.612
No	17 (17.9%)	9 (18.4%)	23 (23.2%)	49 (20.2%)	
Yes	78 (82.1%)	40 (81.6%)	76 (76.8%)	194 (79.8%)	
Toilet					0.387
No	31 (32.6%)	21 (42.9%)	40 (40.4%)	92 (37.9%)	
Yes	64 (67.4%)	28 (57.1%)	59 (59.6%)	151 (62.1%)	
Maternal education					0.077
Mean (SD)	10.03 (1.76)	10.38 (1.46)	9.73 (1.69)	9.98 (1.68)	
Range	5.00–13.00	7.00–13.00	4.00–13.00	4.00–13.00	
Household income in South African Rand (ZAR)					0.023
Mean (SD)	932.98 (590.83)	856.47 (617.28)	689.77 (443.20)	817.12 (547.94)	
Range	142.86–3000.00	100.00–3000.00	50.00–1666.67	50.00–3000.00	
ACE total score					0.003
Mean (SD)	3.39 (2.14)	3.36 (2.61)	4.37 (2.30)	3.80 (2.36)	
Range	0.00–10.00	0.00–12.00	0.00–10.00	0.00–12.00	
Parent-reported pubertal development					0.705
Pre	54 (71.1%)	27 (61.4%)	62 (68.1%)	143 (67.8%)	
Early	14 (18.4%)	9 (20.5%)	18 (19.8%)	41 (19.4%)	
Mid	7 (9.2%)	5 (11.4%)	9 (9.9%)	21 (10.0%)	
Late	1 (1.3%)	3 (6.8%)	2 (2.2%)	6 (2.8%)	
Child-reported pubertal development					0.352
Pre	60 (69.8%)	26 (59.1%)	63 (65.6%)	149 (65.9%)	
Early	18 (20.9%)	9 (20.5%)	20 (20.8%)	47 (20.8%)	
Mid	4 (4.7%)	8 (18.2%)	9 (9.4%)	21 (9.3%)	
Late	4 (4.7%)	1 (2.3%)	4 (4.2%)	9 (4.0%)	
Birth weight					0.446
Mean (SD)	3031.11 (500.18)	2955.40 (413.57)	2948.57 (495.20)	2981.97 (481.42)	
Range	1120.00–4905.00	2000.00–3940.00	1400.00–4200.00	1120.00–4905.00	

(Continued)

TABLE 1 (Continued)

	NoAlc (N = 98)	EarlyAlc (N = 58)	ContinuedAlc (N = 113)	Total (N = 269)	p-value
Prenatal Meth					0.041
Yes	96 (97.0%)	47 (87.0%)	94 (94.9%)	237 (94.0%)	
No	3 (3.0%)	7 (13.0%)	5 (5.1%)	15 (6.0%)	
Prenatal marijuana					0.256
Yes	94 (94.9%)	48 (88.9%)	89 (89.0%)	231 (91.3%)	
No	5 (5.1%)	6 (11.1%)	11 (11.0%)	22 (8.7%)	

Classification of pubertal development follows Cheng et al. (2021).

items from existing literature were compiled across several questionnaires. Individual ACE items were selected in close consultation with research staff in Cape Town to determine which items were: (1) relevant to the lived experiences of the youth participants in their culture; (2) did not require mandatory reporting if endorsed to avoid harming rapport between researchers and the community members within the Cape Town Flats; and (3) retained original meaning after being translated and back-translated into Afrikaans, as determined by the US and South African researchers.

The final ACE questionnaire consisted of 14 dichotomous questions (**Supplementary Table 1**). The children were asked questions which related to whether they had witnessed sexual abuse, or had experienced emotional and physical, neglect and parental separation, substance use, incarceration and mental illness within the household, homelessness or violence, and loss of a loved one. Child participants completed the questionnaire with the research assistant in their preferred language of either English or Afrikaans. A summary score was calculated by counting the total number of questions that the child endorsed.

2.3. Statistical analysis

CRAN R v.4.1 was used to perform statistical analyses (Bates et al., 2015; Kuznetsova et al., 2017; R Development Core Team, 2019; Wickham et al., 2019, 2022; Heinzen et al., 2021).

2.3.1. Mediation analysis

To test whether PAE or PTE were mediators between socioeconomic resources and ACEs, we applied the Baron and Kenny criteria for mediation analysis (Baron and Kenny, 1986). The analytic flow is shown in **Figure 1**. For the first step, we examined the association between socioeconomic resources variables and ACE total score. A generalized linear model (GLM) was fitted with ACE total score as the outcome variable and household income, maternal education, phone, water, and electricity availability as the explanatory variable with a link function for the Gaussian distribution. For the second step, we tested the association between the explanatory variable and the mediator. A GLM was fitted with the same socioeconomic resources variables as the explanatory variables, and PAE or PTE as the outcome variable, with a link function for the binomial distribution. If PAE or PTE was significantly associated with socioeconomic resources variables, it was then included in the last step of the analysis. For the third and last step of the mediation analysis, we examined the direct effect between socioeconomic resources and ACE total score by adjusting for the potential mediator. The condition for a partial mediation was met if (1) the main outcome variable, ACE total score, and the mediator, PAE or PTE, were significantly associated with socioeconomic resources variables; (2) the mediator was significant in the third step analysis; (3) the absolute values of the estimate of the explanatory variables were reduced when the mediator was included.

2.3.2. sMRI analysis

To examine whether PAE/PTE, socioeconomic resources, or ACE were associated with brain volume alterations in the prefrontal and striatum areas, we applied a linear mixed-effects model using the lme4 package in R (Bates et al., 2015; Kuznetsova et al., 2017). Because PAE/PTE, socioeconomic resources and ACE were significantly associated with each other, we examined the effect of PAE/PTE, socioeconomic resources, and ACE on the ROI volumes separately. Hemisphere was included as a within-subject variable. Our models were constructed as follows: first, we constructed a reduced model with only the primary relationship; then, we built up from the reduced model by adjusting for covariates, including child age and sex. In the case of PAE and PTE, we constructed a third model with an interaction term between PTE and PAE and the covariates. We used AIC comparison and log likelihood ratio test to determine whether including the covariates provided a better fit to the model and whether an interaction was appropriate. Lastly, a false discovery rate (FDR) correction was applied to all individual explanatory variables across the 11 ROIs. The results were considered significant if the q-value, the FDR analog of the p-value, was less than 0.05.

2.4. Ethics

The data collection was approved by the Human Research Ethics Committee of the Faculty of Health Sciences of University of Cape Town (HREC UCT REF 248/2014). The Human Research Ethics Committee of the Faculty of Health Sciences of Stellenbosch University gave their ethical approval (REF 248/2014). The Institutional Review Board (IRB) at Children's Hospital in Los Angeles approved the processing of de-identified neuroimaging

TABLE 2 Coefficients and 95% confidence intervals of mediation models.

	ACE total score		PTE	PAE
	1	2	3	4
Monthly household income	−0.001	−0.0004	−0.001**	−0.001
	(−0.001, 0.00001)	(−0.001, 0.0002)	(−0.002, −0.0003)	(−0.001, 0.00003)
Maternal education	−0.293**	−0.235*	−0.248*	0.085
	(−0.492, −0.093)	(−0.434, −0.037)	(−0.449, −0.047)	(−0.100, 0.270)
Phone access	−0.968*	−0.852	−0.523	−1.213*
	(−1.913, −0.023)	(−1.778, 0.074)	(−1.487, 0.441)	(−2.270, −0.156)
Water access	0.174	0.304	−0.581	−0.062
	(−0.797, 1.144)	(−0.648, 1.255)	(−1.539, 0.377)	(−0.995, 0.870)
Toilet access	−0.218	−0.274	0.271	−0.39
	(−1.051, 0.615)	(−1.089, 0.540)	(−0.533, 1.075)	(−1.175, 0.396)
Prenatal tobacco exposure		1.108**		
		(0.403, 1.814)		
Akaike inf. crit.	826.371	818.773	234.663	242.572

$^{*}p < 0.05$, $^{**}p < 0.01$.

data (CHLA-19-00228). The IRB at University of California, Irvine approved the analysis of de-identified data (UCI #212354).

3. Results

Detailed demographic information is presented in Table 1. Of the 313 enrollees, 229 participants (mean age: 9.91 years; 131 (48.7%) male) had available PAE and PTE data. Among them, 50 had early PAE (exposure during the 1st trimester), 100 had extended PAE, and 95 had no PAE. A 110 had no PTE and 159 had PTE. Fifty-five had only PAE, 43 had only PTE, and 116 had both PAE (early or extended) and PTE. On average, the total number of ACEs endorsed was 3.8. The average maternal education was 9.98 years, while the mean monthly household income was 817.12 ZAR (equivalent to $45.55 US dollars). Age, sex, parent-reported and child-reported pubertal development scale did not differ by PAE status ($p > 0.05$). Birth weight also did not differ by PTE and PAE ($p > 0.05$).

3.1. Mediation analysis

In the first-step mediation analysis, we examined the primary relationship between specific socioeconomic resources-related resources and total ACE scores. Lower maternal education ($\beta = -0.293$, $p = 0.01$) and no phone access ($\beta = -0.968$, $p = 0.05$) were both associated with higher ACE total scores. For the second-step analysis, socioeconomic resources was regressed against the two potential mediators, PAE and PTE. Lower household income ($\beta = -0.001$, $p = 0.01$) and lower maternal education ($\beta = -0.248$, $p = 0.05$) were associated with PTE, while no phone access only ($\beta = -1.210$, $p = 0.05$) was associated with PAE (i.e., early PAE, extended PAE, no PAE). In the third step of mediation analysis, PTE (i.e., yes PTE, no PTE) and PAE were included, respectively in the primary association models to test the direct association between socioeconomic resources and ACE after adjusting for the mediators. PAE was not a significant explanatory variable when the model included socioeconomic resources variables, and therefore PAE did not fulfill the criteria as a mediator. PTE remained significant when added to the socioeconomic resources-ACE model $(\beta = 1.110,\ p = 0.01)$, where the presence of PTE was associated with higher ACE total scores. Moreover, the absolute value of the effect estimates of household income and maternal education were reduced after PTE was included in the model (Table 2). Therefore, PTE fulfilled the criteria as a partial mediator between socioeconomic resources and ACE, while PAE did not fulfill the criteria as a partial mediator.

3.2. sMRI analysis

All models were adjusted for age (months) and biological sex (at birth), as the covariates significantly improved model fit as evident in log likelihood ratio tests ($p < 0.05$). The PAE and PTE models did not include the interaction term between PTE and PAE, as in all cases the interaction term did not significantly improve model fit. After FDR correction, PTE was significantly associated with the lower volumes of lateral orbitofrontal region ($\beta = -331.000$, $q = 0.033$) and accumbens areas ($\beta = -34.800$, $q = 0.033$) (Figure 2A). PAE was associated with increased thalamus, accumbens area and caudate before the FDR correction ($p < 0.05$), but these associations did not carry on with the FDR correction ($q > 0.05$). ACE total score was not significantly associated with the volumes of any of the 11 brain ROIs. Phone access was associated with the smaller volumes of superior frontal ($\beta = -1336.036$, $q = 0.046$), lateral orbitofrontal ($\beta = -513.865$, $q = 0.046$), and the caudal anterior cingulate ($\beta = -222.982$, $q = 0.046$) (Figure 2B). Water access was associated with larger volumes of the superior frontal region ($\beta = 1569.527$, $q = 0.013$) (Figure 2C).

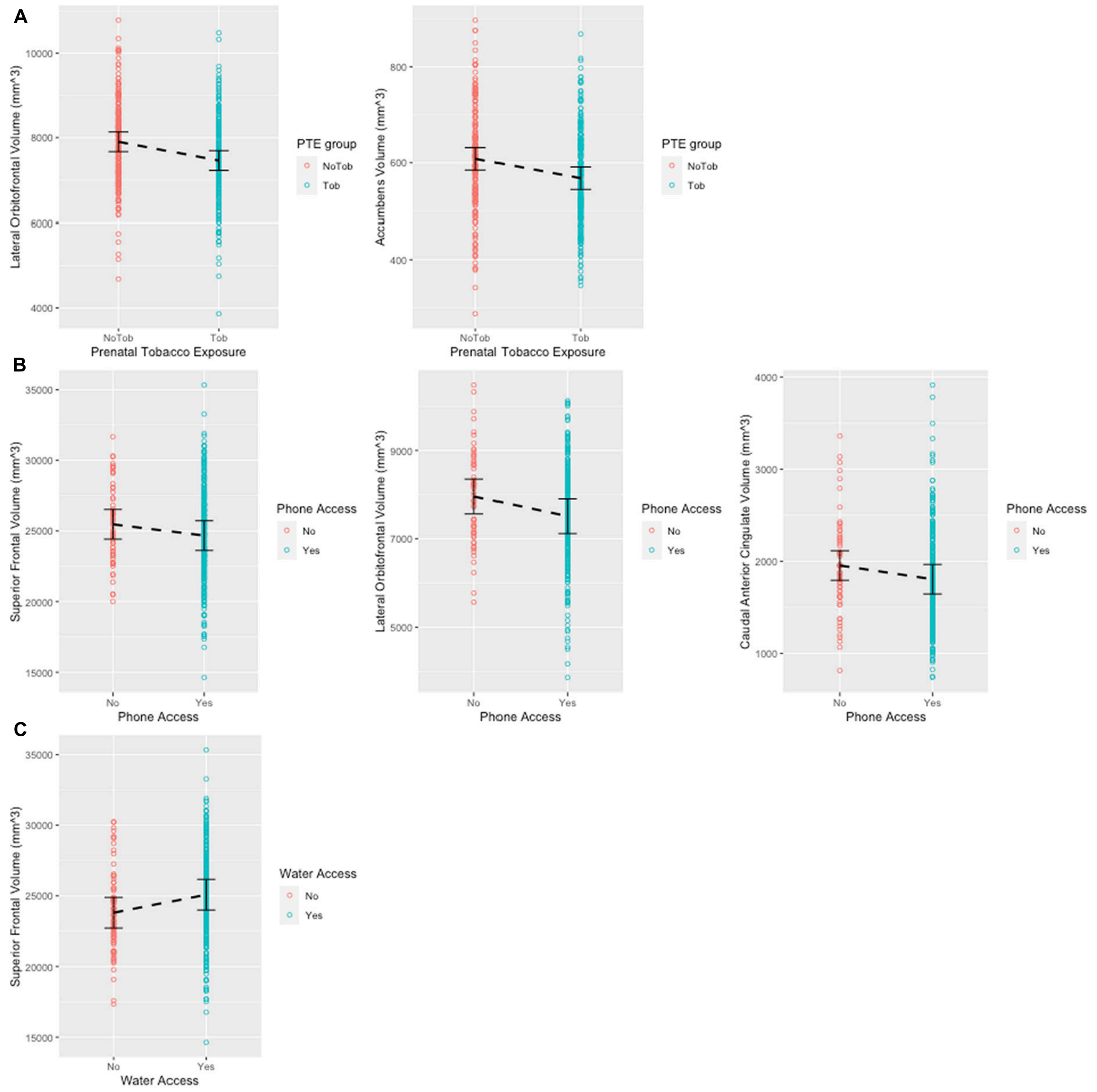

FIGURE 2
Scatter plots showing significant regions post FDR correction. Error bars show 95% confidence interval. **(A)** Significant associations between prenatal tobacco exposure and brain volume. **(B)** Significant associations between phone access and brain volume. **(C)** Significant associations between water access and brain volume.

Uncorrected *p*-values and full model estimates are presented in Supplementary Table 2.

4. Discussion

The present analyses examined a novel reframing of PAE and PTE as mediators for the association between socioeconomic resources and postnatal ACEs on cortical brain volumes. Within a very low socioeconomic resources context, and with prospective community-levels of prenatal substance exposure, we found that PTE, but not PAE, partially mediated the association between less *in utero* socioeconomic resources and subsequent more postnatal ACEs for the youth. Lower socioeconomic resources during pregnancy were associated with higher likelihood of PTE, and in turn PTE was associated with higher total number of endorsed ACEs. Both socioeconomic resources and PTE were associated with smaller volumes in prefrontal and striatum regions. Lower socioeconomic resources during pregnancy were associated with increased likelihood of subsequent PAE. However, given null brain findings with community-levels of PAE in this cohort, whether PAE plays a similar mediating role between socioeconomic resources, ACEs and brain outcomes as PTE does remains unknown, particularly for populations experiencing higher PAE known to cause clinical FASD, or within higher resourced contexts.

Our results demonstrate that PTE, but not PAE, was associated with lower cortical volume in the lateral orbitofrontal region and nucleus accumbens. While lateral orbitofrontal has been consistently associated with processing of rewards and punishments, as well as emotional and social regulations

(Kringelbach and Rolls, 2004), nucleus accumbens serves to integrate information from frontal and temporal regions and facilitate action (Floresco, 2015). These functional correlates of lateral orbitofrontal cortex and nucleus accumbens are consistent with the negative association between PTE and global cognition in children between 9 to 12 years old found in the current literature, suggesting a potential brain-behavior relationship (Fried et al., 1998; Gonzalez et al., 2023). Our results are consistent with prior studies from this same birth cohort representing community patterns of PAE and PTE, showing more widespread cortical and subcortical brain alterations with PTE compared to PAE at ages 6 years old (Uban et al., 2023) and ages 8–12 years (Marshall et al., 2022). Compared to alcohol, tobacco use is less likely to be cut back during pregnancy and more likely to be associated with tobacco exposure after pregnancy (Leech et al., 1999; Cornelius and Day, 2000). Even among women who reduce their tobacco use or quit spontaneously during pregnancy, postpartum relapse is common (Crume, 2019). It is likely that children who had PTE were also exposed to prolonged second-hand smoke perinatally [from birth parent and/or others smoking around child (Paavola et al., 1996; Scherrer et al., 2012)], which has been known to increase the risk of poorer neurodevelopmental outcomes in children (Chen et al., 2013). Therefore, it is possible that the structural brain development differences observed in our analysis were the result of accumulated tobacco exposure via maternal systems from both maternal use as well as use from others via second-hand smoke exposure during perinatal development. The potential for PTE from others' use may be a mechanism for reaching higher doses of exposure, and/or longer durations of exposure across postnatal developmental stages, unlike PAE. Together, these mechanisms for PTE that are unique from those of PAE may explain the more widespread effects on brain development at ages 6 (Uban et al., 2023) and 8–11 years as seen here and in Marshall et al. (2022). Interestingly, PTE dose-response relationships did not show significant results after corrections for multiple comparisons (Marshall et al., 2022), suggesting that PTE exposure from the postnatal period, or relating to perinatal tobacco exposure from others around the pregnant person or baby may be driving PTE outcomes more than maternal use in pregnancy alone. Data on the existence of postnatal tobacco exposure was not collected in our sample, which limited our ability to disentangle prenatal from postnatal tobacco exposure. Future research may investigate whether there is a dose-response relationship between prenatal and postnatal tobacco exposure and structural brain development.

While we are aware of the teratogenic effects of exposure to substances *in utero*, there exist other mechanistic pathways by way of hypoxia that might affect brain development, including the presence of obstetric complications. Obstetric complications, including preeclampsia, eclampsia, and gestational diabetes, can affect brain volumes (Rätsep et al., 2016; Luo et al., 2022). Our analyses are potentially limited by not accounting for obstetric complications that may affect brain morphology *in utero* with continuing effects seen in the growth trajectory of the developing brain through adolescence. Additionally, PTE has been shown to be associated with lower birth weight, smaller head circumference, and shorter length in newborns (Cornelius and Day, 2000). Specifically in our sample, birth weight did not differ by PTE or PAE status, again suggesting that prospective data most likely reflects community-level patterns of exposure and not necessarily high doses that are commonly seen in clinical FASD research samples.

Our analysis showed that phone access (landline and/or mobile phone) and running water access *in utero* were associated with volumes of the frontal regions in our sample of children between 8 to 11 years old in Cape Town, South Africa. Most of the existing literature on the impact of socioeconomic resources on child brain development have included samples from United States. How socioeconomic resources influence child development may be substantially different in a community where access to basic needs is inconsistent. Phone access is not universal in Cape Town, South Africa, because the necessary hardware to support phone service is expensive due to importation and little domestic manufacturing, and cellular data prices are exorbitantly high for lower resourced communities (Walton and Donner, 2012). Running water access for the Cape Town participants in this study is also negatively impacted by the legacy of racial inequality, where restricted access to clean and consistent water supply remains common (Enqvist and Ziervogel, 2019). Therefore, phone and water are likely proxies of the physical environment, such as access to governmental supports for maintaining utilities or exposure to environmental toxins or nutrition. Together, these physical environmental factors may impact child brain development and are potentially associated with housing amenity-based factors impacting ventilation of cooking, sanitation, and neighborhood safety. Given that our sample was derived from a low-resource community, it is also possible that the associations between utility access and structural brain volume may not generalize to communities in developed countries with more resources and infrastructure. Additionally, access to socioeconomic resources has been intertwined with cross-generational race/ethnicity-based oppression. Thus, the brain alterations we found as a function of socioeconomic resources in this sample may also reflect the impact of experienced racism, in addition to environmental exposures and poverty. Further research is needed to assess the interaction between racism, environmental exposure and poverty, and their collective impact on brain development.

Socioeconomic resources, but not ACEs, were related to lower cortical volumes, and less socioeconomic resources were associated increased likelihood of PTE and PAE. The presence of PAE/PTE may be a symptom of existing socioeconomic inequities, which may continue to independently and/or interactively impact the postnatal experience of the child. It is possible that, in this sample of participants, PTE and PAE are symptoms of less access to resources. Substances, including tobacco and alcohol, are commonly used to cope with stressors, including those relating to additional economic and low resourced living conditions (O'Connor et al., 2011; Peer et al., 2014; Watt et al., 2014). PTE may be reflective of additional needs to cope with stressors in a lower socioeconomic resources context in our study. Indeed, tobacco use among women in low resourced communities around Cape Town has been associated with poverty and more psychosocial stress (Peer et al., 2014). Previously, more adverse life events and a perception of lack of control over one's environment were found to be associated with an increased risk of tobacco use among this population (Peer et al., 2014). Thus, the present study provides evidence to extend established socioeconomic resources and PTE associations to the period of pregnancy, and subsequent ACEs endorsed by their children. With intentional incorporation of these factors in PAE brain research, more can be understood about the complex interplay between co-occurring contributing factors with PAE/PTE on brain structure development. It is possible that teratogenic potential of PAE/PTE may differ as a function of many factors, including co-occurring exposures, socioeconomic resources, and variable postnatal experiences.

We did not find an association between the total number of ACEs and brain volume in the prefrontal and striatum regions. While the 14-point ACE scoring system captures the grouped experience of the adverse events, the cumulative score is not specific to the three domains of neglect, abuse, and household challenges scored on the ACE scale. Moreover, the scoring of events such as this on a linear scale deprives us of the sensitivity to the chronicity and intensity of the events. The screening of ACEs may not fully capture the breadth of adverse events experienced by children living in post-apartheid South Africa and perhaps better serves as preliminary data on ACEs for the PASS birth cohort. There are cultural differences in how people experience, and express abuse, neglect, and household challenges compared to the U.S. population with whom these ACE items were first developed. We attempted to minimize the cultural effects through forward- and back-translation, but there may be persisted issues of cultural validity with the measure. In addition, children may not remember adverse events that happened when they were very young and therefore might not report these events accurately, if at all. Given that early childhood is an especially sensitive developmental period, the limitation of the child self-report may also have contributed to our lack of findings. ACEs requiring mandatory reporting were not assessed and may have artificially created a ceiling effect on total ACE scores. Lastly, resilience is known to be important as an interacting force to ACEs and warrants further investigation to understand how it relates to PAE and/or PTE, socioeconomic resources and ACEs for these brain outcomes.

Although not directly tested, known mechanisms implicate stress systems for underlying, in part, the impact of socioeconomic resources and ACEs on brain development. The toxic stress model hypothesizes that poverty and maltreatment influence levels of adversity, which contribute to toxic stress and allostatic load and thus affect brain and cognitive development (McEwen and McEwen, 2017). In this model, toxic stress activates the hypothalamic-pituitary-adrenal (HPA) axis and thereby alters brain structures involved in neuroendocrine functioning, such as the limbic system and the prefrontal cortex (McEwen and McEwen, 2017). Indeed, a substantial body of literature has demonstrated associations between child maltreatment and altered structural and functional connectivity of the fronto-limbic regions (Hanson et al., 2010; Teicher et al., 2012; McLaughlin et al., 2014, 2016; Herzberg and Gunnar, 2020). Similar HPA and brain alterations have been found to associate with PAE. Animal models of implicate HPA-dysregulation as a key mechanism of lasting harm of PAE on brain structural alterations in prefrontal and the limbic regions (Uban et al., 2010, 2013). Few studies to date have examined PAE, PTE, socioeconomic resources, and HPA-function and warrant future investigation.

Additional contextual characteristics of the present study should be noted. Firstly, in the US, the majority of participants in historical PAE brain literature have been recruited from clinical FASD populations and almost always raised as adoptees, outside of their racial/ethnic/culture of origin (Uban et al., 2020). Here, the birth cohort from South Africa was comprised of child and adolescent participants raised by the biological mother, effectively eliminating cultural mismatch or not being raised by the biological mother as drivers of brain alterations observed with PAE. Second, given the prospective nature, PAE and PTE patterns reflected community-level patterns of PAE. The majority of PAE-focused published work identified participants with established facial dysmorphology or severe patterns of PAE, commonly associated with diagnoses such as fetal alcohol syndrome (FAS) or partial FAS (pFAS) (Coles et al., 2020). Community-patterns of PAE with consideration of PTE may better capture FASD-related diagnoses that have been historically underrepresented in FASD clinical brain research, such as alcohol related neurodevelopmental disorder (ARND).

The birth cohort data leveraged in this study is from a low-resource community in Cape Town, South Africa, which has experienced cross-generational stressors through displacement and race/ethnicity-based oppression through historical apartheid. Specific to the Cape Town Flats region where the study participants reside, the physical environment is limited by lasting infrastructure challenges, in part due to the legacy of Apartheid (Henri and Grunebaum, 2005; O'Connell, 2018). Black communities were displaced from the Cape Town city area and rendered to the peripheral where basic infrastructure is lacking even today (Henri and Grunebaum, 2005; O'Connell, 2018). Systemic race-based oppression spanning generations combined with lack of resources have often led to experiences of toxic stress and substance use (Watt et al., 2014). This community has historically been labeled as having high FASD prevalence in research (Croxford and Viljoen, 1999; May et al., 2000; Olivier et al., 2016). Our study is contextualized with this consideration of poverty and systemic race-based oppression. Future research may further examine specific pathways through which poverty and psychosocial stress during pregnancy, as well as PAE/PTE, become associated with ACEs endorsed by children, and whether interventions and community services may disrupt the intergenerational transmission of adversity in this population.

In summary, our findings support the hypothesis that contextual factors, such as access to socioeconomic resources, may impact brain development through multiple pathways, including a direct pathway through the availability of certain resources and an indirect pathway through increasing the risk of teratogenic exposure (e.g., tobacco). These socioeconomic resources are entangled with cross-generational race/ethnicity-based oppression and poverty stemming from the legacy of the Apartheid. Therefore, our findings may not *necessarily* reflect differences in brain development due solely to poverty. Future studies may conceptualize the teratogen exposure as one factor embedded within a web of contextual factors that also influence brain development. Intentional incorporation of contextual factors that can also drive differences in brain development are needed to expand future teratogenic research, and to help destigmatize birth parents. Understanding varying patterns of PAE and PTE in the context of broader socioeconomic resources influences and their connections with postnatal ACEs can present novel policy-level and community-level interventions. This broader understanding of PAE and PTE outcomes may lead to support and awareness for affected individuals that is consistent with current recommendations to address social determinants of substance use.

Data availability statement

The original contributions presented in this study are included in this article/**Supplementary material**, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving human participants were reviewed and approved by the Human Research Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (HREC UCT REF 248/2014), the Human Research Ethics Committee of the Faculty of Health Sciences of Stellenbosch University (REF 248/2014), the Institutional Review Board at Children's Hospital in Los Angeles (CHLA-19-00228), and the Institutional Review Board at the University of California, Irvine (UCI #212354). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

SB, DJ, DS, KN, SJ, HO, and KU acquired the funding. YX, VR, SB, DJ, BS, KD, WC, JI, EK, KN, and KU contributed to the data acquisition and processing. YX, VR, HA, and KU contributed to the statistical analysis. YX wrote the manuscript. VR, SB, DJ, BS, KD, DS, HA, and KU contributed to the manuscript. ERS contributed to the funding and manuscript. All authors contributed to the conceptualization of the manuscript and approved the submitted version.

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Conflict of interest

HA was employed by University Statistical Consulting, LLC.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnint.2023.1104788/full#supplementary-material

References

Andre, Q. R., Mcmorris, C. A., Kar, P., Ritter, C., Gibbard, W. B., Tortorelli, C., et al. (2020). Different brain profiles in children with prenatal alcohol exposure with or without early adverse exposures. *Hum. Brain Mapp.* 41, 4375–4385. doi: 10.1002/hbm.25130

Archibald, S. L., Fennema-Notestine, C., Gamst, A., Riley, E. P., Mattson, S. N., and Jernigan, T. L. (2001). Brain dysmorphology in individuals with severe prenatal alcohol exposure. *Dev. Med. Child Neurol.* 43, 148–54.

Baglivio, M. T., Wolff, K. T., Epps, N., and Nelson, R. (2017). Predicting adverse childhood experiences. *Crime Delinquency* 63, 166–188. doi: 10.3390/children8090761

Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* 51, 1173–1182. doi: 10.1037//0022-3514.51.6.1173

Bates, D., Maechler, M., Bolker, B., and Walker, S. (2015). Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48.

Bick, J., and Nelson, C. A. (2016). Early adverse experiences and the developing brain. *Neuropsychopharmacology* 41, 177–196. doi: 10.1038/npp.2015.252

Bingol, N., Schuster, C., Fuchs, M., Iosub, S., Turner, G., Stone, R. K., et al. (1987). The influence of socioeconomic factors on the occurrence of fetal alcohol syndrome. *Adv. Alcohol Substance Abuse* 6, 105–118. doi: 10.1300/J251v06n04_08

Breen, M. S., Wingo, A. P., Koen, N., Donald, K. A., Nicol, M., Zar, H. J., et al. (2018). Gene expression in cord blood links genetic risk for neurodevelopmental disorders with maternal psychological distress and adverse childhood outcomes. *Brain Behav. Immun.* 73, 320–330. doi: 10.1016/j.bbi.2018.05.016

Buffarini, R., Hammerton, G., Coll, C. V. N., Cruz, S., Da Silveira, M. F., and Murray, J. (2022). Maternal adverse childhood experiences (ACES) and their associations with intimate partner violence and child maltreatment: Results from a Brazilian birth cohort. *Prev. Med.* 155:106928. doi: 10.1016/j.ypmed.2021.106928

Chen, R., Clifford, A., Lang, L., and Anstey, K. J. (2013). Is exposure to secondhand smoke associated with cognitive parameters of children and adolescents?-a systematic literature review. *Ann. Epidemiol.* 23, 652–661. doi: 10.1016/j.annepidem.2013.07.001

Cheng, T. W., Magis-Weinberg, L., Guazzelli Williamson, V., Ladouceur, C. D., Whittle, S. L., Herting, M. M., et al. (2021). A researcher's guide to the measurement and modeling of puberty in the ABCD study§at baseline. *Front. Endocrinol.* 12:608575. doi: 10.3389/fendo.2021.608575

Coleman-Cowger, V. H., Schauer, G. L., and Peters, E. N. (2017). Marijuana and tobacco co-use among a nationally representative sample of US pregnant and non-pregnant women: 2005–2014 National survey on drug use and health findings. *Drug Alcohol Depend.* 177, 130–135. doi: 10.1016/j.drugalcdep.2017.03.025

Coles, C. D., Kable, J. A., Granovska, I. V., Pashtepa, A. O., Plotka, L. D., Dolhov, V. B., et al. (2019). Gestational age and socioeconomic status as mediators for the impact of prenatal alcohol exposure on development at 6?months. *Birth Defects Res.* 111, 789–796. doi: 10.1002/bdr2.1408

Coles, C. D., Kalberg, W., Kable, J. A., Tabachnick, B., May, P. A., and Chambers, C. D. (2020). Characterizing alcohol-related neurodevelopmental disorder: Prenatal alcohol exposure and the spectrum of outcomes. *Alcohol. Clin. Exp. Res.* 44, 1245–1260. doi: 10.1111/acer.14325

Cornelius, M. D., and Day, N. L. (2000). The effects of tobacco use during and after pregnancy on exposed children. *Alcohol Res. Health* 24, 242–249.

Cornelius, M. D., and Day, N. L. (2009). Developmental consequences of prenatal tobacco exposure. *Curr. Opin. Neurol.* 22, 121–125. doi: 10.1097/WCO.0b013e328326f6dc

Croxford, J., and Viljoen, D. (1999). Alcohol consumption by pregnant women in the Western Cape. *S. Afr. Med. J.* 89, 962–5.

Crume, T. (2019). Tobacco use during pregnancy. *Clin. Obstetr. Gynecol.* 62, 128–141. doi: 10.1016/j.placenta.2022.09.012

Culhane, J. F., and Elo, I. T. (2005). Neighborhood context and reproductive health. *Am. J. Obstetr. Gynecol.* 192, S22–S29. doi: 10.1016/j.ajog.2005.01.071

Dannlowski, U., Stuhrmann, A., Beutelmann, V., Zwanzger, P., Lenzen, T., Grotegerd, D., et al. (2012). Limbic scars: Long-term consequences of childhood maltreatment revealed by functional and structural magnetic resonance imaging. *Biol. Psychiatry* 71, 286–293. doi: 10.1016/j.biopsych.2011.10.021

Dukes, K. A., Burd, L., Elliott, A. J., Fifer, W. P., Folkerth, R. D., Hankins, G. D. V., et al. (2014). The safe passage study: Design, methods, recruitment, and follow-up approach. *Paediatr. Perinatal Epidemiol.* 28, 455–465. doi: 10.1111/ppe.12136

El Marroun, H., Schmidt, M. N., Franken, I. H. A., Jaddoe, V. W. V., Hofman, A., Van Der Lugt, A., et al. (2014). Prenatal tobacco exposure and brain morphology: A prospective study in young children. *Neuropsychopharmacology* 39, 792–800. doi: 10.1038/npp.2013.273

Enqvist, J. P., and Ziervogel, G. (2019). Water governance and justice in Cape Town: An overview. *Wires Water* 6:e1354.

Finch, B. K., Vega, W. A., and Kolody, B. (2001). Substance use during pregnancy in the state of California. USA. *Soc. Sci. Med.* 52, 571–583. doi: 10.1016/s0277-9536(00)00161-1

Finkelhor, D., Shattuck, A., Turner, H., and Hamby, S. (2013). Improving the adverse childhood experiences study scale. *JAMA Pediatr.* 167, 70–5. doi: 10.1001/jamapediatrics.2013.420

Fischl, B. (2004). Automatically parcellating the human cerebral cortex. *Cereb. Cortex* 14, 11–22. doi: 10.1093/cercor/bhg087

Fischl, B., Salat, D. H., Busa, E., Albert, M., Dieterich, M., Haselgrove, C., et al. (2002). Whole brain segmentation. *Neuron* 33, 341–355.

Floresco, S. B. (2015). The nucleus accumbens: An interface between cognition, emotion, and action. *Annu. Rev. Psychol.* 66, 25–52. doi: 10.1146/annurev-psych-010213-115159

Fried, P. A., Watkinson, B., and Gray, R. (1998). Differential effects on cognitive functioning in 9- to 12-year olds prenatally exposed to cigarettes and marihuana. *Neurotoxicol. Teratol.* 20, 293–306. doi: 10.1016/s0892-0362(97)00091-3

Gibson, C. L., Morris, S. Z., and Beaver, K. M. (2009). Secondary exposure to violence during childhood and adolescence: Does neighborhood context matter? *Justice Q.* 26, 30–57. doi: 10.1177/2378023121992941

Glass, L., Ware, A. L., and Mattson, S. N. (2014). Neurobehavioral, neurologic, and neuroimaging characteristics of fetal alcohol spectrum disorders. *Handb. Clin. Neurol.* 125, 435–462. doi: 10.1016/B978-0-444-62619-6.00025-2

Gonzalez, M. R., Palmer, C. E., Uban, K. A., Jernigan, T. L., Thompson, W. K., and Sowell, E. R. (2020). Positive economic, psychosocial, and physiological ecologies predict brain structure and cognitive performance in 9–10-year-old children. *Front. Hum. Neurosci.* 14:578822. doi: 10.3389/fnhum.2020.578822

Gonzalez, M. R., Uban, K. A., Tapert, S. F., and Sowell, E. R. (2023). Prenatal tobacco exposure associations with physical health and neurodevelopment in the ABCD cohort. *Health Psychol.* doi: 10.1037/hea0001265 [Epub ahead of print].

Greenmyer, J. R., Klug, M. G., Kambeitz, C., Popova, S., and Burd, L. (2018). A multicountry updated assessment of the economic impact of fetal alcohol spectrum disorder: Costs for children and adults. *J. Addict. Med.* 12, 466–473. doi: 10.1097/ADM.0000000000000438

Hanson, J. L., Chung, M. K., Avants, B. B., Shirtcliff, E. A., Gee, J. C., Davidson, R. J., et al. (2010). Early stress is associated with alterations in the orbitofrontal cortex: A tensor-based morphometry investigation of brain structure and behavioral risk. *J. Neurosci.* 30, 7466–7472. doi: 10.1523/JNEUROSCI.0859-10.2010

Heinzen, E., Sinnwell, J., Atkinson, E., Gunderson, T., and Dougherty, G. (2021). *arsenal: An arsenal of 'R' functions for large-scale statistical summaries*.

Henri, Y., and Grunebaum, H. (2005). *Re-historicising trauma: Reflections on violence and memory in current-day Cape Town*. Cape Town: Direct Action Centre for Peace and Memory.

Herzberg, M. P., and Gunnar, M. R. (2020). Early life stress and brain function: Activity and connectivity associated with processing emotion and reward. *NeuroImage* 209:116493. doi: 10.1016/j.neuroimage.2019.116493

Jones, K. L., and Smith, D. W. (1973). Recognition of the fetal alcohol syndrome in early infancy. *Lancet* 302, 999–1001. doi: 10.1016/s0140-6736(73)91092-1

Kambeitz, C., Klug, M. G., Greenmyer, J., Popova, S., and Burd, L. (2019). Association of adverse childhood experiences and neurodevelopmental disorders in people with fetal alcohol spectrum disorders (FASD) and non-FASD controls. *BMC Pediatr.* 19:498. doi: 10.1186/s12887-019-1878-8

Karriker-Jaffe, K. J. (2013). Neighborhood socioeconomic status and substance use by U.S. adults. *Drug Alcohol Depend.* 133, 212–221. doi: 10.1016/j.drugalcdep.2013.04.033

Kerker, B. D., Zhang, J., Nadeem, E., Stein, R. E. K., Hurlburt, M. S., Heneghan, A., et al. (2015). Adverse childhood experiences and mental health, chronic medical conditions, and development in young children. *Acad. Pediatr.* 15, 510–517. doi: 10.1016/j.acap.2015.05.005

Kringelbach, M. L., and Rolls, E. T. (2004). The functional neuroanatomy of the human orbitofrontal cortex: Evidence from neuroimaging and neuropsychology. *Progr. Neurobiol.* 72, 341–372. doi: 10.1016/j.pneurobio.2004.03.006

Kuznetsova, A., Brockhoff, P. B., and Christensen, R. H. B. (2017). lmertest package: Tests in linear mixed effects models. *J. Stat. Softw.* 82, 1–26.

Lange, S., Shield, K., Rehm, J., and Popova, S. (2013). Prevalence of fetal alcohol spectrum disorders in child care settings: A meta-analysis. *Pediatrics* 132, e980–e995. doi: 10.1542/peds.2013-0066

Leech, S. L., Richardson, G. A., Goldschmidt, L., and Day, N. L. (1999). Prenatal substance exposure: Effects on attention and impulsivity of 6-year-olds. *Neurotoxicol. Teratol.* 21, 109–118. doi: 10.1016/s0892-0362(98)00042-7

Luby, J. L., Tillman, R., and Barch, D. M. (2019). Association of timing of adverse childhood experiences and caregiver support with regionally specific brain development in adolescents. *JAMA Netw. Open* 2:e1911426. doi: 10.1001/jamanetworkopen.2019.11426

Luby, J., Belden, A., Botteron, K., Marrus, N., Harms, M. P., Babb, C., et al. (2013). The effects of poverty on childhood brain development: The mediating effect of caregiving and stressful life events. *JAMA Pediatr.* 167, 1135–1142. doi: 10.1001/jamapediatrics.2013.3139

Luo, S., Hsu, E., Lawrence, K. E., Adise, S., Herting, M. M., Buchanan, T., et al. (2022). Associations between prenatal exposure to maternal diabetes and child adiposity markers: Mediating effects of brain structure. *medRxiv* [Preprint]. doi: 10.1101/2022.02.03.22270398

Mall, S., Platt, J. M., Temmingh, H., Musenge, E., Campbell, M., Susser, E., et al. (2020). The relationship between childhood trauma and schizophrenia in the Genomics of Schizophrenia in the Xhosa people (Sax) study in South Africa. *Psychol. Med.* 50, 1570–1577. doi: 10.1017/S0033291719001703

Marshall, A. T., Bodison, S. C., Uban, K. A., Adise, S., Jonker, D., Charles, W., et al. (2022). The impact of prenatal alcohol and/or tobacco exposure on brain structure in a large sample of children from a South African birth cohort. *Alcohol. Clin. Exp. Res.* 46, 1980–1992. doi: 10.1111/acer.14945

Mattson, S. N., Bernes, G. A., and Doyle, L. R. (2019). Fetal alcohol spectrum disorders: A review of the neurobehavioral deficits associated with prenatal alcohol exposure. *Alcohol. Clin. Exp. Res.* 43, 1046–1062.

Mattson, S. N., Riley, E. P., Sowell, E. R., Jernigan, T. L., Sobel, D. F., and Jones, K. L. (1996). A decrease in the size of the basal ganglia in children with fetal alcohol syndrome. *Alcohol. Clin. Exp. Res.* 20, 1088–1093.

May, P. A., Blankenship, J., Marais, A.-S., Gossage, J. P., Kalberg, W. O., Barnard, R., et al. (2013). Approaching the prevalence of the full spectrum of fetal alcohol spectrum disorders in a South African population-based study. *Alcohol. Clin. Exp. Res.* 37, 818–830. doi: 10.1111/acer.12033

May, P. A., Brooke, L., Gossage, J. P., Croxford, J., Adnams, C., Jones, K. L., et al. (2000). Epidemiology of fetal alcohol syndrome in a South African community in the Western Cape Province. *Am. J. Public Health* 90, 1905–1912. doi: 10.2105/ajph.90.12.1905

May, P. A., Chambers, C. D., Kalberg, W. O., Zellner, J., Feldman, H., Buckley, D., et al. (2018). Prevalence of fetal alcohol spectrum disorders in 4 US communities. *JAMA* 319, 474–482.

McEwen, C. A., and McEwen, B. S. (2017). Social structure, adversity, toxic stress, and intergenerational poverty: An early childhood model. *Annu. Rev. Sociol.* 43, 445–472.

McLachlan, K., Zhou, D., Little, G., Rasmussen, C., Pei, J., Andrew, G., et al. (2020). Current socioeconomic status correlates with brain volumes in healthy children and adolescents but not in children with prenatal alcohol exposure. *Front. Hum. Neurosci.* 14:223. doi: 10.3389/fnhum.2020.00223

McLaughlin, K. A., Sheridan, M. A., and Lambert, H. K. (2014). Childhood adversity and neural development: Deprivation and threat as distinct dimensions of early experience. *Neurosci. Biobehav. Rev.* 47, 578–591. doi: 10.1016/j.neubiorev.2014.10.012

McLaughlin, K. A., Sheridan, M. A., Gold, A. L., Duys, A., Lambert, H. K., Peverill, M., et al. (2016). Maltreatment exposure, brain structure, and fear conditioning in children and adolescents. *Neuropsychopharmacology* 41, 1956–1964.

Melchior, M., Moffitt, T. E., Milne, B. J., Poulton, R., and Caspi, A. (2007). Why do children from socioeconomically disadvantaged families suffer from poor health when they reach adulthood? A life-course study. *Am. J. Epidemiol.* 166, 966–974. doi: 10.1093/aje/kwm155

Myer, L., Stein, D. J., Grimsrud, A., Seedat, S., and Williams, D. R. (2008). Social determinants of psychological distress in a nationally-representative sample of South African adults. *Soc. Sci. Med.* 66, 1828–1840. doi: 10.1016/j.socscimed.2008.01.025

Noble, K. G., and Farah, M. J. (2013). Neurocognitive consequences of socioeconomic disparities: The intersection of cognitive neuroscience and public health. *Dev. Sci.* 16, 639–640. doi: 10.1111/desc.12076

Noble, K. G., Houston, S. M., Kan, E., and Sowell, E. R. (2012). Neural correlates of socioeconomic status in the developing human brain. *Dev. Sci.* 15, 516–527.

Noble, K. G., Wolmetz, M. E., Ochs, L. G., Farah, M. J., and Mccandliss, B. D. (2006). Brain-behavior relationships in reading acquisition are modulated by socioeconomic factors. *Dev. Sci.* 9, 642–654. doi: 10.1111/j.1467-7687.2006.00542.x

O'Connell, S. (2018). Apartheid afterlives. *Third Text* 32, 32–45.

O'Connor, M. J., Frankel, F., Paley, B., Schonfeld, A. M., Carpenter, E., Laugeson, E. A., et al. (2006). A controlled social skills training for children with fetal alcohol spectrum disorders. *J. Consult Clin. Psychol.* 74, 639–648.

O'Connor, M. J., Tomlinson, M., Leroux, I. M., Stewart, J., Greco, E., and Rotheram-Borus, M. J. (2011). Predictors of alcohol use prior to pregnancy recognition among township women in Cape Town, South Africa. *Soc. Sci. Med.* 72, 83–90.

Olivier, L., Viljoen, D., and Curfs, L. (2016). Fetal alcohol spectrum disorders: Prevalence rates in South Africa: The new millennium. *S. Afr. Med. J.* 106, 103–106.

Paavola, M., Vartiainen, E., and Puska, P. (1996). Predicting adult smoking: The influence of smoking during adolescence and smoking among friends and family. *Health Educ. Res.* 11, 309–315.

Pear, V. A., Petito, L. C., and Abrams, B. (2017). The role of maternal adverse childhood experiences and race in intergenerational high-risk smoking behaviors. *Nicotine Tob. Res.* 19, 623–630. doi: 10.1093/ntr/ntw295

Peer, N., Lombard, C., Steyn, K., and Levitt, N. (2014). Differential patterns of tobacco use among black men and women in Cape Town: The cardiovascular risk in black South Africans study. *Nicotine Tob. Res.* 16, 1104–1111. doi: 10.1093/ntr/ntu042

R Development Core Team (2019). *R: A language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing.

Rätsep, M. T., Paolozza, A., Hickman, A. F., Maser, B., Kay, V. R., Mohammad, S., et al. (2016). Brain structural and vascular anatomy is altered in offspring of pre-eclamptic pregnancies: A pilot study. *Am. J. Neuroradiol.* 37, 939–945. doi: 10.3174/ajnr.A4640

Reuter, M., Rosas, H. D., and Fischl, B. (2010). Highly accurate inverse consistent registration: A robust approach. *NeuroImage* 53, 1181–1196. doi: 10.1016/j.neuroimage.2010.07.020

Riley, E. P., Mattson, S. N., Sowell, E. R., Jernigan, T. L., Sobel, D. F., and Jones, K. L. (1995). Abnormalities of the corpus callosum in children prenatally exposed to alcohol. *Alcohol. Clin. Exp. Res.* 19, 1198–1202.

Rivkin, M. J., Davis, P. E., Lemaster, J. L., Cabral, H. J., Warfield, S. K., Mulkern, R. V., et al. (2008). Volumetric MRI study of brain in children with intrauterine exposure to cocaine, alcohol, tobacco, and marijuana. *Pediatrics* 121, 741–750. doi: 10.1542/peds.2007-1399

Scherrer, J. F., Xian, H., Pan, H., Pergadia, M. L., Madden, P. A. F., Grant, J. D., et al. (2012). Parent, sibling and peer influences on smoking initiation, regular smoking and nicotine dependence. Results from a genetically informative design. *Addict. Behav.* 37, 240–247. doi: 10.1016/j.addbeh.2011.10.005

Ségonne, F., Dale, A. M., Busa, E., Glessner, M., Salat, D., Hahn, H. K., et al. (2004). A hybrid approach to the skull stripping problem in MRI. *NeuroImage* 22, 1060–1075. doi: 10.1016/j.neuroimage.2004.03.032

Sevenoaks, T., Fouche, J.-P., Phillips, N., Heany, S., Myer, L., Zar, H. J., et al. (2022). Childhood trauma and mental health in the Cape Town adolescent antiretroviral cohort. *J. Child Adolesc. Trauma* 15, 353–363. doi: 10.1007/s40653-021-00362-0

Shoff, C., and Yang, T.-C. (2013). Understanding maternal smoking during pregnancy: Does residential context matter? *Soc. Sci. Med.* 78, 50–60.

Sled, J. G., Zijdenbos, A. P., and Evans, A. C. (1998). A nonparametric method for automatic correction of intensity nonuniformity in MRI data. *IEEE Trans. Med. Imaging* 17, 87–97.

Sowell, E. R., Mattson, S. N., Kan, E., Thompson, P. M., Riley, E. P., and Toga, A. W. (2008). Abnormal cortical thickness and brain-behavior correlation patterns in individuals with heavy prenatal alcohol exposure. *Cereb. Cortex* 18, 136–144. doi: 10.1093/cercor/bhm039

Sowell, E. R., Mattson, S. N., Thompson, P. M., Jernigan, T. L., Riley, E. P., and Toga, A. W. (2001). Mapping callosal morphology and cognitive correlates: Effects of heavy prenatal alcohol exposure. *Neurology* 57, 235–244. doi: 10.1212/wnl.57.2.235

Sowell, E. R., Thompson, P. M., Mattson, S. N., Tessner, K. D., Jernigan, T. L., Riley, E. P., et al. (2002). Regional brain shape abnormalities persist into adolescence after heavy prenatal alcohol exposure. *Cereb. Cortex* 12, 856–865. doi: 10.1093/cercor/12.8.856

Teicher, M. H., Anderson, C. M., and Polcari, A. (2012). Childhood maltreatment is associated with reduced volume in the hippocampal subfields CA3, dentate gyrus, and subiculum. *Proc. Natl. Acad. Sci. U.S.A.* 109, E563–E572. doi: 10.1073/pnas.1115396109

Teicher, M. H., Samson, J. A., Anderson, C. M., and Ohashi, K. (2016). The effects of childhood maltreatment on brain structure, function and connectivity. *Nat. Rev. Neurosci.* 17, 652–666.

Uban, K. A., Bodnar, T., Butts, K., Sliwowska, J. H., Comeau, W., and Weinberg, J. (2010). "Direct and indirect mechanisms of alcohol teratogenesis: Implications for understanding alterations in brain and behavior in FASD," in *Fetal alcohol spectrum disorder. management and policy perspectives of FASD*, eds E. P. Riley, S. Clarren, J. Weinberg, and E. Jonsson (Hoboken, NJ: Wiley-Blackwell), 71–108.

Uban, K. A., Comeau, W. L., Ellis, L. A., Galea, L. A. M., and Weinberg, J. (2013). Basal regulation of Hpa and dopamine systems is altered differentially in males and females by prenatal alcohol exposure and chronic variable stress. *Psychoneuroendocrinology* 38, 1953–1966. doi: 10.1016/j.psyneuen.2013.02.017

Uban, K. A., Jonker, D., Donald, K. A., Bodison, S. C., Brooks, S. J., Kan, E., et al. (2023). Associations between community-level patterns of prenatal alcohol and tobacco exposure on brain structure in a non-clinical sample of 6-year-old children: A South African pilot study. *Acta Neuropsychiatr.* doi: 10.1017/neu.2022.34 [Epub ahead of print].

Uban, K. A., Kan, E., Wozniak, J. R., Mattson, S. N., Coles, C. D., and Sowell, E. R. (2020). The relationship between socioeconomic status and brain volume in children and adolescents with prenatal alcohol exposure. *Front. Hum. Neurosci.* 14:85. doi: 10.3389/fnhum.2020.00085

Walton, M., and Donner, J. (2012). *Public access, private mobile: The interplay of shared access and the mobile internet for teenagers in Cape Town. Global impact study research report series*. Cape Town: University of Cape Town.

Watt, M. H., Eaton, L. A., Choi, K. W., Velloza, J., Kalichman, S. C., Skinner, D., et al. (2014). "It's better for me to drink, at least the stress is going away": Perspectives on alcohol use during pregnancy among South African women attending drinking establishments. *Soc. Sci. Med.* 116, 119–125. doi: 10.1016/j.socscimed.2014.06.048

Wickham, H., Averick, M., Bryan, J., Chang, W., Mcgowan, L. D. A., François, R., et al. (2019). Welcome to the tidyverse. *J. Open Source Softw.* 4:1686.

Wickham, H., François, R., Henry, L., and Müller, K. (2022). *dplyr: A grammar of data manipulation. R package version 1.0.8.*

World Health Organization [WHO] (2021). *Global alcohol action plan: First draft*. Geneva: World Health Organization.

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Brain morphological variability between whites and African Americans: the importance of racial identity in brain imaging research

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In a segregated society, marked by a historical background of inequalities, there is a consistent under-representation of ethnic and racial minorities in biomedical research, causing disparities in understanding genetic and acquired diseases as well as in the effectiveness of clinical treatments affecting different groups. The repeated inclusion of small and non-representative samples of the population in neuroimaging research has led to generalization bias in the morphological characterization of the human brain. A few brain morphometric studies between Whites and African Americans have reported differences in orbitofrontal volumetry and insula cortical thickness. Nevertheless, these studies are mostly conducted in small samples and populations with cognitive impairment. For this reason, this study aimed to identify brain morphological variability due to racial identity in representative samples. We hypothesized that, in neurotypical young adults, there are differences in brain morphometry between participants with distinct racial identities. We analyzed the Human Connectome Project (HCP) database to test this hypothesis. Brain volumetry, cortical thickness, and cortical surface area measures of participants identified as *Whites* ($n = 338$) or *African Americans* ($n = 56$) were analyzed. Non-parametrical permutation analysis of covariance between these racial identity groups adjusting for age, sex, education, and economic income was implemented. Results indicated volumetric differences in choroid plexus, supratentorial, white matter, and subcortical brain structures. Moreover, differences in cortical thickness and surface area in frontal, parietal, temporal, and occipital brain regions were identified between groups. In this regard, the inclusion of sub-representative minorities in neuroimaging research, such as African American persons, is fundamental for the comprehension of human brain morphometric diversity and to design personalized clinical brain treatments for this population.

KEYWORDS

brain volumetry, cortical thickness, cortical surface area, racial identity, MRI, Human Connectome Project

1 Introduction

Human population studies are contributing to understand variability in the prevalence of diseases, treatment response, risk factors, and relationships between genetic and environmental outcomes between diverse societal groups (Falk et al., 2013; Batai et al., 2021). Accordingly, human brain morphological variability has been robustly associated with individual genetic ancestry (Fan et al., 2015) and sociocultural influences (Holz et al., 2014; Noble et al., 2015). One of the methodologies used for the characterization of the human brain has been morphological neuroimaging analysis, which consists of the implementation of computational analysis methods of brain magnetic resonance imaging (MRI), aimed to identify the structural characteristics of the brain, highlighting analysis of volume and area, such as cortical surface area and cortical thickness (Mietchen and Gaser, 2009). Brain volumetry is a measure that includes surface area and cortical thickness (Panizzon et al., 2009); the former being a parameter of cortical folding and gyrification (Rakic, 2009) and the latter a parameter of density and dendritic arborization (Huttenlocher, 1990).

Neuroimaging studies have been implemented to identify brain morphometric differences due to educational level (Ho et al., 2011), socioeconomic status (Farah, 2017), gender, and age (Smith et al., 2007; Takahashi et al., 2011). Nevertheless, few neuroimaging studies are designed to explore brain morphometric differences related to racial identity. In this sense, it has been reported that African American persons diagnosed with hypertension and cognitive impairment, commonly referred to as a decline in memory and cognition performance, have lower insular thickness compared to White persons with the same diagnosis (Chand et al., 2017). Moreover, Isamah et al. (2010) implemented a volumetric analysis using magnetic resonance imaging (MRI) in neurotypical White and African American persons. After controlling for variables such as age, sex, years of education, and total brain volume, they reported that African American participants had a greater brain volume of the left orbitofrontal cortex than White participants. These authors agree that morphometric studies in populations with diverse racial identifications will reduce the under-representation of ethnic minorities as well as the comprehension of the influence of these variables on the differentiation in specific brain structures and the prevalence of neuropsychiatric diseases among different populations.

Racial identity has generally been used as a demographic variable and not as a variable of interest in neuroimaging research, which contributes to generalization bias of brain findings based on persons with high educational and socioeconomic status belonging to majority racial groups (Falk et al., 2013; Rouan et al., 2021). Furthermore, studies including minority racial groups are mainly implemented in small samples and in populations with cognitive impairment (Isamah et al., 2010; Chand et al., 2017). Thus, our study aimed to identify morphological brain variability among distinct racial identities in a representative sample of neurotypical young adults. We analyzed brain morphometric data from the Human Connectome Project (HCP) (van Essen et al., 2012). Our selection criteria indicate that *White* and *African American* racial identities were the most representative samples in the HCP database. In this regard, we expect to identify differences in brain morphometry between people identified as *Whites* or *African Americans*.

2 Methods

In order to access participants' racial identity information, all authors accepted the terms of data used to access restricted data of the HCP database. After the request was accepted by the WU-Minn HCP Consortium, the database from 1,206 participants was downloaded from the ConnectomeDB, a web-based user interface from the HCP (Hodge et al., 2015). Apart from racial identity information, restricted data included demographic, clinical, psychiatric, and morphometric brain information for each participant. Data were filtered to exclude participants with psychiatric symptoms, substance use and abuse disorders, endocrine disorders, irregular menstrual cycles, neurological abnormalities, and technical issues in the acquisition or preprocessing of their structural brain images. In the filtered database, participants identified as Hispanics were discarded due to unbalanced sample representation between the selected racial identity groups (Hispanic-Whites = 22, Hispanic-African Americans $n = 1$). Beyond this classification, ethnic identity was not considered for further analysis. Racial identity categories referred to Whites and African Americans were taken from the HCP demographic data based on the NIH Toolbox and U.S. Census classification.[1]

Three hundred thirty-eight participants identified as *Whites* [$M_{age(y)} = 29.12$, $SD = \pm 3.60$, $M_{education(y)} = 15.15$, $SD = \pm 1.69$] and 56 subjects identified as *African Americans* [$M_{age(y)} = 29.25$, $SD = \pm 3.62$, $M_{education(y)} = 14.41$, $SD = \pm 1.90$] satisfied the inclusion criteria from the filtering process of the original HCP database. Although age [$t_{(392)} = -0.2533$, $p = 0.800$] was not significantly different, years of education between groups resulted in significant differences [$t_{(70.96)} = 2.760$, $p = 0.007$]. Moreover, three participants identified as *Whites* were excluded from the permutation analysis because of missing education and economic income information (see Table 1).

Summary statistics of FreeSurfer morphometric measures (volume, cortical surface area, and cortical thickness) from the HCP database previously processed by HCP investigators were analyzed (Glasser et al., 2013). These preprocessing methods consist of a *PreFreeSurfer* pipeline, which was implemented to preprocess high-resolution T1w and T2w (weighted) brain images (0.7 mm thickness) for each participant to produce an undistorted "native" structural volume space. The pipeline aligned the T1w and T2w brain images, executed a B1 (bias field) correction for each volume, and co-registered the participant's undistorted structural volume space to MNI space. Subsequently, a *Freesurfer* pipeline was executed to divide the native volume into cortical and subcortical parcels, reconstruct white and pial cortical surfaces, and perform the standardized FreeSurfer's folding-based surface mapping to their surface atlas (fsaverage) (Glasser et al., 2013). Volumetric, cortical thickness, and surface area brain measures were grouped by participants' racial identity—*Whites* or *African Americans*. Before applying statistical analysis, volumetric results for each participant were standardized by dividing the raw volumetric scores by intracranial volume (ICV). Due to unbalanced samples between groups, ANCOVA permutation analyses adjusting for *age, sex, education,* and *economic income* were implemented to identify differences between groups for each brain morphometric measure. The estimation of value of *p*s was based on the criterion in which iteration stopped when the estimated standard error of the estimated proportion of the value of *p* was less than one-thousandth of the estimated value of *p* (Anscombe, 1953). A maximum of 5,000 iterations were selected for the analysis. Adjustment of value of *p*s for multiple comparisons were implemented by the family-wise error (FWE) rate method (Holm, 1979). Due to sample imbalance, a

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[1] https://www.humanconnectome.org/storage/app/media/documentation/q3/HCP_Q3_Release_Appendix_VII.pdf

TABLE 1 Descriptive results between African Americans and Whites.

	N	Racial identity		Value of *p*[2]
		African Americans, *N* = 56[1]	Whites, *N* = 338[1]	
Age (years)	394	29.25 (3.62)	29.12 (3.60)	0.801
Sex	394			
Male		23 (41%)	190 (56%)	
Female		33 (59%)	148 (44%)	
Education (years)	392	14.41 (1.90)	15.15 (1.69)	0.007
Economic Income (US$)	391			
<$10,000		7 (12%)	12 (3.6%)	
10K-19999		10 (18%)	22 (6.6%)	
20K-29999		9 (16%)	34 (10%)	
30K-39999		10 (18%)	32 (9.6%)	
40K-49999		5 (8.9%)	39 (12%)	
50K-74999		8 (14%)	76 (23%)	
75K-99999		1 (1.8%)	53 (16%)	
> = 100,000		6 (11%)	67 (20%)	
Missing		0	3	

[1]Mean (SD) of age and education in years. Frequencies (*n*) and percentages (%) of economic income ranges in US dollars. [2]Welch two sample t-test of age and education between African Americans and Whites ($p < 0.05$).

subsample selection from the filtered database was implemented, based on the criteria that participants from the higher sample size group (*Whites*) were similarly paired in *age, sex, education,* and *economic income* to the low sample size group (African Americans) (see Supplementary Table S4). ANCOVA permutation analyses corrected for multiple comparisons (FWE) on the same morphological parameters described above were implemented for this subsample.

The ordering of the database, data filtering, and statistical analysis was carried out in the programming language R version 3.6.3 mounted on the RStudio software version 1.2.5033. ANCOVA permutation analysis was implemented by the aovp function of the *lmperm* package in R (Wheeler and Torchiano, 2016). The pipeline used for the statistical analysis can be consulted at https://github.com/Daniel-atilano/HCP_structural_analysis.git.

3 Results

3.1 Brain volumetry differences between groups

Volume comparisons resulted in significant differences in cortical and subcortical brain structures (see Table 2 and Figure 1).

Volumetric measures were obtained from a volume-based stream where MRI volumes are labeled to classify subcortical and cortical tissues based on subject-independent probabilistic atlas and subject-specific measured values of voxels. Anatomical visualization of brain regions with significant statistical volumetric differences is represented in Figure 2.

Similar results were found on the paired subsample volumetric measures; nevertheless, after multiple comparisons correction (FWER), the bilateral and total cortical white matter, the left cerebellar white matter, the bilateral thalamus, and the anterior section of the corpus callosum maintain significant differences (see Supplementary Table S5).

3.2 Differences in cortical thickness between groups

Cortical thickness results indicated significant differences in frontal, temporal, parietal, and occipital brain regions (see Table 3 and Figure 3).

Cortical thickness measures were obtained from the mean distance between the white and the pial surfaces of the cortex. Anatomical visualization of brain regions with significant statistical cortical thickness differences is represented in Figure 4.

Similar results were found on the paired subsample cortical thickness measures; nevertheless, after multiple comparisons correction (FWER), the right banks of the superior temporal sulcus, left cuneus cortex, the right middle temporal gyrus, the right supramarginal gyrus, and the right lateral occipital cortex maintain significant differences (see Supplementary Table S6).

3.3 Differences in cortical surface areas between groups

Cortical surface results indicated significant differences in frontal, temporal, parietal, and occipital brain regions (see Table 4 and Figure 5).

Cortical surface measures were obtained from the sum of areas of triangles from the tessellation of the brain surface. Anatomical visualization of brain regions with significant statistical cortical surface area differences is represented in Figure 6.

Similar results were found on the paired subsample cortical surface area measures; nevertheless, none of the brain regions presents significant differences after applying multiple comparisons correction (FWER) (see Supplementary Table S7).

4 Discussion

Social, educational, and economic inequalities have impacted the health and human rights of ethnic and racial minorities, causing their under-representation in biomedical studies, leading to bias in the effectiveness of clinical treatments and misconceptions of genetic and environmental diseases affecting these groups (Konkel, 2015). According to some estimates, reducing such disparities would have saved the United States more than $ 1.2 billion in direct and indirect medical costs (Laveist et al., 2011). Even though the White non-Hispanic population has been steadily declining in recent years, African Americans and Hispanic/Latinos only represent 5 and 1% of participation in human research, while Whites represent over 70% (Ricard et al., 2022). In this regard, racial/ethnic identity is essential

TABLE 2 ANCOVA permutation volumetric brain results between African Americans and Whites adjusting for *age, sex, education,* and *economic income.*

Volumetric measure (mm^3/ICV)	African Americans, *N* = 56 Mean (SD)	Whites, *N* = 335 Mean (SD)	df	MSS	Iteration	Value of *p*	*p*-adjust value
Subcortical gray matter	0.04055 (0.005034)	0.03834 (0.002698)	1	0.00011	5,000	2e-16	0.0000***
Cortical white matter, L	0.1456 (0.01530)	0.1400 (0.01035)	1	0.00112	5,000	0.0004	0.0148*
Cortical white matter, R	0.148 (0.01591)	0.142 (0.01041)	1	0.00133	5,000	2e-16	0.0000***
Total cortical white matter	0.2936 (0.03118)	0.2820 (0.02072)	1	0.00491	5,000	2e-16	0.0000***
Thalamus proper, L	0.005662 (0.0007313)	0.005314 (0.0004950)	1	2.97e-06	5,000	2e-16	0.0000***
Caudate, L	0.002561 (0.0003973)	0.002389 (0.0002699)	1	6.66e-07	5,000	2e-16	0.0000***
Choroid plexus, L	0.0007718 (0.0001564)	0.0006879 (0.0001265)	1	2.74e-07	5,000	2e-16	0.0000***
Cerebellum white matter, R	0.010071 (0.001618)	0.009315 (0.001034)	1	2.31e-05	5,000	2e-16	0.0000***
Caudate, R	0.002643 (0.0003947)	0.002467 (0.0002746)	1	7.50e-07	5,000	2e-16	0.0000***
Pallidum, R	0.001005 (0.0001865)	0.000927 (0.0001037)	1	1.76e-07	5,000	2e-16	0.0000***
Ventral diencephalon, R	0.002813 (0.0003966)	0.002673 (0.0002312)	1	6.68e-07	5,000	2e-16	0.0000***
Choroid plexus, R	0.0008843 (0.0002290)	0.0007852 (0.0001559)	1	4.19e-07	5,000	2e-16	0.0000***
Optic chiasm	0.0001660 (3.156e-05)	0.0001423 (2.936e-05)	1	2.83e-08	5,000	2e-16	0.0000***
Posterior corpus callosum	0.0006727 (1.129e-04)	0.0005998 (9.114e-05)	1	1.44e-07	5,000	2e-16	0.0000***
Anterior corpus callosum	0.0006323 (9.232e-05)	0.0005577 (8.614e-05)	1	1.75e-07	5,000	2e-16	0.0000***

(***) Significant results at a value of p of < 0.001 and (*) a value of p of < 0.05 when multiple comparison correction test (FWER) was applied. R, Right Hemisphere. L, Left Hemisphere. MSS, Mean sum of squares. Brain volumetry is standardized as the ratio of cubic millimeters / intracranial volume (mm^3/ICV).

to contextualize neurophysiological and neuroimaging results on structural inequities in society (Harnett et al., 2023). In neuroimaging research, this under-representation bias may be responsible for the reproducibility, generalizability, external validity, and inference crisis in brain research, which exacerbates the disparities and inequalities of minorities in neuroscience (Falk et al., 2013; Dotson et al., 2020). Data sharing and open access to multimodal brain imaging in consortium repositories have been proposed as research opportunities to diminish racial disparities and methodological bias (Falk et al., 2013; Weinberger et al., 2020). Consequently, some advantages of using the HCP database are its public accessibility, a large ethnic/racially diverse sample, preprocessing methods, high-resolution structural brain imaging, and demographic and clinical information of participants (Glasser et al., 2016).

Based on the HCP database, our results indicate volumetric brain differences in white matter structures, subcortical regions, plexus choroids, and total subcortical grey matter between participants identified as African Americans and Whites. Differences in subcortical brain volumetric regions were identified in the bilateral caudate, left thalamus, right globus pallidus, and right ventral diencephalon. Moreover, differences were identified in other brain structures, such as the optic chiasm, the white matter of the right cerebellum, and the corpus callosum in their anterior and posterior portions. In contrast with Isamah et al.'s (2010) study, where differences in bilateral amygdala and total cerebral volume between persons identified as African Americans and White were found, we identified volumetric differences in the bilateral caudate and total cortical white matter. Differences in regional brain volumes in cortical and subcortical structures, such as the bilateral caudate, have been identified between White and Chinese populations (Tang et al., 2010). Moreover, brain differences in total cortical gray matter volume, total cortical white matter volume, total gray matter volume, estimated intracranial volume, and cortical regional volumes have been reported between Indian and White persons (Rao et al., 2017). Furthermore, our results indicate surface area differences in frontal, parietal, temporal, occipital, and frontal brain regions between African American and White racial identities. Specifically, cortical thickness differences were identified in the bilateral cuneus cortex, left fusiform gyrus, bilateral

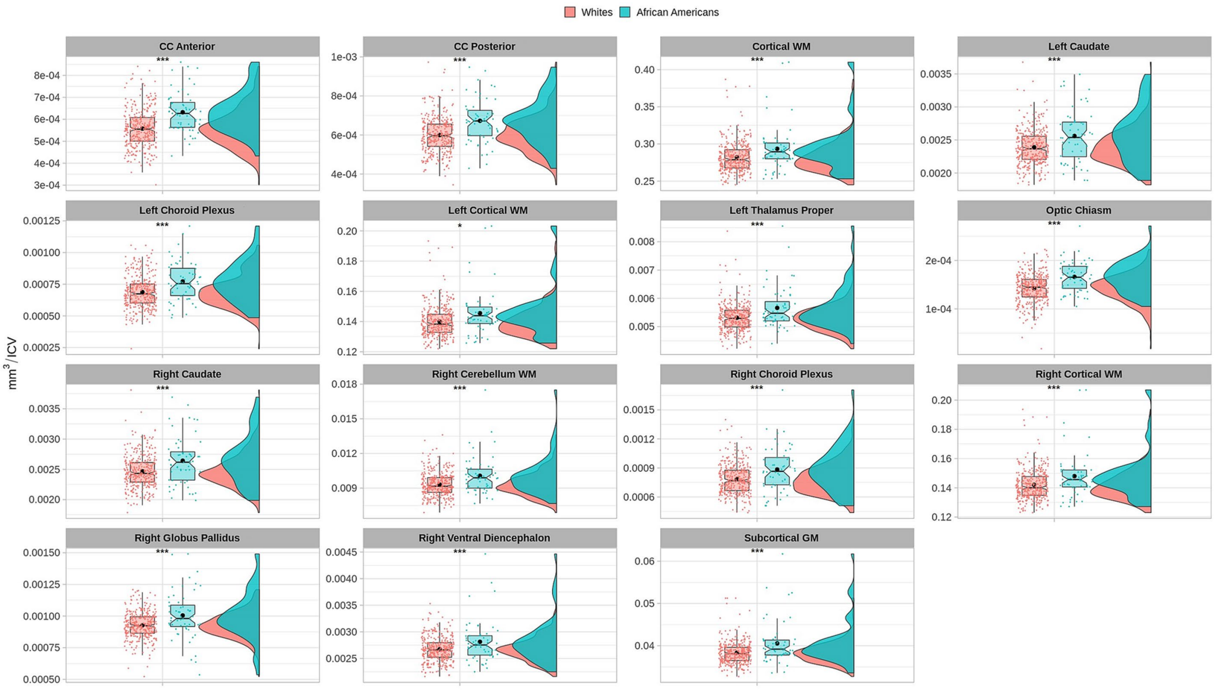

FIGURE 1
Permutational ANCOVA brain volumetric results between Whites and African Americans with significant differences after applying multiple comparison correction test (FWER). Brain volumetry is standardized as the ratio of cubic millimeters/intracranial volume (mm^3/ICV). CC anterior: anterior subregion of corpus callosum. CC posterior: posterior subregion of corpus callosum. WM, white matter. GM, gray matter. Asterisks (***) indicate significant results at a value of *p* of <0.001 and (*) a value of *p* of <0.05.

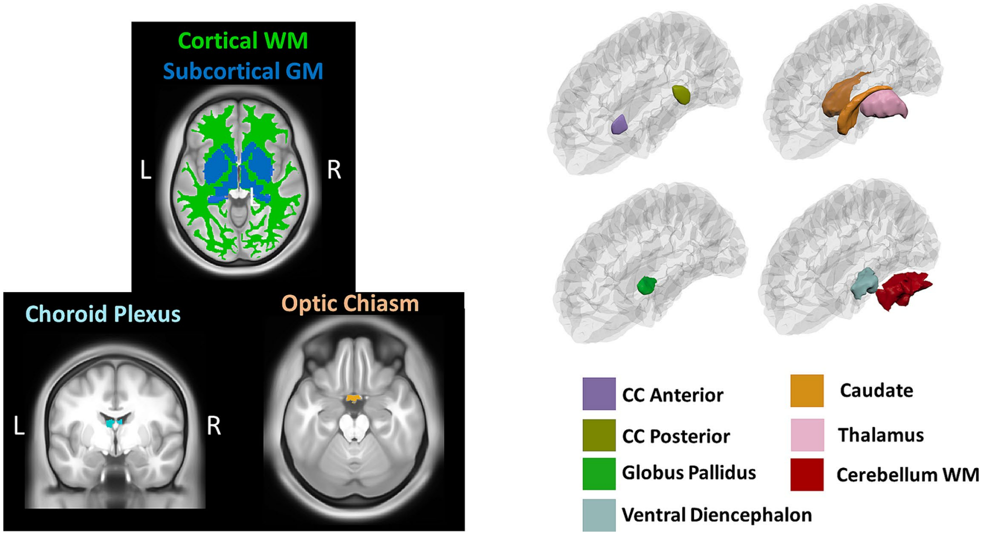

FIGURE 2
Brain regions representing volumetric differences between Whites and African Americans. CC, corpus callosum; WM, white matter. GM, gray matter. Brain images were created with *BrainPainter* software (Marinescu et al., 2019).

occipital cortex, left pericalcarine cortex, bilateral lingual gyrus, bilateral postcentral gyrus, right superior temporal sulcus, right rostral anterior cingulate cortex, right supramarginal gyrus, right entorhinal cortex, right middle temporal gyrus, and right transverse temporal cortex. Moreover, cortical surface area differences were identified in the bilateral cuneus cortex, left entorhinal cortex, left inferior temporal gyrus, bilateral occipital cortex, left lateral orbitofrontal cortex, left lingual gyrus, bilateral parsopercularis, right parsorbitalis, right caudal middle frontal gyrus, right frontal pole, right fusiform gyrus, bilateral right superior frontal gyrus, and bilateral superior parietal cortex. There are few studies that have reported differences in brain cortical thickness and surface area due to ethnic or racial identity. Accordingly,

TABLE 3 **Permutational ANCOVA cortical thickness results between African Americans and Whites adjusting for *age, sex, education,* and *economic income.***

Brain region (mm)	African Americans, *N* = 56 Mean (SD)	Whites, *N* = 335 Mean (SD)	df	MSS	Iteration	Value of *p*	*p*-adjust value
Banks of superior temporal sulcus, R	2.744 (0.1603)	2.810 (0.1342)	1	0.21868	5,000	2e-16	0.0000***
Cuneus cortex, L	2.040 (0.1011)	2.099 (0.1214)	1	0.20477	5,000	2e-16	0.0000***
Cuneus cortex, R	2.042 (0.1147)	2.099 (0.1105)	1	0.17220	5,000	2e-16	0.0000***
Entorhinal cortex, R	3.313 (0.2290)	3.445 (0.2412)	1	0.64413	5,000	2e-16	0.0000***
Fusiform gyrus, L	2.850 (0.09736)	2.889 (0.12094)	1	0.06748	5,000	2e-16	0.0000***
Inferior parietal cortex, R	2.618 (0.09668)	2.657 (0.10264)	1	0.09692	5,000	2e-16	0.0000***
Lateral occipital cortex, L	2.234 (0.1040)	2.312 (0.1099	1	0.27342	5,000	2e-16	0.0000***
Lateral occipital cortex, R	2.273 (0.1102)	2.366 (0.1036)	1	0.35269	5,000	2e-16	0.0000***
Lingual gyrus, L	2.125 (0.09406)	2.189 (0.11238)	1	0.14523	5,000	2e-16	0.0000***
Lingual gyrus, R	2.132 (0.1075)	2.208 (0.1101)	1	0.23351	5,000	2e-16	0.0000***
Middle temporal gyrus, R	3.013 (0.1111)	3.074 (0.1211)	1	0.13934	5,000	2e-16	0.0000***
Pericalcarine cortex, L	1.978 (0.1141)	2.020 (0.1170)	1	0.11471	5,000	2e-16	0.0000***
Postcentral gyrus, L	2.176 (0.09014)	2.230 (0.10179)	1	0.12848	5,000	2e-16	0.0000***
Postcentral gyrus, R	2.204 (0.10093)	2.248 (0.09787)	1	0.08111	5,000	2e-16	0.0000***
Rostral anterior Cingulate cortex, R	3.056 (0.1737)	2.996 (0.1853)	1	0.18686	5,000	0.0006	0.0312*
Supramarginal gyrus, R	2.668 (0.1017)	2.715 (0.1152)	1	0.14505	5,000	2e-16	0.0000***
Transverse temporal cortex, R	2.653 (0.1645)	2.765 (0.1709)	1	0.50098	5,000	2e-16	0.0000***

(***) Significant results at a value of p of < **0**.001 and (*) a value of p of < 0.05 when multiple comparison correction test (FWER) was applied. R, right hemisphere. L, left hemisphere. MSS, mean sum of squares.

Jha et al. (2019) identified cortical thickness differences in the bilateral postcentral gyrus, superior parietal lobules, precuneus, supramarginal gyrus, right precentral gyrus, insula, inferior parietal lobule, supplementary motor area, and rolandic operculum in a large cohort of neonates of African American and White mothers. Furthermore, in middle-aged cognitively impaired hypertensive persons, differences in insular cortical thickness were identified between African Americans and White people (Chand et al., 2017). Similar to our results, Kang et al. (2020) identified differences in surface area and cortical thickness in frontal, parietal, temporal, and occipital subregions; however, these results were based on an analysis of brain surface morphometry between older Chinese and White adults.

The U.S. Census has created racial categories that include White and African American people, allowing the self-identification of individuals in groups that represent their community and cultural background (Anderson et al., 2004). In a segregated society, racial identity has emerged as the sense of collective identity based on a perceived common heritage with a racial group (Helms, 1995), promoting wellbeing and protection against racism in African Americans (Hughes et al., 2015). In this sense, Afro-American identity is constituted by an African conscience that establishes behaviors, spirituality, and ancestral knowledge affecting self-concept, self-esteem, and self-image. Moreover, racism and oppression, rooted in a historical background of environmental and interpersonal adversity, have caused a mental and physical pathologization of their identity (Toldson and Toldson, 2001). In contrast, White American identity is rooted in social and economic privileges (McDermott and Samson, 2005) that establish racial attitudes, beliefs, behaviors, and experiences in a racially hierarchical society (Schooley et al., 2019). From this perspective, racial identity is defined and addressed as a social construct from which racial groups are socially created to attach differences between groups (Anderson et al., 2004). In this sense, the descriptive results in our sample related to years of education indicate that participants identified as African American reported less years of education than White participants; moreover, Whites tend to report higher economic income than African Americans. These results may reflect the inequalities in education (Johnson, 2014; Hill et al., 2017) and socioeconomic status (Hardaway and McLoyd, 2008) between White and African American people. Low socioeconomic status has been associated with reduced cortical gray matter thickness in

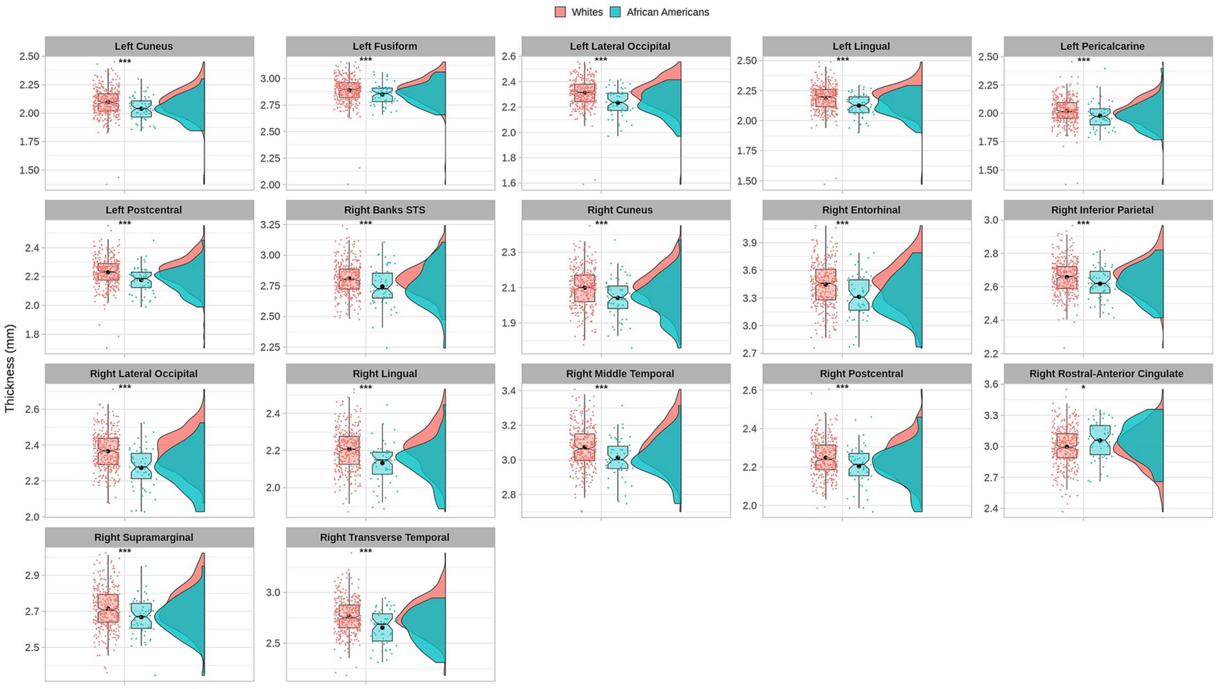

FIGURE 3
Permutational ANCOVA cortical thickness (mm) results between Whites and African Americans with significant differences after applying multiple comparison correction tests (FWER). Asterisks (***) indicate significant results at a value of *p* of <0.001 and (*) a value of *p* of <0.05.

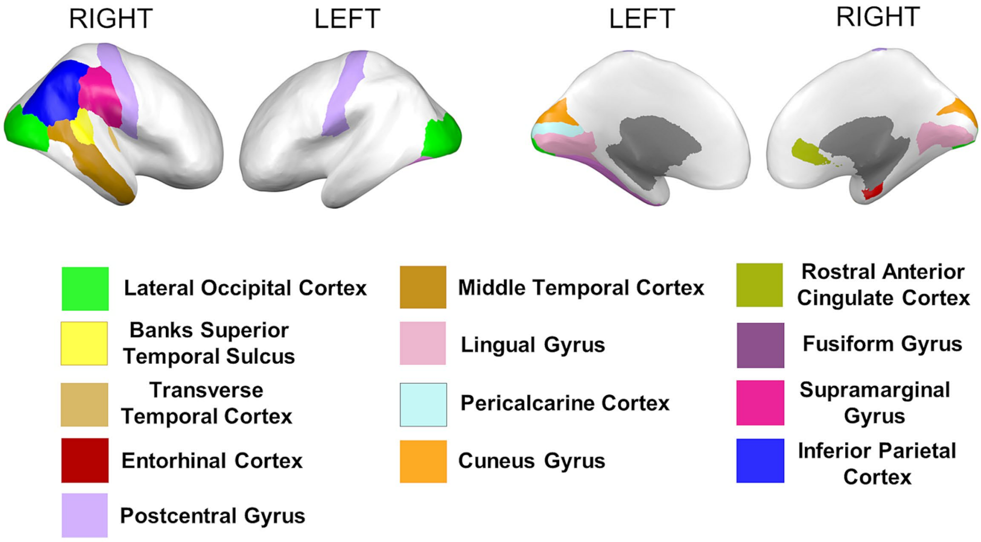

FIGURE 4
Brain regions representing cortical thickness differences between Whites and African Americans. Brain images were created with *BrainPainter* software (Marinescu et al., 2019).

middle-aged persons (Chan et al., 2018). In addition, diverse studies have indicated that socioeconomic status and parental education strongly influence cerebral cortical thickness, surface area, and volume during childhood (Noble et al., 2015; Farah, 2017), particularly average cortical thickness in neonates of African American mothers (Jha et al., 2019). Although our analysis was adjusted for economic income and education, these are only dimensions of socioeconomic status that also imply prenatal and postnatal factors such as biological risks (e.g., nutrition and toxin exposure), psychosocial stress, variability in cognitive and linguistic stimulation, and parenting practices during childhood (Farah, 2017). Our results referred to differences in volume, cortical thickness, and surface area in diverse brain regions between distinct racial identities may be due to these prenatal and postnatal factors anchored in racial inequalities. In this

TABLE 4 **Permutational ANCOVA surface cortical area results between African Americans and Whites adjusting for *age, sex, education,* and *economic income.***

Brain region (mm^2)	African Americans, *N* = 56 Mean (SD)	Whites, *N* = 335 Mean (SD)	df	MSS	Iteration	Value of *p*	*p*-adjust value
Caudal middle frontal gyrus, R	2031.68 (430.703)	2289.21 (412.912)	1	1,313,656	5,000	2e-16	0.0000***
Entorhinal cortex, L	392.036 (79.9331)	442.269 (89.4814)	1	58,967	5,000	2e-16	0.0000***
Frontal pole, R	255.232 (41.2782)	286.684 (46.4144)	1	22,534	5,000	2e-16	0.0000***
Fusiform gyrus, R	3091.07 (409.400)	3385.21 (485.103)	1	979,123	5,000	0.0004	0.0208*
Inferior temporal gyrus, L	3151.93 (459.970)	3535.21 (514.899)	1	2,869,915	5,000	2e-16	0.0000***
Lateral occipital cortex, L	4432.77 (606.078)	4869.55 (621.979)	1	4,366,717	5,000	2e-16	0.0000***
Lateral occipital cortex, R	4281.59 (629.353)	4734.67 (607.326)	1	3,922,367	5,000	2e-16	0.0000***
Lateral orbitofrontal cortex, L	2511.55 (288.722)	2733.41 (318.287)	1	703,296	5,000	2e-16	0.0000***
Lingual gyrus, L	2863.04 (396.938)	3190.75 (415.092)	1	2,569,762	5,000	2e-16	0.0000***
Parsopercularis, L	1589.21 (246.493)	1777.46 (293.377)	1	774,206	5,000	2e-16	0.0000***
Parsopercularis, R	1292.12 (226.984)	1498.99 (265.773)	1	1,301,307	5,000	2e-16	0.0000***
Parsorbitalis, R	745.054 (95.406)	822.463 (106.355)	1	90,705	5,000	2e-16	0.0000***
Precuneus cortex, R	3770.21 (527.036)	4201.71 (609.588)	1	2,710,670	5,000	2e-16	0.0000***
Superior frontal gyrus, L	6931.23 (868.670)	7610.22 (962.951)	1	7,349,511	5,000	2e-16	0.0000***
Superior frontal gyrus, R	6849.00 (828.756)	7445.82 (928.692)	1	4,132,493	5,000	2e-16	0.0000***
Superior parietal cortex, L	5080.77 (565.338)	5680.33 (731.003)	1	6,302,632	5,000	2e-16	0.0000***
Superior parietal cortex, R	5100.62 (558.739)	5704.45 (699.319)	1	6,535,061	5,000	2e-16	0.0000***

(***) Significant results at a value of *p* of < 0.001 and (*) a value of *p* of < 0.05 when multiple comparison correction test (FWER) was applied. R, right hemisphere. L, left hemisphere. MSS, mean sum of squares.

regard, it has been reported that African Americans, compared to the White population, have a higher risk of developing Alzheimer's disease due to exposure to air pollutants (Younan et al., 2021), access to healthcare (Cooper et al., 2010) and educational disparities (Peterson et al., 2020). Moreover, racism and discrimination have been related to higher levels of blood pressure (Lewis et al., 2009), preterm infant birth (Collins et al., 2011; Dominguez, 2011), and stressful life experiences (Williams, 2018). Furthermore, the recent study by Fani et al. (2021) identified that racial discrimination experiences of Afro-American women were associated with functional activation of the middle occipital gyrus, ventromedial frontal cortex, middle and superior temporal gyrus, and cerebellum. Assari and Mincy (2021) have reported that racism may impact the volume brain growth of African American children. Accordingly, with these studies, the morphological variability identified between White and African American identities in our study may also be related to racism and oppression, mostly affecting the African American community, due to historical racial segregation (Toldson and Toldson, 2001; Grigoryeva and Ruef, 2015). In this regard, acknowledging inequalities in education (Johnson, 2014; Hill et al., 2017), health (Monk, 2015; Yearby, 2018), justice (Hetey and Eberhardt, 2018), and socioeconomic status (Hardaway and McLoyd, 2008) between Whites and African American people is fundamental to acknowledge that racial identity implies social and environmental factors that can impact in human development (Huston and Bentley, 2009) and brain morphology (Ho et al., 2011; Holz et al., 2014; Noble et al., 2015; Gur et al., 2019).

Most studies in human cognitive neuroscience come from majority identities, such as the White population, in contrast to Hispanics, Asians, and African Americans, who have been markedly underrepresented (Dotson et al., 2020). In this sense, our results suggest brain morphological variability between overrepresented and underrepresented samples, supporting the

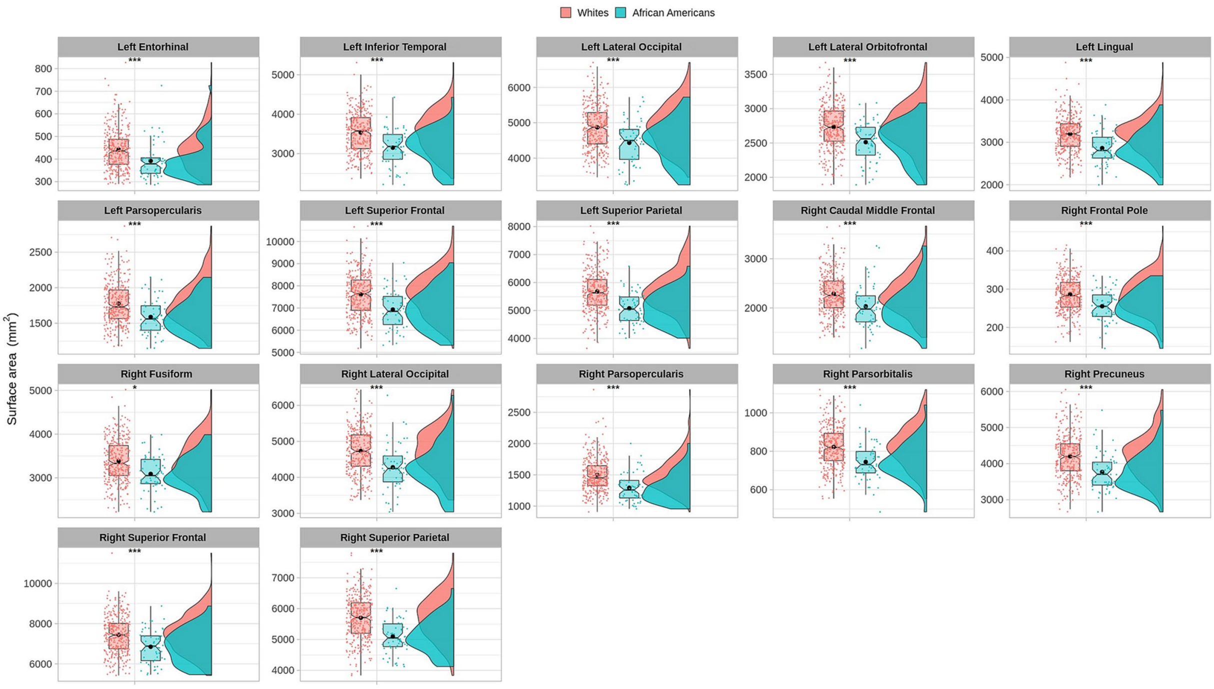

FIGURE 5
Permutational ANCOVA cortical surface area (mm^2) results between Whites and African Americans with significant differences after applying the multiple comparison correction test (FWER). Asterisks (***) indicate significant results at a value of *p* of <0.001 and (*) a value of *p* of <0.05.

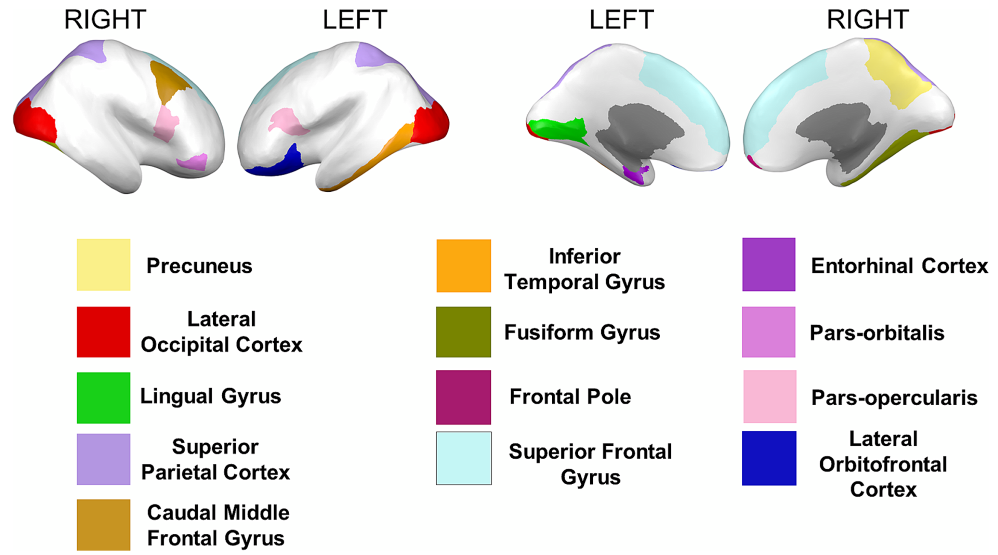

FIGURE 6
Brain regions representing cortical surface area differences between Whites and African Americans. Brain images were created with *BrainPainter* software (Marinescu et al., 2019).

urgency to avoid the extrapolation and generalization of brain findings based on WEIRD (Western, Educated, Industrialized, Rich, and Democratic) population (Chiao and Cheon, 2010; Falk et al., 2013). Accordingly, it is important to consider the human brain as a multilevel ecological system that regards social and biological factors from which it is necessary to develop cross-cultural sampling methods and multidisciplinary collaboration to improve the generalizability of neuroscience studies and the comprehension of individual differences in the human brain (Falk et al., 2013). Neuroimaging research groups have developed structural MRI brain atlas and templates based on specific populations due to differences in brain morphology while contrasting with WEIRD samples (Tang et al., 2010; Gu and Kanai, 2014).

The African Ancestry Neuroscience Research program has emerged as an initiative to reduce health disparities in the African American community and to promote focused brain research in this population to treat brain disorders by developing personalized therapies and treatments (Weinberger et al., 2020). The evidence of morphological brain variability in our study could contribute to understanding brain disorders and psychological factors affecting African Americans and the prospect of developing brain templates for this population.

Although our study was based on a large sample from the HCP database, some limitations must be considered. First, the sample is unbalanced due to the overrepresentation of persons identified as Whites ($n = 877$) compared to persons identified as African Americans ($n = 193$) according to the original HCP database.[2] Even though the HCP project is focused on neurotypical young adults, this database includes participants with heavy consumption of tobacco, alcohol, and recreational drugs (van Essen et al., 2012). Moreover, we identified participants with psychiatric symptoms, endocrine disorders, irregular menstrual cycles, and neurological abnormalities, as well as technical issues in the acquisition and preprocessing of their structural brain images. In this sense, we consider implementing exclusion criteria to discard these confounding variables that could affect morphological brain results in large neuroimaging data (Smith and Nichols, 2018). Nevertheless, these considerations maintain the imbalance of our sample between Whites ($n = 338$) and African Americans ($n = 56$) persons, which reduces the possibility to apply parametric statistical analysis (Kaur and Kumar, 2015). In this regard, we implement a method of sub-selection of persons identified as White ($n = 56$) and African American ($n = 56$) paired in age, sex, economic income, and education to overcome the confounding bias. Finally, racial identity was defined from the self-identification of participants. However, genetic ancestry information could have contributed to a more careful characterization of the sample from which specific genetic sequences and gene/environmental interactions could be analyzed to further interpret brain morphological results (Fan et al., 2015).

5 Conclusion

The human brain is constituted in a unique genetic, social, and experiential domain that is embedded in global hardships such as poverty and discrimination (White and Gonsalves, 2021). In this regard, morphological brain differences in persons identified as African Americans and Whites may be embedded in historical inequalities, oppression, and racism in American society that may impact brain structure. In this study, white matter, forebrain, midbrain, and hindbrain structures display morphological variability between racial groups which could be relevant for understanding neurological or psychiatric disorders differentially affecting these populations. Due to the recurrent misrepresentation of ethnic and racial minorities in neuroimaging research, their inclusion in further studies is fundamental for the comprehension of human brain morphometric variability.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://wiki.humanconnectome.org/display/PublicData/HCP+Wiki+-+Public+Data.

Ethics statement

The studies involving human participants were reviewed and approved by Data Restricted Access by the Washington University - University of Minnesota Consortium of the Human Connectome Project (WU-Minn HCP). The patients/participants provided their written informed consent to participate in this study.

Author contributions

DA-B and FB contributed to the conception and design of the study. DA-B organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. FB improved the manuscript by writing additional sections. All authors contributed to manuscript revision, read, and approved the submitted version.

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[2] https://wiki.humanconnectome.org/display/PublicData/Summary+Demographic+Data+for+HCP+Young+Adult

Conflict of interest

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnint.2023.1027382/full#supplementary-material

References

Anderson, N. B., Bulatao, R. A., and Cohen, B., & National Research Council (US) Panel on Race, E. and H. in L. L. (2004). Racial and ethnic identification, official classifications, and health disparities. Available at: https://www.ncbi.nlm.nih.gov/books/NBK25522/

Anscombe, F. J. (1953). Sequential estimation. *J. Royal Statistic. Soc.* 15, 1–21. doi: 10.1111/J.2517-6161.1953.TB00121.X

Assari, S., and Mincy, R. (2021). Racism may interrupt age-related brain growth of African American children in the United States. *J. Pediatrics Child Health Care.* 6:1047.

Batai, K., Hooker, S., and Kittles, R. A. (2021). Leveraging genetic ancestry to study health disparities. *Am. J. Phys. Anthropol.* 175, 363–375. doi: 10.1002/AJPA.24144

Chan, M. Y., Na, J., Agres, P. F., Savalia, N. K., Park, D. C., and Wig, G. S. (2018). Socioeconomic status moderates age-related differences in the brain's functional network organization and anatomy across the adult lifespan. *Proc. Natl. Acad. Sci.* 115, E5144–E5153. doi: 10.1073/PNAS.1714021115

Chand, G. B., Wu, J., Qiu, D., and Hajjar, I. (2017). Racial differences in insular connectivity and thickness and related cognitive impairment in hypertension. *Front. Aging Neurosci.* 9:177. doi: 10.3389/FNAGI.2017.00177

Chiao, J. Y., and Cheon, B. K. (2010). The weirdest brains in the world. *Behav. Brain Sci.* 33, 88–90. doi: 10.1017/S0140525X10000282

Collins, J. W., David, R. J., Handler, A., Wall, S., and Andes, S. (2011). Very low birthweight in African American infants: the role of maternal exposure to interpersonal racial discrimination 94, 2132–2138. doi: 10.2105/AJPH.94.12.2132,

Cooper, C., Tandy, A. R., Balamurali, T. B. S., and Livingston, G. (2010). A systematic review and meta-analysis of ethnic differences in use of dementia treatment, care, and research. *Am. J. Geriatric Psychiatry* 18, 193–203. doi: 10.1097/JGP.0B013E3181BF9CAF

Dominguez, T. P. (2011). Adverse birth outcomes in African American women: the social context of persistent reproductive disadvantage 26, 3–16. doi: 10.1080/10911350902986880,

Dotson, V. M., and Duarte, A. (2020). The importance of diversity in cognitive neuroscience. *Ann. N. Y. Acad. Sci.* 1464, 181–191. doi: 10.1111/nyas.14268

Falk, E. B., Hyde, L. W., Mitchell, C., Faul, J., Gonzalez, R., Heitzeg, M. M., et al. (2013). What is a representative brain? Neuroscience meets population science. *Proceed. National Academy Sci. U. S. A.* 110, 17615–17622. doi: 10.1073/pnas.1310134110

Fan, C. C., Bartsch, H., Schork, A. J., Schork, N. J., Jernigan, T. L., and Dale Correspondence, A. M. (2015). Modeling the 3D geometry of the cortical surface with genetic ancestry. *Curr. Biol.* 25, 1988–1992. doi: 10.1016/j.cub.2015.06.006

Fani, N., Carter, S. E., Harnett, N. G., Ressler, K. J., and Bradley, B. (2021). Association of Racial Discrimination with Neural Response to threat in Black women in the US exposed to trauma. *JAMA Psychiatry* 78, 1005–1012. doi: 10.1001/JAMAPSYCHIATRY.2021.1480

Farah, M. J. (2017). The neuroscience of socioeconomic status: correlates, causes, and consequences. *Neuron* 96, 56–71. doi: 10.1016/J.NEURON.2017.08.034

Glasser, M. F., Smith, S. M., Marcus, D. S., Andersson, J. L. R., Auerbach, E. J., Behrens, T. E. J., et al. (2016). The human connectome Project's neuroimaging approach. *Nat. Neurosci.* 19, 1175–1187. doi: 10.1038/nn.4361

Glasser, M. F., Sotiropoulos, S. N., Wilson, A., Coalson, T. S., Fischl, B., Andersson, J. L., et al. (2013). The minimal preprocessing pipelines for the human connectome project. *NeuroImage* 80, 105–124. doi: 10.1016/j.neuroimage.2013.04.127

Grigoryeva, A., and Ruef, M. (2015). The historical demography of racial segregation. *Impact Factor* 80, 814–842. doi: 10.1177/0003122415589170

Gu, J., and Kanai, R. (2014). What contributes to individual differences in brain structure? *Front. Hum. Neurosci.* 8:262. doi: 10.3389/FNHUM.2014.00262/BIBTEX

Gur, R. E., Moore, T. M., Rosen, A. F. G., Barzilay, R., Roalf, D. R., Calkins, M. E., et al (2019). Burden of environmental adversity associated with psychopathology, maturation, and brain behavior parameters in youths. *JAMA Psych.* 76, 966–975. doi: 10.1001/JAMAPSYCHIATRY.2019.0943

Hardaway, C. R., and McLoyd, V. C. (2008). Escaping poverty and securing middle class status: how race and socioeconomic status shape mobility prospects for African Americans during the transition to adulthood. *J. Youth Adolesc.* 38, 242–256. doi: 10.1007/S10964-008-9354-Z

Harnett, N. G., Fani, N., Carter, S., Sanchez, L. D., Rowland, G. E., Davie, W. M., et al. (2023). Structural inequities contribute to racial/ethnic differences in neurophysiological tone, but not threat reactivity, after trauma exposure. *Mol. Psychiatry* 28, 2975–2984. doi: 10.1038/s41380-023-01971-x

Helms, J. E. (1995). An update of Helm's White and people of color racial identity models. *Handbook of multicultural counseling.* (eds.) J. G. Ponterotto, J. M. Casas, L. A. Suzuki, and C. M. Alexander. Sage Publications, Inc. 181–198.

Hetey, R. C., and Eberhardt, J. L. (2018). The numbers Don't speak for themselves: racial disparities and the persistence of inequality in the criminal justice. *System* 27, 183–187. doi: 10.1177/0963721418763931

Hill, N. E., Jeffries, J. R., and Murray, K. P. (2017). New tools for old problems: inequality and educational opportunity for ethnic minority youth and parents 674, 113–133. doi: 10.1177/0002716217730618,

Ho, A. J., Raji, C. A., Becker, J. T., Lopez, O. L., Kuller, L. H., Hua, X., et al. (2011). The effects of physical activity, education, and body mass index on the aging brain. *Hum. Brain Mapp.* 32, 1371–1382. doi: 10.1002/HBM.21113

Hodge, M. R., Horton, W., Brown, T., Herrick, R., Olsen, T., Hileman, M. E., et al. (2015). ConnectomeDB-sharing human brain connectivity data. *NeuroImage* 124, 1102–1107. doi: 10.1016/j.neuroimage.2015.04.046

Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scand. J. Stat.* 6, 65–70.

Holz, N. E., Boecker, R., Hohm, E., Zohsel, K., Buchmann, A. F., Blomeyer, D., et al. (2014). The long-term impact of early life poverty on orbitofrontal cortex volume in adulthood: results from a prospective study over 25 years. *Neuropsychopharmacology* 40, 996–1004. doi: 10.1038/npp.2014.277

Hughes, M., Kiecolt, K. J., Keith, V. M., and Demo, D. H. (2015). Racial identity and well-being among African Americans. *Soc. Psychol. Quart.* 78, 25–48. doi: 10.1177/0190272514554043,

Huston, A. C., and Bentley, A. C. (2009). Human development in societal. *Context.* 61, 411–437. doi: 10.1146/ANNUREV.PSYCH.093008.100442

Huttenlocher, P. R. (1990). Morphometric study of human cerebral cortex development. *Neuropsychologia* 28, 517–527. doi: 10.1016/0028-3932(90)90031-I

Isamah, N., Faison, W., Payne, M. E., MacFall, J., Steffens, D. C., Beyer, J. L., et al. (2010). Variability in frontotemporal brain structure: the importance of recruitment of African Americans in neuroscience research. *PLoS One* 5:e13642. doi: 10.1371/journal.pone.0013642

Jha, S. C., Xia, K., Ahn, M., Girault, J. B., Li, G., Wang, L., et al. (2019). Environmental influences on infant cortical thickness and surface area. *Cereb. Cortex* 29, 1139–1149. doi: 10.1093/CERCOR/BHY020

Johnson, O. (2014). Still separate, still unequal: the relation of segregation in neighborhoods and schools to education inequality. *J. Negro Educ.* 83, 199–215. doi: 10.7709/JNEGROEDUCATION.83.3.0199

Kang, D. W., Wang, S. M., Na, H. R., Park, S. Y., Kim, N. Y., Lee, C. U., et al. (2020). Differences in cortical structure between cognitively normal east Asian and Caucasian older adults: a surface-based morphometry study. *Scientific Reports* 10, 1–9. doi: 10.1038/s41598-020-77848-8

Kaur, A., and Kumar, R. (2015). Comparative analysis of parametric and non-parametric tests. *J. Comput. Mathematical Sci.* 6, 336–342.

Konkel, L. (2015). Racial and ethnic disparities in research studies: the challenge of creating more diverse cohorts. *Environ. Health Perspect.* 123, A297–A302. doi: 10.1289/ehp.123-A297

Laveist, T., Gaskin, D., and Richard, P. (2011). Estimating the economic burden of racial health inequalities in the United States. *Int. J. Health Serv.* 41, 231–238. doi: 10.2190/HS.41.2.c

Lewis, T. T., Barnes, L. L., Bienias, J. L., Lackland, D. T., Evans, D. A., and Mendes De Leon, C. F. (2009). Perceived discrimination and blood pressure in older African American and White adults. *J. Gerontol.* 64A, 1002–1008. doi: 10.1093/GERONA/GLP062

Marinescu, R. V., Eshaghi, A., Alexander, D. C., and Golland, P. (2019). BrainPainter: A software for the visualisation of brain structures, biomarkers and associated pathological processes. Multimodal brain image analysis and mathematical foundations of computational anatomy: In 4th International Workshop, MBIA 2019, and 7th International Workshop, MFCA 2019, held in conjunction with MICCAI 2019, Shenzhen, China, October 17

McDermott, M., and Samson, F. L. (2005). White racial and ethnic identity in the United States 31, 245–261. doi: 10.1146/ANNUREV.SOC.31.041304.122322,

Mietchen, D., and Gaser, C. (2009). Computational morphometry for detecting changes in brain structure due to development, aging, learning, disease and evolution. *Front. Neuroinform.* 3:25. doi: 10.3389/neuro.11.025.2009

Monk, E. P. (2015). The cost of color: skin color, discrimination, and health among African-Americans1 121, 396–444. doi: 10.1086/682162

Noble, K. G., Houston, S. M., Brito, N. H., Bartsch, H., Kan, E., Kuperman, J. M., et al. (2015). Family income, parental education and brain structure in children and adolescents. *Nat. Neurosci.* 18, 773–778. doi: 10.1038/nn.3983

Panizzon, M. S., Fennema-Notestine, C., Eyler, L. T., Jernigan, T. L., Prom-Wormley, E., Neale, M., et al. (2009). Distinct genetic influences on cortical surface area and cortical thickness. *Cereb. Cortex* 19, 2728–2735. doi: 10.1093/cercor/bhp026

Peterson, R. L., Fain, M. J., Butler, E. A., Ehiri, J. E., and Carvajal, S. C. (2020). The role of social and behavioral risk factors in explaining racial disparities in age-related cognitive impairment: a structured narrative review. *Aging Neuropsychol. Cognit.* 27, 173–196. doi: 10.1080/13825585.2019.1598539

Rakic, P. (2009). Evolution of the neocortex: A perspective from developmental biology. *Nature Reviews Neuroscience Nature Publishing Group.* 10, 724–735. doi: 10.1038/nrn2719

Rao, N. P., Jeelani, H., Achalia, R., Achalia, G., Jacob, A., Dawn Bharath, R., et al. (2017). Population differences in brain morphology: need for population specific brain template. *Psychiatry Res. Neuroimaging* 265, 1–8. doi: 10.1016/j.pscychresns.2017.03.018

Ricard, J. A., Parker, T. C., Dhamala, E., Kwasa, J., Allsop, A., and Holmes, A. J. (2022). Confronting racially exclusionary practices in the acquisition and analyses of neuroimaging data. *Nat. Neurosci.* 26, 4–11. doi: 10.1038/s41593-022-01218-y

Rouan, J., Velazquez, G., Freischlag, J., and Kibbe, M. R. (2021). Publication bias is the consequence of a lack of diversity, equity, and inclusion. *J. Vasc. Surg.* 74, 111S–117S. doi: 10.1016/J.JVS.2021.03.049

Schooley, R. C., Lee, D. L., and Spanierman, L. B. (2019). Measuring whiteness: a systematic review of instruments and call to action. *Counsel. Psychol.* 47, 530–565. doi: 10.1177/0011000019883261

Smith, C. D., Chebrolu, H., Wekstein, D. R., Schmitt, F. A., and Markesbery, W. R. (2007). Age and gender effects on human brain anatomy: A voxel-based morphometric study in healthy elderly. *Neurobiol. Aging* 28, 1075–1087. doi: 10.1016/J.NEUROBIOLAGING.2006.05.018

Smith, S. M., and Nichols, T. E. (2018). Statistical challenges in "big data" human neuroimaging. *Neuron* 97, 263–268. doi: 10.1016/J.NEURON.2017.12.018

Takahashi, R., Ishii, K., Kakigi, T., and Yokoyama, K. (2011). Gender and age differences in normal adult human brain: voxel-based morphometric study. *Hum. Brain Mapp.* 32, 1050–1058. doi: 10.1002/HBM.21088

Tang, Y., Hojatkashani, C., Dinov, I. D., Sun, B., Fan, L., Lin, X., et al. (2010). The construction of a Chinese MRI brain atlas: A morphometric comparison study between Chinese and Caucasian cohorts. *NeuroImage* 51, 33–41. doi: 10.1016/J.NEUROIMAGE.2010.01.111

Toldson, I. L., and Toldson, I. A. (2001). Biomedical Ethics: an African-centered psychological perspective. *Biomed. Ethics J. Black Psychol.* 27, 401–423. doi: 10.1177/0095798401027004002

van Essen, D. C., Ugurbil, K., Auerbach, E., Barch, D., Behrens, T. E. J., Bucholz, R., et al. (2012). The human connectome project: A data acquisition perspective. *NeuroImage* 62, 2222–2231. doi: 10.1016/j.neuroimage.2012.02.018

Weinberger, D. R., Dzirasa, K., and Crumpton-Young, L. L. (2020). Missing in action: African ancestry brain research. *Neuron* 107, 407–411. doi: 10.1016/J.NEURON.2020.07.008

Wheeler, B., and Torchiano, M. (2016). *Permutation tests for linear models in R*. Available at: https://cran.microsoft.com/web/packages/lmPerm/vignettes/lmPerm.pdf (Accessed August 21, 2022).

White, T. L., and Gonsalves, M. A. (2021). Dignity neuroscience: universal rights are rooted in human brain science. *Ann. N. Y. Acad. Sci.* 1505, 40–54. doi: 10.1111/NYAS.14670

Williams, D. R. (2018). Stress and the mental health of populations of color: advancing our understanding of race-related stressors. *J. Health Soc. Behav.* 59, 466–485. doi: 10.1177/0022146518814251

Yearby, R. (2018). Racial disparities in health status and access to healthcare: the continuation of inequality in the United States due to structural racism. *Am. J. Econ. Sociol.* 77, 1113–1152. doi: 10.1111/AJES.12230

Younan, D., Wang, X., Gruenewald, T., Gatz, M., Serre, M. L., Vizuete, W., et al. (2021). Racial/ethnic disparities in Alzheimer's disease risk: role of exposure to ambient fine particles. *J. Gerontol.* 77, 977–985. doi: 10.1093/GERONA/GLAB231

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Might culture impact the assessment of handedness in Black participants in neuroscience research?

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black, culture, diversity, neuroscience, hand dominance, handedness screening assessments

Introduction

There is growing evidence to suggest cognitive impairment and adverse brain health outcomes are associated with chronic health conditions such as diabetes, hypertension, and cardiovascular disease (Barnes and Bennett, 2014; Lock et al., 2023; National Academies of Sciences et al., 2023). These conditions can contribute to cognitive dysfunction by disrupting physiological feedback mechanisms that regulate oxidative stress (Pugazhenthi et al., 2017), causing fluctuations in systemic blood pressure (Wanleenuwat et al., 2019), or promoting vasoconstriction that impairs cerebral perfusion (Stephan et al., 2017). The higher prevalence of these conditions in the Black population (Ajuwon and Love, 2020; Musemwa and Gadegbeku, 2017; Wang et al., 2021) may be associated with an increased risk of dementias, such as Alzheimer's disease, increasingly seen in Black Americans (Basu and Gujral, 2020; Rajan et al., 2019).

While the compelling scientific need for further evaluation of these connections may be helpful in addressing Black health disparities, neuroscience studies have often been slow to advance such contributions in the United States (U.S.) Black population (Burke et al., 2017; Zuelsdorff et al., 2020). This may stem from underpowered Black participation in neuroscience research (Rutten-Jacobs et al., 2024), which is commonly attributed to historically rooted mistrust in medical research (Otado et al., 2015; Scharff et al., 2010; Webb et al., 2022) or ineffective sampling (Abiodun, 2019; Awidi and Hadidi, 2021). An often-overlooked factor that may further impact the inclusion of Black participants in neuroscience studies is researchers' decision-making processes for participants who report forced hand use on screening assessments.

Handedness screening assessments are a common method for establishing hand dominance in neuroscience studies (Scharoun and Bryden, 2014). Hand "dominance" is characterized by a distinct affinity for the hand that demonstrates the highest proficiency when performing manual tasks (Serrien et al., 2006), while hand "preference" is defined by the hand an individual habitually selects for task performance, independent of proficiency (Chatagny et al., 2013). Handedness is believed to influence an individual's mental and neuropsychological abilities (Johncy et al., 2021). Researchers, particularly in human neuroscience, may selectively analyze the data of right-handed individuals to minimize variance in datasets (Bailey et al., 2019; Willems et al., 2014). Unrealized biases embedded in handedness screening tools may unknowingly facilitate misclassification error for Black participants with a history of culturally influenced handedness practices.

Researchers' understanding of how cultural and religious practices shape handedness in diverse Black communities could affect the internal validity of handedness assessment tools that assess forced hand use. We encountered this issue in a preliminary study on racism and cognitive processing, where assumptions about responses to forced hand use, and its potential link to hand dominance, were susceptible to misunderstandings of the cultural and religious factors influencing forced use. Given the need for greater inclusion in neuroscience research, an examination of the decision-making methods surrounding Black participants' employment of handedness warrants further investigation. Examining how cultural and religious practices are established within the Black population and their relationship to handedness could serve as one intervention to increase researchers' acceptance of Black participants who report a history of forced hand use.

Understanding cultural/religious right-hand practices of African immigrant populations and their descendants

When assessing handedness in culturally diverse populations, it is useful to establish criteria for including or excluding individuals based on the forced use of the right hand, given the historical preference for right-handedness in formal and functional tasks (De Kovel et al., 2019; Galobardes et al., 1999; Klöppel et al., 2010). In some West African countries like Ghana, Nigeria, and Senegal individuals can display a preference for the right hand when performing tasks that require direct contact with others (Alhassan, 2018). Conversely, in these same regions, the left hand is perceived as dirty or intolerable (Awidi and Hadidi, 2021) and relegated to private tasks such as washing one's body or using the bathroom. In particular, the rare hereditary pattern of left handedness may contribute to its cultural perception as an unlucky trait, leading to public avoidance of left-hand use (Jing, 2020). In other words, the use of the right or left hand for a particular activity may not be a matter of dominance nor preference but an enforced practice honored by one's culture.

The left hand is also subject to stigmatization within the religious teachings of Christianity and Islam, commonly practiced among African and African American communities (Agbiji and Swart, 2015; Park et al., 2020; Simmons, 2008). Christian doctrines have historically associated left handedness with the devil (Hertz, 2013), while Islamic scriptures have regarded the left hand as a symbol of uncleanliness or impurity (Fagard and Dahmen, 2004; Singh and Kundu, 1994). Devoutly religious individuals may therefore refrain from using their left hand during social activities, even for simple gestures like handing over an object or receiving money, as they can have significant social repercussions (Alhassan, 2018). To avoid ostracism, adherents to religious customs must often consciously use the right or left hand in a socially cued manner. Consideration of such practices in the Black diaspora may enhance the efficacy of screening protocols while allowing for the appropriate determination of handedness (Shanunu et al., 2022; Zverev, 2006).

This is important knowledge to incorporate in handedness assessments as a longitudinal analysis of U.S. migration trends revealed that the Black population grew by 20 million over the last four decades (Tamir and Anderson, 2022). Additionally, Tamir (2022) reported that the number of Black immigrants living in the U.S. reached 4.6 million in 2019, a substantial increase from the documented 800,000 in 1980. This growth represents nearly a fifth of the total Black population and it is projected that Black immigrants will contribute to approximately one-third of the overall increase in the U.S. Black population's growth by 2060 (Tamir, 2022). Presently, one in every ten Black Americans is foreign-born and these immigrants often maintain strong religious affiliations that underpin their handedness practices (Mohamed et al., 2021; Shanunu et al., 2022). While such ideologies may originate in Africa, cultural socialization plays a significant role in defining the identity of ethnic-racial populations (Wang et al., 2023). Individuals of African ancestry may retain handedness habits passed down from previous familial generations. With the growing influx of African immigrants to the U.S. (Corra, 2023), an effort to recognize their cultural handedness behaviors is essential to effectively refining research screening tools to ensure the integrity of scientific practices in neuroscience research. Further, it would be worth investigating whether these socialized hand preferences correlate to shifts in brain laterality.

Integration of cultural competencies in handedness assessments

A primary goal of handedness screening assessments is to determine an individual's hand dominance based on their reported hand preference across a variety of tasks. These assessments draw from a basic inventory to evaluate hand dominance, with some screening tools incorporating additional survey questions that examine the influence of familial factors on handedness (Klöppel et al., 2010). Inventories typically include questions about the direction and degree of hand use for routine activities, such as writing, eating, and throwing, while concurrently assessing how frequently one hand is favored over the other (Oldfield, 1971). While handedness inventories are generally regarded as a reliable instrument for evaluating hand dominance, it is important to heed the caution given by psychologist Richard Charles Oldfield, inventor of the Edinburgh Handedness Inventory (EHI). Oldfield acknowledged that the selection of tasks in such inventories requires greater cultural sensitivity to be universally applicable to participants of differing social groups, including variations in sex, culture, nationality, and socioeconomic status (Oldfield, 1971). For example, researchers translating an English version of the EHI within a Chinese validity study identified tasks in the questionnaire that could be revised to better model Chinese practices. Altering a task description from "knife without a fork" to "knife to cut meat or vegetables," and replacing "spoon" with "chopsticks" ensured that the language used in the EHI was more aligned with Chinese culture (Yang et al., 2018).

Our team's experimental study on racism and cognitive function among Black males revealed the potential for cultural perspectives to influence handedness assessment responses. Participants born to West African immigrants were more likely to report mixed hand use or forced hand conversion. These individuals were initially excluded from the study by us, resulting in an overall decline in the number of eligible participants. To better understand this occurrence, we asked participants to provide more details about their responses to the questionnaire. We discovered that our handedness assessment may not have accounted for African cultural and religious practices where the right hand is traditionally reserved for formal tasks and the left hand for chores (Alhassan, 2018; Awidi and Hadidi, 2021).

Participants in our study frequently sought clarification on a particular survey question about forced right-hand conversion (see Supplementary material). Our team later identified two distinct interpretations of this question by participants. The first interpretation was perceived as whether a parent ever attempted to convert the participant's true handedness from left to right. Meanwhile, the second interpretation was perceived as whether a parent required the participant to temporarily use a preferred hand during task performance. As a result, responses could have different implications depending on participants' comprehension of the question. For example, marking "yes" to the latter interpretation might indicate that the use of the right hand was enforced short-term for specific tasks rather than as a permanent change in handedness.

On the contrary, marking "yes" may lead researchers to conclude that a participant has spent significant effort in converting their handedness to the right side. This is a critical inference because, if a serious attempt at hand conversion is assumed, scientists may believe that permanent changes to brain laterality have occurred (Siebner et al., 2002). Such an assumption could lead to the potential dismissal of participants from a study. Given this implication, further research is needed to examine how cultural practices influence assessment responses across the broader Black community and whether they impact hand dominance, leading to long-term brain changes.

Potential culturally sensitive modifications to handedness screening assessments

To improve the internal validity of screening tools, adding questions that address the role of culture and religion could provide a more holistic understanding of handedness in ethnically diverse populations. We suggest incorporating questions designed to determine if a cultural or religious practice might account for a dextral response. We recommend including questions that examine whether:

- Participants experience forced changes in handedness based on cultural or religious beliefs (i.e., were you forced to use your preferred hand for this task due to a cultural or religious belief?).
- Hand preference deviates from hand dominance (i.e., is your preferred hand for this task different from your dominant hand?).
- Frequency of the hand used in tasks is equivalent to the assumption of handedness (i.e., how often do you utilize this task in your daily routine?).

Adopting such changes may enlighten neuroscience researchers about the sociocultural dimensions of handedness. A related concern beyond the screening itself is the unavailability of a scientific workforce that can and will drive a research agenda inclusive of racial/ethnic/religious factors that may matter in neuroscience research. Addressing this requires continued efforts to diversify the workforce and incorporate varied perspectives throughout the research process. One effective approach would be for research teams studying culturally diverse populations to enlist community advisory boards (La Scala et al., 2023). These boards, composed of members representative of the study population, can critically review screening tools, and determine whether tasks and associated survey questions are culturally appropriate.

Conclusion

To advance our knowledge of how cultural and religious differences impact handedness screening tools, careful assessment of handedness research protocols is needed. In the face of improved tools for determining lateralization, neuroscience researchers should consider including left-handed individuals as stratified samples in cognitive studies, as this may help reveal the impact of handedness on cognitive function. To improve the internal validity of handedness research, future studies should examine the effects of culture and religion on hand dominance and its relationship to structure and function in the brain. Researchers can help mitigate disparities in neuroscience research by carefully evaluating tools for potential bias, and thoroughly assessing study inclusion/exclusion criteria that may unknowingly exclude those who bear a greater burden of health disparities. Neuroscience research stands to benefit from reducing brain health disparities in Black populations by driving research agendas whose criteria and knowledge of diversity is based on inclusive science.

Author contributions

MN: Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. AO: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. CM: Investigation, Writing – original draft, Writing – review & editing. JS: Conceptualization, Project administration, Supervision, Writing – review & editing. EZ: Conceptualization, Project administration, Supervision, Writing – original draft. VM: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnhum.2024.1390881/full#supplementary-material

References

Abiodun, S. J. (2019). "Seeing Color," a discussion of the implications and applications of race in the field of neuroscience. *Front. Hum. Neurosci.* 13:280. doi: 10.3389/fnhum.2019.00280

Agbiji, O. M., and Swart, I. (2015). Religion and social transformation in Africa: a critical and appreciative perspective. *Scriptura* 114, 1–20. doi: 10.7833/114-0-1115

Ajuwon, A. M., and Love, R. (2020). Type 2 diabetes and depression in the African American population. *J. Am. Assoc. Nurse Pract.* 32, 120–127. doi: 10.1097/JXX.0000000000000240

Alhassan, A. B. (2018). Left-handedness and stigmatization in Africa: implications for parents and teachers. *Global J. Archaeol. Anthropol.* 7, 1–5. doi: 10.19080/GJAA.2018.07.555713

Awidi, M., and Hadidi, S. (2021). Participation of Black Americans in cancer clinical trials: current challenges and proposed solutions. *JCO Oncol. Pract.* 17, 265–271. doi: 10.1200/OP.21.00001

Bailey, L. M., McMillan, L. E., and Newman, A. J. (2019). A sinister subject: quantifying handedness-based recruitment biases in current neuroimaging research. *Eur. J. Neurosci.* 51, 1642–1656. doi: 10.1111/ejn.14542

Barnes, L. L., and Bennett, D. A. (2014). Alzheimer's disease in African Americans: risk factors and challenges for the future. *Health Affairs* 33, 530–536. doi: 10.1377/hlthaff.2013.1353

Basu, A., and Gujral, K. (2020). Evidence generation, decision making, and consequent growth in health disparities. *Proc. Natl. Acad. Sci. USA.* 117, 14042–14051. doi: 10.1073/pnas.1920197117

Burke, S. L., Cadet, T., and Maddux, M. (2017). Chronic health illnesses as predictors of mild cognitive impairment among African American older adults. *J. Natl. Med. Assoc.* 110, 314–325. doi: 10.1016/j.jnma.2017.06.007

Chatagny, P., Badoud, S., Kaeser, M., Gindrat, A., Savidan, J., Fregosi, M., et al. (2013). Distinction between hand dominance and hand preference in primates: a behavioral investigation of manual dexterity in nonhuman primates (macaques) and human subjects. *Brain Behav.* 3, 575–595. doi: 10.1002/brb3.160

Corra, M. (2023). Immigration from Africa to the United States: key insights from recent research. *Front. Sociol.* 8:1171818. doi: 10.3389/fsoc.2023.1171818

De Kovel, C. G., Carrión-Castillo, A., and Francks, C. (2019). A large-scale population study of early life factors influencing left-handedness. *Sci. Rep.* 9:584. doi: 10.1038/s41598-018-37423-8

Fagard, J., and Dahmen, R. (2004). Cultural influences on the development of lateral preferences: a comparison between French and Tunisian children. *Laterality* 9, 67–78. doi: 10.1080/13576500342000167

Galobardes, B., Bernstein, M. S., and Morabia, A. (1999). The association between switching hand preference and the declining prevalence of left-handedness with age. *Am. J. Public Health* 89, 1873–1875. doi: 10.2105/AJPH.89.12.1873

Hertz, R. (2013). The pre-Eminence of the right hand. *HAU* 3, 335–357. doi: 10.14318/hau3.2.024

Jing, S. S. (2020). Hand dominance: nature, nurture, and relevance for hand surgeons. *J. Hand Microsurg.* 14, 111–112. doi: 10.1055/s-0040-1713557

Johncy, S. S., Sau, M., T., and Samuel, T. V. (2021). Impact of handedness on mental and neuropsychological performance in young adults. *Natl. J. Physiol. Phar. Pharmacol.* 11, 51–55. doi: 10.5455/njppp.2021.10.08213202003092020

Klöppel, S., Mangin, J., Vongerichten, A., Frackowiak, R. S., and Siebner, H. R. (2010). Nurture versus nature: long-term impact of forced right-handedness on structure of pericentral cortex and basal ganglia. *J. Neurosci.* 30, 3271–3275. doi: 10.1523/JNEUROSCI.4394-09.2010

La Scala, S., Mullins, J. L., Firat, R. B., Emotional Learning Research Community Advisory, B.oard, and Michalska, K. J. (2023). Equity, diversity, and inclusion in developmental neuroscience: practical lessons from community-based participatory research. *Front. Integr. Neurosci.* 16:1007249. doi: 10.3389/fnint.2022.1007249

Lock, S. L., Chura, L. R., Dilworth-Anderson, P., and Peterson, J. (2023). Equity across the life course matters for brain health. *Nat. Aging* 3, 466–468. doi: 10.1038/s43587-023-00413-1

Mohamed, B., Cox, K., Diamant, J., and Gecewicz, C. (2021). Faith among Black Americans. *Pew Research Center.* Available at: https://www.pewresearch.org/religion/2021/02/16/faith-among-black-americans/ (accessed September 18, 2024).

Musemwa, N., and Gadegbeku, C. A. (2017). Hypertension in African Americans. *Curr. Cardiol. Rep.* 19:129. doi: 10.1007/s11886-017-0933-z

National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Health Sciences Policy; Forum on Neuroscience and Nervous System Disorders, Posey Norris, S. M., Childers, E., and Brookshire, B. (2023). *Health Disparities in Central Nervous System Disorders: Access to Care: Proceedings of a Workshop—in Brief.* New York: National Academies Press (US).

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia* 9, 97–113. doi: 10.1016/0028-3932(71)90067-4

Otado, J., Kwagyan, J., Edwards, D., Ukaegbu, A., Rockcliffe, F., and Osafo, N. (2015). Culturally competent strategies for recruitment and retention of african american populations into clinical trials. *Clin. Transl. Sci.* 8, 460–466. doi: 10.1111/cts.12285

Park, J., Chang, J., and Davidson, J. (2020). Equal opportunity beliefs beyond black and white American Christianity. *Religions* 11:348. doi: 10.3390/rel11070348

Pugazhenthi, S., Qin, L., and Reddy, P. H. (2017). Common neurodegenerative pathways in obesity, diabetes, and Alzheimer's disease. *Biochim. Biophys. Acta Mol. Basis Dis.* 1863, 1037–1045. doi: 10.1016/j.bbadis.2016.04.017

Rajan, K. B., Weuve, J., Barnes, L. L., Wilson, R. S., and Evans, D. A. (2019). Prevalence and incidence of clinically diagnosed Alzheimer's disease dementia from 1994 to 2012 in a population study. *Alzheimer's Demen.* 15, 1–7. doi: 10.1016/j.jalz.2018.07.216

Rutten-Jacobs, L., McIver, T., Reyes, A., Pereira, M., Rosenthal, R., Parusel, C. T., et al. (2024). Racial and ethnic diversity in global neuroscience clinical trials. *Contempor. Clin. Trials Commun.* 37:101255. doi: 10.1016/j.conctc.2024.101255

Scharff, D., Mathews, K., Jackson, P., Hoffsuemmer, J., Martin, E., and Edwards, D. (2010). More than tuskegee: understanding mistrust about research participation. *J. Health Care Poor Underser.* 21, 879–897. doi: 10.1353/hpu.0.0323

Scharoun, S. M., and Bryden, P. J. (2014). Hand preference, performance abilities, and hand selection in children. *Front. Psychol.* 5:82. doi: 10.3389/fpsyg.2014.00082

Serrien, D. J., Ivry, R. B., and Swinnen, S. P. (2006). Dynamics of hemispheric specialization and integration in the context of motor control. *Nat. Rev. Neurosci.* 7, 160–166. doi: 10.1038/nrn1849

Shanunu, Z., Ibrahim, M. G., and Alhassan, E. (2022). Cultural underpinnings on the use of left-hand in Gbanjong community of the Tolon district of Ghana. *J. Educ. Lear. Technol.* 3, 13–27. doi: 10.38159/jelt.2022321

Siebner, H. R., Limmer, C., Peinemann, A., Drzezga, A., Bloem, B. R., Schwaiger, M., et al. (2002). Long-term consequences of switching handedness: a positron emission tomography study on handwriting in "converted" left-handers. *J. Neurosci.* 22, 2816–2825. doi: 10.1523/JNEUROSCI.22-07-02816.2002

Simmons, G. (2008). From Muslims in America to American Muslims. *J. Islamic Law Cult.* 10, 254–280. doi: 10.1080/15288170802481145

Singh, M., and Kundu, A. (1994). Hand preference and approval among Hindus and Muslims in India. *Int. J. Neurosci.* 75, 19–29. doi: 10.3109/00207459408986285

Stephan, B., Harrison, S. L., Keage, H., Babateen, A., Robinson, L., and Siervo, M. (2017). Cardiovascular disease, the nitric oxide pathway and risk of cognitive impairment and dementia. *Curr. Cardiol. Rep.* 19:87. doi: 10.1007/s11886-017-0898-y

Tamir, C. (2022). Key findings about Black immigrants in the U.S. *Pew Research Center.* Available at: https://www.pewresearch.org/short-reads/2022/01/27/key-findings-about-black-immigrants-in-the-u-s/#:$\sim$:text=One%2Din%2Dten%20Black%20people,million%20during%20the%20same%20period (accessed September 14, 2024).

Tamir, C., and Anderson, M. (2022). One-in-Ten Black People Living in the U.S. are Immigrants. *Pew Research Center.* Available at: https://www.pewresearch.org/race-ethnicity/2022/01/20/one-in-ten-black-people-living-in-the-u-s-are-immigrants/ (accessed September 17, 2024).

Wang, Q., Davis, P. B., Gurney, M. E., and Xu, R. (2021). COVID-19 and dementia: Analyses of risk, disparity, and outcomes from electronic health records in the US. *Alzheimer's Dement.* 17, 1297–1306. doi: 10.1002/alz.12296

Wang, Y., Zhang, Y., and Wadsworth, H. (2023). Family and peer ethnic-racial socialization in adolescents' everyday life: a daily transactional model with ethnic-racial identity and discrimination. *Child Dev.* 94, 1566–1580. doi: 10.1111/cdev.13937

Wanleenuwat, P., Iwanowski, P., and Kozubski, W. (2019). Alzheimer's dementia: pathogenesis and impact of cardiovascular risk factors on cognitive decline. *Postgrad. Med.* 131, 415–422. doi: 10.1080/00325481.2019.1657776

Webb, E., Etter, J., and Kwasa, J. (2022). Addressing racial and phenotypic bias in human neuroscience methods. *Nat. Neurosci.* 25, 410–414. doi: 10.1038/s41593-022-01046-0

Willems, R. M., Van der Haegen, L., Fisher, S. E., and Francks, C. (2014). On the other hand: including left-handers in cognitive neuroscience and neurogenetics. *Nat. Rev. Neurosci.* 15, 193–201. doi: 10.1038/nrn3679

Yang, N., Waddington, G., Adams, R., and Han, J. (2018). Translation, cultural adaptation, and test-retest reliability of Chinese versions of the edinburgh handedness inventory and waterloo footedness questionnaire. *Laterality* 23, 255–273. doi: 10.1080/1357650X.2017.1357728

Zuelsdorff, M., Okonkwo, O. C., Norton, D., Barnes, L. L., Graham, K. L., Clark, L. R., et al. (2020). Stressful life events and racial disparities in cognition among middle-aged and older adults. *JAD* 73, 671–682. doi: 10.3233/JAD-190439

Zverev, Y. (2006). Cultural and environmental pressure against left-hand preference in urban and semi-urban Malawi. *Brain Cogn.* 60, 295–303. doi: 10.1016/j.bandc.2005.07.008

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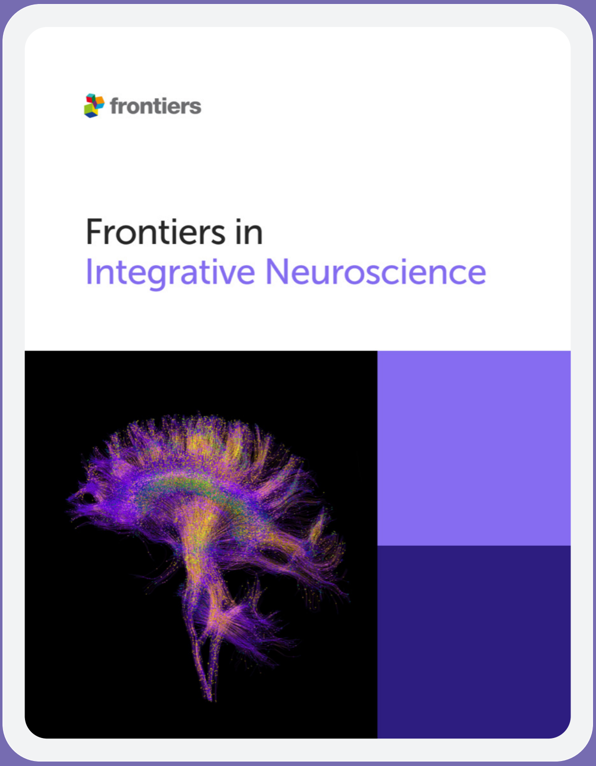

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