nature neuroscience

Perspective

https://doi.org/10.1038/s41593-024-01832-y

Considering the interconnected nature of social identities in neuroimaging research

Received: 30 November 2023

Accepted: 24 October 2024

Published online: 27 December 2024

Check for updates

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Considerable heterogeneity exists in the expression of complex human behaviors across the cognitive, personality and mental health domains. It is increasingly evident that individual variability in behavioral expression is substantially affected by sociodemographic factors that often interact with life experiences. Here, we formally address the urgent need to incorporate intersectional identities in neuroimaging studies of behavior, with a focus on research in mental health. We highlight how diverse sociodemographic factors influence the study of psychiatric conditions, focusing on how interactions between those factors might contribute to brain biology and illness expression, including prevalence, symptom burden, help seeking, treatment response and tolerance, and relapse and remission. We conclude with a discussion of the considerations and actionable items related to participant recruitment, data acquisition and data analysis to facilitate the inclusion and incorporation of diverse intersectional identities in neuroimaging.

Human behaviors are intimately related to neurobiology and life experiences. These influences on behavior are further interwoven with distinct sociodemographic identities, including but not limited to age, sex, gender, race, ethnicity, socioeconomic status, neurodivergence, physical ability status, religion, political beliefs and sexual orientation. These identities are linked to individual variability in the prevalence, expression and trajectory of psychiatric illnesses along a multidimensional continuum[1]. For example, depression diagnoses vary by sex, gender[2] and socioeconomic status[3], whereas suicide risk differs by sex, gender, age, socioeconomic status and employment status, among other factors[4]. To understand the integral relationships between neurobiology, the environment and behavior, we here discuss a biopsychosocial model of health and disease considering the independent and intersectional influences of sociodemographic identities[5]. Accounting for interindividual variations in these factors is crucial for moving away from nosological 'one-size-fits-all' medicine and toward personalized diagnosis and treatment.

Over the last few decades, our understanding of the neurobiological underpinnings of human behavior and psychiatric illness has considerably advanced. However, the influence of biological systems on health and disease has largely been studied without considering individual sociocultural and environmental factors, limiting the generalizability of scientific findings[6,7]. The continued exclusion of minoritized, marginalized and disadvantaged populations from research further limits the joint study of biological and sociocultural factors[7,8]. However, it is not only the inclusion of certain populations but also study design and analytical choices that matter. Scientific research and the accompanying medical advancements have thus benefited certain populations over others, exacerbating healthcare inequities across sociodemographic groups[9].

Recognizing the effect of exclusion, researchers, academic institutions, funding agencies and scientific publishers have implemented policies to make research more inclusive. However, despite these mandates, much of the current research still lacks appropriate analyses of

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https://doi.org/10.1038/s41593-024-01832-y

BOX 1

Importance of considering intersectionality in preclinical research

A challenge in preclinical work is the ability to improve translation as a large percentage of clinical trials fail[136]. The high failure rate may be due, in part, to the lack of attention to intersecting variables on the biological (sex, age and genotype) and environmental (cage bedding, cage size, diet, room temperature, light and humidity) sides. Indeed, these variables influence brain structure, electrophysiology and behavior. Sex influences the morphology and electrophysiological properties of the cortical and subcortical brain regions[137]. Even with funding agencies mandating the incorporation of sex as a biological variable in preclinical research, few studies in neuroscience have used sex as a meaningful variable or in an optimal way for the discovery of possible sex differences[10]. Historically, it was argued that female species are more variable than male species. However, male and female species are not inherently more variable across a wide range of physiological and behavioral measures[138]. Indeed, housing conditions may create more variability than sex[138]. Housing conditions can affect dominance status and social support, both of which can affect brain outcomes[139,140]. The environment has a large role in brain outcomes in laboratory rodents as enriched versus impoverished environments are known to influence brain plasticity and behavior[141]. The ability of enriched environments to influence brain plasticity depends on several factors, including the timing and duration of exposure, animal strain, type of enrichment and sex[142–144]. Modulating environments in animal models can be used as a model of socioeconomic status (as there are similarities in outcomes[145]) and underscore the importance of considering intersectionality in animal models. Given the myriad experiential effects that influence brain structure, electrophysiology, brain activation and behavior, and that can modulate associated group differences, it is clear that preclinical work will benefit from paying attention to intersectionality factors, which will undoubtedly improve translational value.

these sociodemographic factors as meaningful variables[10–13]. Here, we highlight recent progress in understanding how sociodemographic identities can influence the brain and behavior. Moreover, we outline recommendations for participant recruitment, data acquisition and data analysis to facilitate the inclusion and study of diverse populations. While we primarily focus on neuroimaging and mental health research, the issues discussed here and the recommendations provided also apply to basic and clinical neuroscience studies, including preclinical research (Box 1).

Discrimination, intersectionality and neuroimaging research

Stigma refers to attitudes or beliefs about an individual on the basis of group membership, whereas discrimination is the unfair or disadvantaged treatment owing to that group membership[14]. Individuals who are part of one or more disadvantaged groups are more likely to accumulate additional disadvantaged statuses throughout their lifetime, further increasing their risk for discrimination[15]. Individuals with psychiatric illnesses are more likely to be members of disadvantaged groups[16] as the cumulative experience of stigma and discrimination throughout the lifespan can modulate neurobiology and increase the risk for psychiatric illness[17]. The double disadvantage hypothesis suggests that the interaction of multiple disadvantaged identities within an individual can lead to poorer health outcomes throughout the lifespan[15]. Allostatic load, which refers to the cumulative burden of chronic stress and life events and involves the interaction of distinct physiological processes, may help explain these observations[18]. The presence of these interactive effects highlights the fundamental importance of considering these identities in research.

Intersectionality describes how multiple aspects of an individual's identity can interact to create different modes of advantage and discrimination[19]. Recent work has considered the influence of intersectionality on the emergence of psychiatric symptoms[16] and their genomic underpinnings[20], but this topic has been largely understudied in neuroimaging research. Many studies, including large-scale data collection efforts, do not collect standardized data that enable the study of sociodemographic influences. With the growing reliance on large-scale datasets to study the neurobiological underpinnings of behavior, it is crucial that we adequately capture information along sociodemographic dimensions and think critically about their influences on the brain and behavior. It is also important that we engage different communities to determine whether variables will inform important matters critical to health for certain populations. Therefore, we call on researchers to intentionally integrate an intersectional framework to account for how intersectional identities may affect the study of the brain, behavior and psychiatric illnesses.

Exclusionary research practices

Research in psychiatry and neuroscience has struggled with bias, omission and the exclusion of disadvantaged populations. Bias can be defined as favoring one group over others[21,22]. Omission can be defined as the lack of data characterizing different groups[21]. Bias can be a direct or indirect result of exclusionary criteria and practices in recruitment and data acquisition, whereas omission influences data reporting and analysis.

Biomedical research has historically excluded individuals on the basis of sex and/or gender[9,10,21–24]. Consequently, our understanding of brain disorders is derived from data generated almost exclusively in male individuals. Even when individuals across sexes and genders are included, studies often conflate sex (based on anatomy, physiology, genetics and/or hormones) and gender (reflecting socially constructed roles and behaviors). More recently, although men and women are recruited in comparable numbers for healthy control populations, clinical studies struggle with equal representation[25]. Moreover, studies overlook health factors specific to women or men. As an example, publications examining how pregnancy, the menstrual cycle, hormone-based medications and menopause shape the brain represent less than 0.5% of all neuroimaging papers over the past 30 years[9]. The consequences of this oversight are vast. Women are more likely to be underdiagnosed or misdiagnosed for common brain disorders (for example, attention-deficit/hyperactivity disorder[26]). Even if they do receive an accurate diagnosis, they are more likely to experience adverse effects from drugs and medical devices[27]. Meanwhile, men are at a higher risk for suicide[28].

Importantly, neither sex nor gender is binary, but studies have generally considered them as such, reinforcing the erasure of nonbinary identities[29]. Sexual and gender minorities (SGM) experience higher rates of discrimination and elevated risks for mental health concerns[30]. They also face unique stressors and risk factors for psychiatric illnesses, contributing to distinct healthcare needs[31]. Historical practices also pathologized SGM identities, further stigmatizing and marginalizing these groups[32,33]. Moving forward, studies must ensure the representation of these populations. We refer researchers to Eliot et al.[34] for a detailed discussion on why and how to account for sex and gender in neuroscience research.

Biomedical research has also excluded racial and ethnic groups owing to methodological inadequacies[8]. Phenotypic differences

(for example, skin pigmentation and hair type) can render certain individuals unable to provide usable electroencephalography and functional near-infrared spectroscopy data[35,36]. This issue is further pronounced when recruitment practices lack diversity or when researchers overlook culturally inclusive approaches, such as protocols, language considerations and culturally relevant stimuli.

Exclusion can also occur because of geographic and socioeconomic constraints. Neuroimaging research is primarily conducted at universities or academic institutions in urban areas. Without intentional outreach and recruitment efforts directed at rural communities, studies often exclude these populations. Additionally, individuals who cannot give up several hours of their day because of having inflexible jobs and/or other commitments are automatically excluded. Individuals with unstable housing (common across multiple psychiatric disorders) often lack reliable phone and/or computer access, which may further place a barrier to research participation, particularly in longitudinal studies. Finally, individuals without consistent access to medical care may not have access to medical records and services required to confirm eligibility for magnetic resonance imaging scans (for example, orbital X-rays for individuals who have worked with metals). These issues are likely to disproportionately affect those from lower socioeconomic backgrounds, skewing research samples to individuals in higher income brackets who can 'afford' to participate in research. These inequities are exacerbated in regions where individual access to healthcare depends on employer insurance instead of single-payer, government-supported options.

Across sexes, ages, geographical regions and income levels, differences in the prevalence rate of psychiatric illnesses have been reported[37] (Fig. 1), suggesting clear influences of sociodemographic factors on mental well-being. However, without the inclusion of diverse populations and the explicit consideration of factors in our research studies, we cannot fully account for the influence of sociodemographic factors on the brain and behavior across healthy and clinical populations.

The exclusion of specific populations from scientific research and the subsequent lack of representation of diverse groups in biomedical datasets can arise through several routes. First, researchers may be ignorant or unaware of the lack of diversity. Second, researchers may intentionally focus on convenience sampling. Third, researchers may be limited by internal and/or external constraints that make it difficult to reach specific populations. Finally, researchers may ignore sample diversity considerations for preliminary or pilot analyses. Regardless of the reason, the consequence is the same: an information deficit with downstream consequences on understanding, preventing and treating psychiatric and other health conditions across those un(der) represented groups[38]. As an example, information deficits have led to widespread disparities in Native American communities. Data genocide is a term used to describe the neglect and erasure of data demonstrating poor health outcomes in Native American communities, which has subsequently led to underfunded programs, inaccessible healthcare services and health inequities[39].

Information deficit due to exclusion occurs in two main forms[38]. First, failure to conduct research within a specific population can result in gaps or an absence of knowledge regarding conditions that exclusively or primarily affect that population[38]. For example, perinatal depression, postpartum depression and premenstrual dysphoric disorder exclusively occur in the human female population. Exclusion of female individuals from general studies of depression (or their inclusion in small numbers) can lead to a massive gap in how we understand, prevent and treat these conditions. Second, the exclusion of a specific population can result in inaccurate knowledge about a given behavior or condition that can affect all individuals throughout a population[38]. Although depression occurs in all sexes, the prevalence is higher in female individuals, and it co-occurs with endocrine transitions (including puberty, initiation of oral contraceptives, the postpartum period and perimenopause)[40]. Exclusion of female individuals from depression studies (or their inclusion at disproportionate rates) may prevent the detection of sex and/or gender differences in the presentation and treatment response, resulting in the identification of biomarkers or phenotypes that are specific to or more prevalent in male individuals. Exclusion of a specific group can also result in the complete ignorance of illnesses that affect only that group (for example, postpartum depression). In such cases, comparison across groups (that is, across sexes) is not necessary or relevant; rather, it is important to consider the specific mechanisms that may be driving these illnesses within that group. Knowledge generated from these unique scenarios can subsequently lead to treatments that are beneficial for all. Both types of information deficit can have important consequences for morbidity, mortality, diagnosis, treatment and recovery[38].

Neuroimaging research is expensive, and much of it takes place in the Western world. This results in the inclusion of largely WEIRD (Western, educated, industrialized, rich and democratic) samples, which represent only 12% of the global population, by WEIRD researchers[41]. Consequently, even datasets that include populations spanning different sociodemographic groups within a catchment area will not necessarily be representative of the global population[42]. To advance the field of neuroimaging and to better understand, diagnose and treat psychiatric illnesses, we must include diverse populations in our research and consider how intersectional sociodemographic identities influence the brain and mental health[43].

Concurrently, we need to expand the pool of researchers to include individuals with diverse sociodemographic identities. Without accurate representation of the diversity in the study populations and within the research team, we risk conducting and disseminating research that can miss important complexities of minoritized groups disproportionately removed from the research enterprise.

Influence of intersectional identities on brain biology and psychiatric illnesses

Considering sociodemographic identities and their intersections is crucial given the long history of bias and exclusion of disadvantaged populations and prioritization of perspectives from the Western world. Data collection regarding constructs important for intersectional representation often relies on census or government-derived categories. Although some of these categories have evolved to reflect population diversity better, often in response to changing social norms and demographics, they are still lacking[44]. As an example, individuals from Middle Eastern and North African countries are categorized as 'white' within the US census (and most research settings) although many do not self-identify as white and are not generally perceived as white[45]. Moreover, terms such as 'intersectionality', 'disadvantaged', 'underrepresented', 'marginalized', 'minoritized' and 'historically excluded' will not hold the same meaning or represent the same groups or identities globally. Therefore, a global discussion is necessary to provide clear definitions of terminology related to sociodemographic variables and develop guidelines on how to acquire appropriate data[46].

Studies addressing the influences of sociodemographic factors on health and behavior have largely considered variables in isolation. However, these variables, along with their influences, are interdependent in nature. Sociodemographic variables are independently associated with brain biology and health outcomes[47–53]. As an example, the coronavirus disease experience is associated with social determinants of inequity, including household income[54]. However, the associations between interconnected sociodemographic identities and brain biology are reciprocal and compounding (Fig. 2). Environmental factors influence neurobiology and mental health, including urbanicity[55–57], access to clean water[58–60], food insecurity[61–63], air quality[64–66] and noise pollution[67–69]; these also covary with sociodemographic variables and with one another[70–74]. Therefore, individual relationships between

https://doi.org/10.1038/s41593-024-01832-y

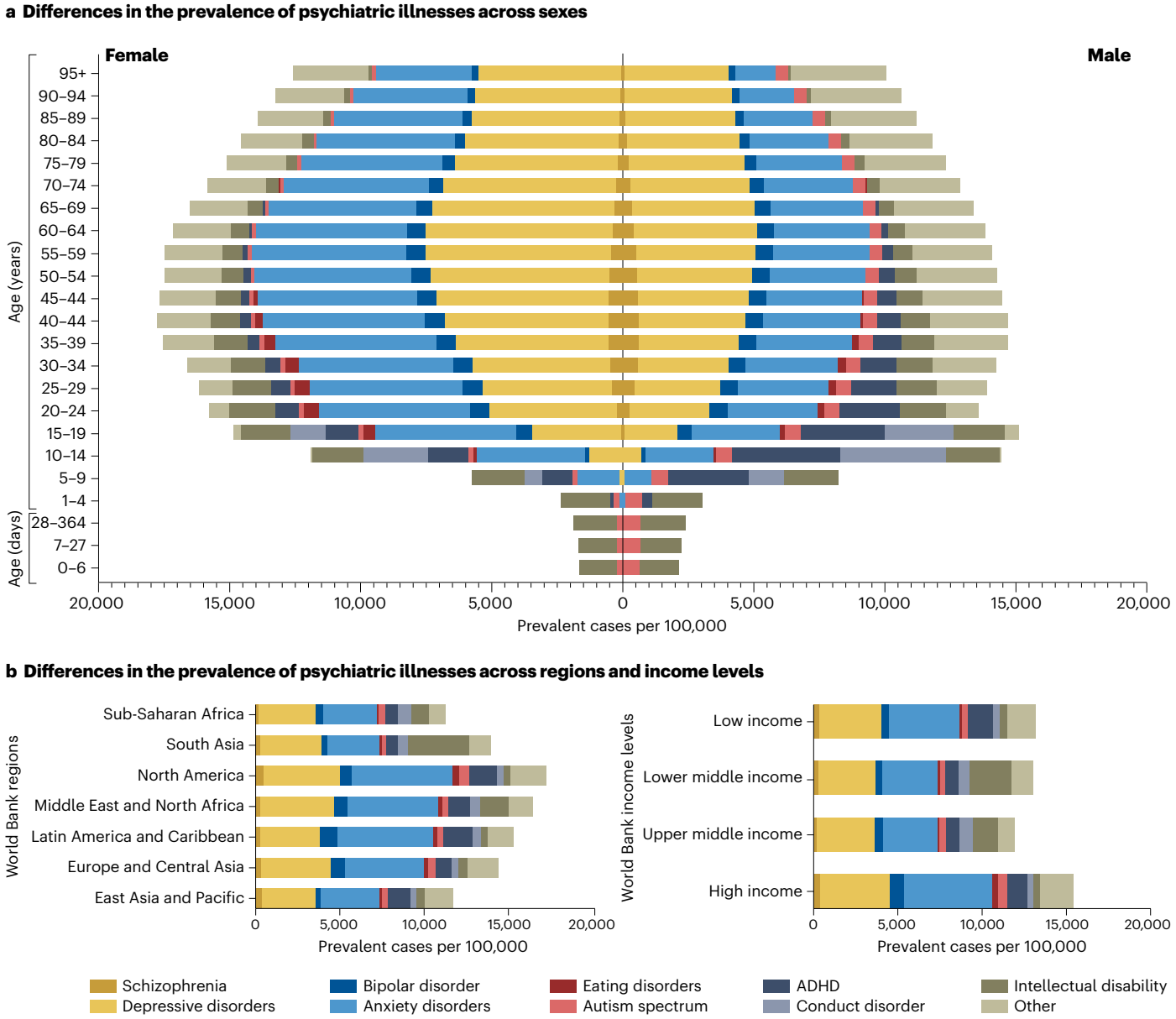

Fig. 1 | Differences in the prevalence of psychiatric illnesses across sexes, ages, regions and income levels. a,**b**, Stacked bar plots displaying data from the Global Burden of Disease Study (2019)[37] for prevalent cases per 100,000 across the sexes throughout the lifespan (**a**) and across World Bank regions (**b**, left) and World Bank income levels (**b**, right) for schizophrenia, depressive disorders, bipolar disorder, anxiety disorders, eating disorders, autism spectrum, attention-deficit/hyperactivity disorder, conduct disorder, intellectual disability and other psychiatric illnesses. See ref. 37 for details. Of note, estimates of prevalence rates are generated using data acquired from hospitals, governments, surveys and other databases, which may be inconsistent, fragmented or incomplete. As a result, these estimates, while providing crucial insights into potential disparities, are likely biased by systematic differences in sampling bias, diagnostic bias, diagnostic inconsistency, underreporting, awareness and understanding of mental health conditions, accessibility to mental health professionals, stigma and medical mistrust across different sociodemographic groups. ADHD, attention-deficit/hyperactivity disorder.

a particular sociodemographic variable, environmental factor and neurobiological measure are difficult to disentangle.

Psychiatric illnesses vary across distinct intersectional groups[75] in terms of symptom profiles[76,77], perceived need for mental health treatment and treatment-seeking behaviors[78,79], as well as treatment access and response[80]. Across different populations, there are crucial differences in the prevalence (Fig. 1) and expression of illnesses, cultural variations in stigma and the recognition of distinct health conditions. Additional complexities arise from differences in the ability to describe symptoms and illnesses accurately across various languages, dialects and nuanced expressions. Mistrust of healthcare providers, stigmatization and fear of potential legal consequences (for example, termination of parental rights, deportation or loss of employment) can decrease the likelihood that individuals from disadvantaged groups will seek treatment[81–83]. Crucial differences also exist in the avenues individuals rely on when seeking help for mental health concerns and the comfort they may feel when sharing their experiences with clinicians and researchers alike. Specific groups are more likely to rely on community leaders before seeking help from psychiatrists, psychologists, nurses or social workers[84]. Even when individuals seek help, the availability of mental health services varies globally. While some countries have as many as 1 mental healthcare professional for every 361 individuals, others only have 1 for almost every 3 million[85]. There is also variability in the types of mental health professionals, services and treatments one might have access to. Within a country, disparities in access vary across regions and income groups. Mental health facilities tend to be

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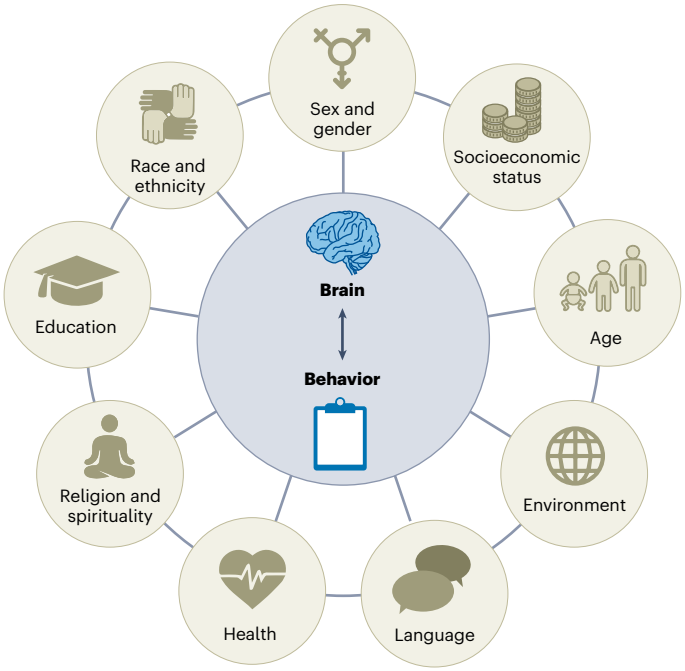

Fig. 2 | Sociodemographic factors influence both brain biology and behaviors linked to psychiatric illnesses. A key goal of research in the brain sciences is to capture relationships between the brain and behavior. When studying these brain–behavior relationships, it is crucial to recognize that sociodemographic factors, such as sex, gender, race, ethnicity, education, religion, spirituality, health, language, environment, age and socioeconomic status (among others), can independently and interdependently influence these reciprocal associations.

in urban areas, drastically reducing accessibility for those living in rural areas[86]. Lower socioeconomic status is associated with poorer mental health outcomes in the United States[87] and reduced access to mental health services in Germany[88]. Additionally, SGM populations in the United States report poorer mental health along with greater barriers to mental healthcare[89]. In Canada, SGM individuals are more likely to report untreated mental illnesses and an unmet need for mental healthcare relative to heterosexual cisgender women. These effects are partially driven by discrimination, decreased social support and systemic exclusion from healthcare[90]. Self-reported and formal diagnostic rates also differ as individuals from disadvantaged groups may be less likely to endorse psychiatric diagnoses while exhibiting similar or greater levels of symptoms[91]. The lack of well-defined culturally sensitive clinical diagnostic criteria poses considerable challenges in accurate diagnosis across populations. Moreover, when considering cultural, racial and ethnic influences, it is important to examine them within the framework of generational differences, especially in individuals with a diasporic heritage. This pertains to those who were either born or raised in environments marked by cultural divergence from that of preceding generations. Applying this cultural lens can lead to the recognition of distinct manifestations of psychiatric illnesses across generations[76,92].

In the following sections, we discuss considerations for participant recruitment, data acquisition and data analysis to facilitate inclusionary research practices and the evaluation of intersectional influences on the brain and behavior.

Considerations for participant recruitment

Convenience sampling is the practice of recruiting participants from populations 'convenient' for the researcher, for instance, owing to their location, availability and/or cost. Often, this decision is made with the assumption that neuroscientific studies index universal laws of human behavior that are robust to population characteristics. Specific populations may be more convenient to study simply because they are already presenting at the research site(s), live nearby, and/or are directly or indirectly affiliated with the research institution. While this approach can be used to recruit large samples of participants, the resulting samples may not be representative of individuals within the local catchment area or our broader society.

One key issue in clinical research is the substantial resources required to recruit clinical samples. This can result in researchers relying on convenience samples for corresponding control or comparison groups. Therefore, the intersectional characteristics of clinical and healthy groups may be different. Additionally, when studying clinical populations, it is often easier to schedule research visits during business hours to fit with ongoing clinical appointments. Conversely, nonclinical participants may seek to come in outside of business hours because of work and other responsibilities. Even something as seemingly innocuous as when we collect our samples may unintentionally introduce biases due to consistent temporal differences across populations[93]. These biases may be related to circadian factors, participant fatigue, hydration, or caffeine and nicotine intake that can influence estimates of brain anatomy[94,95], brain functioning[96] and behavior[97].

Representation within a dataset may be particularly challenging in pilot studies with a limited budget. In these cases, representation along multiple aspects of social identities may lead to increased heterogeneity, limiting the researchers' ability to capture accurate brain–behavior relationships. In such cases, focusing on a limited set of social identities that may be of crucial importance is recommended. As an example, as elevated rates of substance use behaviors are observed in SGM populations[98], a pilot study investigating the neurobiological underpinnings of substance use disorders may benefit from ensuring SGM representation in its sample. This inclusion would further enable the researchers to assess, as a secondary aim, whether it is SGM status or a separate factor (for example, higher rates of discrimination and stigmatization) that may be driving potential differences. Subsequent large-scale studies could then aim to have broader representation across multiple sociodemographic dimensions and consider their influences. Regardless of the sample included, we encourage researchers to justify their sample collection within the context of their research focus.

Ensuring diversity in clinical datasets is not an easy task. While many research groups use base rates to determine which proportion of our samples should be from a given group, this may introduce some unintended consequences if we do not consider demographic characteristics more carefully. Given the estimated sociodemographic differences in the prevalence rates of psychiatric illnesses (Fig. 1), general population estimates of a sociodemographic identity may not be representative of a specific clinical population if prevalence rates are much higher within a particular group. The subgroup problem describes the phenomenon that occurs when we adequately capture different broad or overarching categories (for example, Asian participants) but fail to properly account for the presence of subgroups (for example, South Asian or East Asian participants) within those populations. When recruiting for a research study, we must consider the relevant group and subgroup categories and the upshot of improving the representation of those categories in that specific context. Here, it is particularly important that research groups are engaged in active partnerships with patients and the community[99].

It is also important to recognize that a lack of evidence demonstrating the influence of specific variables does not mean that the influence does not exist. Lack of evidence may instead indicate that the variable or group has not been explicitly considered in prior research. By continuing to increase diversity and representativeness in our datasets, we can better understand the influences of sociodemographic factors on the brain and behavior. In this regard, the rapid growth of population imaging cohorts (for example, Adolescent Brain Cognitive Development[100], Brain Genomics Superstruct Project[101], Chinese Color

Nest Project[102], and Consortium on Vulnerability to Externalizing Disorders and Addictions[103]) provides a framework for the study of diverse populations. Initial work has focused on the appropriate consideration of sex, gender, and diverse ancestries and cultures when examining the genetic, anatomical and functional underpinnings of human behavior[56,104,105]. Continued recruitment of representative samples[6,7] and attempts to understand how sociodemographic factors influence brain–behavior relationships[6,106–108] are necessary.

Research recruitment and participant engagement strategies also need to recognize the unique contributions of stigma, discrimination and distrust across sociodemographic groups. Populations that have historically experienced medical and research mistreatment and developed medical mistrust may be hesitant to participate in research. Consequently, the demographic distribution of individuals who participate in research may be distinct from that of individuals who present for treatment. Targeted and culturally sensitive recruitment strategies can increase the inclusion of diverse participants. The use of electronic health records-based recruitment strategies (for example, direct-to-patient messages and candidate lists[109]) and referrals from physicians and healthcare workers practicing in community clinics may further facilitate inclusion beyond the use of passive recruitment approaches (for example, flyers in community spaces or social media advertisements).

The availability of resources to support participants and the inclusion of research team members who can facilitate communication are crucial. A diverse research team (including translators, where relevant) can connect and engage with specific populations within the community that may otherwise feel excluded or hesitant to participate. An option for participants to engage with an entirely female research team (including scanner technicians and/or operators) and have access to culturally sensitive, research-appropriate clothing (for example, long-sleeved scrubs) can also help. Partnering with individuals with lived experiences and with different community groups can further increase engagement with underrepresented communities and increase the real-world relevance of research findings.

Considerations for data acquisition

Data acquisition can be challenging in clinical populations. Lengthy neuroimaging scans requiring active participant participation and extensive behavioral evaluations may not be feasible. Neuroimaging has a history of racially exclusionary practices[8], and many behavioral scales were developed in WEIRD populations. A critical need exists for the development of reliable frameworks to acquire scans and quantify behaviors, along with techniques to facilitate data harmonization[110]. Relatedly, factors including communication barriers, perceived stigma and/or discrimination, and perceived comfort and/or safety in research settings by the participants can distinctly influence the accuracy and reliability of self-report and clinical assessments. As an example, certain languages may not have words to describe specific feelings and behaviors[111], subsequently restricting how individuals conceptualize and report them. Moreover, some clinically relevant behaviors such as substance use may be largely criminalized in specific contexts or settings but not in others, influencing participants' willingness to discuss them in a research setting.

Data quality must also be carefully monitored. The use of strict quality control thresholds tends to result in greater exclusion of specific groups within the population[112]. Evaluating the correlation between head motion and demographics in the Adolescent Brain Cognitive Development dataset, researchers found that the sample with lower head motion included more female individuals, non-Hispanic white individuals, individuals with married parents, individuals whose parents reported greater education and individuals with higher household incomes[112]. A separate study in the same cohort found that exclusion owing to image quality issues resulted in a sample with a greater proportion of female and white individuals[113]. Similarly, the Brain Genomics Superstruct Project dataset showed that neuroimaging scan quality was not uniform across the sample, with greater signal-to-noise ratio and lower motion found in female than in male individuals[101]. An evaluation of the demographic distributions of those who are included or excluded from analyses based on quality control thresholds can provide insights into whether researchers should be rethinking their data acquisition and quality control practices.

The use of clearly defined criteria to determine the nominal categories we include is crucial as inaccuracies can be introduced owing to the use of poorly formulated sociodemographic questionnaires. The collection of sociodemographic data is crucial for future evaluations of these factors and their influences on neurobiology and behavior. It is also important to ensure that these data are collected at sufficient granularity to determine whether the subgroup problem applies to that dataset. Importantly, sensitivity and discretion must be prioritized when acquiring these data, especially in vulnerable populations. In SGM populations, these questionnaires may reveal to caregivers sensitive information about gender identity and sexual orientation that participants might wish to keep confidential, or they may be worded such that the target population may not answer in the way expected by the researcher[114]. To prevent this, researchers should use careful language and provide safe spaces to maintain privacy[115]. Additionally, research studies often use annual income brackets to categorize individuals across socioeconomic groups. Unfortunately, this can be largely biased as individuals paid hourly wages or lacking stable employment may not be able to provide accurate estimates. Similar income brackets can also represent different socioeconomic status across regions owing to variations in the cost of living or employment stability. These considerations are especially crucial when collecting large-scale open-access datasets that will then be mined for different research questions for years to come. Notably, many studies do not report these data even when they have been collected. When these data are reported, they have often been used to justify and perpetuate racist beliefs and practices[116,117]. Recently, scientific publishers, including the Nature Portfolio, have begun to introduce relevant guidelines[116,118]. Moving forward, we call on researchers to follow these guidelines and explicitly report this information.

The very act of being scanned may provoke anxiety in certain individuals; this experience coupled with community-level distrust of research needs to be considered. Individuals with disabilities may face a unique set of challenges. Disabilities can involve impairment in body structure or function, activity limitation and/or restrictions in day-to-day activities. Traveling to the appointment, preparing for the scan and accessing the scanner itself may pose difficulty[119]. By offering advanced and flexible scheduling, providing and supporting the use of assistive aids, and offering additional time and support to enter and exit the scanner, researchers can improve accessibility[119]. Neurodivergent individuals may find the scanner environment particularly inaccessible owing to increased sensory stimulation, lack of environmental adjustments and unclear communication of the study protocol[120]. Noise reduction and sensory adaptations can be used to improve the experience[121]. The use of mock scanners and videos that depict how a neuroimaging experiment is conducted (for example, https://www.semel.ucla.edu/bccl) and literature aimed at addressing fears and misconceptions about research may be helpful. It will likely be even more impactful to have these resources feature individuals from diverse backgrounds. Finally, providing staff with formal training on how to handle disabilities and neurodiversity in a research setting can help them offer participants a person-centered neuroimaging experience[121].

Research participants may have difficulty understanding regulations related to data privacy, use and sharing. Clear science communication articulating this information along with the pros and cons of participating in research in an accessible manner is crucial for increasing participation. This is certainly where codesign of relevant materials and engagement with community representatives and individuals

with lived experiences will be crucial. Despite the expense, funders and researchers must also consider how to make the experience less challenging for individuals to participate in research studies. This could include building in time for breaks and providing a quiet and safe room for participants, especially for activities that are more personal in nature (for example, using the restroom and changing for a scanning session). Overall, we need to consider the needs of participants as a means of improving inclusion rather than think about what is convenient and cost-effective for researchers.

Considerations for data analysis

Unrepresentative samples will produce results that are not generalizable to a broader population[122,123]. When dealing with unrepresentative samples in precollected neuroimaging datasets, researchers can explicitly evaluate how the results do or do not generalize across population subgroups and acknowledge the limitations that exist given the sample used. They can also collect more data or exclude some data to ensure that the sociodemographic distributions of the sample are more representative of the broader dataset or population of interest[113]. Currently, biomedical researchers more commonly either ignore the lack of representation or include sociodemographic variables as covariates, although these are not recommended. Consequently, a limited subset of the global population has benefited from the resulting scientific advances. In recent years, more researchers have begun to acknowledge the limitations of their findings more actively, explicitly recognizing their use of underrepresentative samples and the lack of generalizability in their findings. However, this does not address the underlying issue. Collecting more data, while the most prudent solution, may not always be feasible, especially when operating with limited research resources. Moving forward, limitations must be recognized and innovative approaches must be implemented to collect more representative data.

Demographic data tend to be categorized at a group level, and the extent to which the effects of distinct individual and interconnected identities can be analyzed is limited by how the data are collected and categorized. In certain countries, the collection of sociodemographic information is tightly regulated and thus is often not conducted[46]. Even when data are collected, they may not be useful if appropriate subgroup information is not collected. This is also an issue when integrating multicenter, international data as they may use different groupings. In these cases, the implementation of demographic data harmonization strategies[124] can help generate comparable information across the studies and enable pooling in the analyses.

Nonresponses resulting in the presence of missing data are unlikely to be random[125], and the exclusion of individuals with missing data can introduce biases such that the sample is no longer representative. Although different strategies for data imputation exist[125], they must be implemented with caution to ensure that additional biases are not introduced. Moreover, different users of the same dataset may apply unique strategies to compensate for missing data, resulting in the introduction of unique problematic biases and flawed interpretations[125].

In efforts to standardize neuroimaging data across individuals and sites, images are often mapped onto a shared template space. Unfortunately, brain morphology varies across populations, including across sexes and developmental stages[126]. Registering brain images to a template derived from a population different from the one(s) the individual belongs to could inadvertently introduce biases[127,128]. Hence, the development of novel scientific pipelines and tools for data analysis should incorporate the actual population variability we hope to capture in our analyses.

The lack of generalizability in scientific findings across populations is well documented. Brain–behavior relationships captured in one sex or race have limited generalizability to the other sex[129,130] or races[107], respectively, and may potentially be further influenced by intersectional identities. To address these concerns, many researchers 'control' or 'correct' for variance introduced by sociodemographic variables, forcing relationships between the predictor and outcome of interest to be the same across groups[117,131]. Unfortunately, this can remove meaningful information and lead to incorrect findings and detrimental conclusions[117,131]. Instead, we recommend that researchers consider these factors as variables of importance and disaggregate their data where possible. In recent years, population-specific predictive modeling approaches have been successfully implemented to reveal sex- and race-specific brain–behavior relationships[53,106,107,129,130]. These approaches seek to capture relationships between brain measures and behavioral phenotypes in a group-specific manner and evaluate whether those relationships are shared or unique across the groups[123]. While this may not be feasible for all intersectional groups, results from these approaches can serve as a baseline to evaluate how different sociodemographic variables may influence a given relationship of interest. Another alternative to the covariate approach is the use of propensity scores, which can help characterize how multiple sociodemographic factors may be jointly associated with the phenotype of interest at an individual level[132]. The score can then be used to match individuals, stratify groups, adjust covariates or weight models.

Population-specific analyses are also crucial for understanding whether treatments are limited to one group. They are also essential for making risk–benefit judgments, especially for drugs with considerable side effects. A classic example is the sedative zolpidem, otherwise known as Ambien. Adverse effects due to the drug resulted in emergency visits twice as often in women than in men as the same dose was used across the sexes without consideration for sex-specific metabolic processes[133]. After the sex-disproportionate risk of impairment for activities requiring mental alertness became clear, Food and Drug Administration guidelines were changed to recommend sex-specific dosing[134]. Relatedly, overlooking how systemic racism has influenced a group's health over time and the effects of racism on study designs (for example, the use of methods that may not accurately capture the intended data in certain races[8]) can lead to inaccuracies in concluding race-based variations in brain function or structure[117,135].

Research questions themselves must also include a consideration of the lived experience. 'Inclusion' goes beyond achieving balanced enrollment tables and requires recognizing that research in specific groups need not always compare to an assumed standard. As an example, the postpartum period is a time of great vulnerability for brain health and mental well-being. Understanding why this period is of great risk for birthing parents does not require comparing with non-birthing parents. Here, the research instead should consider postpartum, non-postpartum or non-pregnant individuals.

Clear and accurate communication of scientific findings is crucial to prevent misrepresentation, sensationalism and harmful recommendations based on essentialist claims. Research findings should be presented with nuanced discussions that recognize the complexity and variability of social constructs within the groups being studied. The observation of differences between groups is not evidence of biological superiority or inferiority. Findings should be contextualized in terms of the historical, cultural, environmental and social factors that may, in part, drive the results beyond the biological factors studied. Researchers should also acknowledge that sociodemographic identities are constructs that may change over time. By seeking input from diverse perspectives when framing their discussion, researchers are more likely to avoid overlooking important nuances and complexities. Overall, in reporting results, it is important to consider the potential consequences of oversimplified interpretations and generalizations[39].

Future directions

Advances in neuroimaging methods and analytic approaches have allowed researchers to visualize and quantify brain structure and function in healthy and clinical populations with ever-growing

BOX 2

Inclusionary practices in neuroimaging

Here, we summarize action items that neuroimaging researchers can implement in their own laboratories and research studies during the recruitment, acquisition and analysis stages to facilitate more inclusionary science.

Recruitment

- Recruit beyond convenience samples.
  - Post flyers in diverse community-oriented spaces and on virtual platforms.
  - Develop close ties with community liaisons.
  - Build a diverse research team.
- Develop an inclusive study design and recruitment plan.
  - Engage individuals with lived experiences.
  - Use practices engaging in community-based participatory research.
  - Incorporate global open-access datasets instead of ones exclusively containing WEIRD participants.
- Consider your inclusion and exclusion criteria.
  - Ensure inclusive communication in flyers and communications.
  - Remove any exclusionary language.
- Avoid sociodemographic biases in study samples.
  - Address issues in representation at the group and subgroup levels.
  - Provide services or resources needed to confirm eligibility for magnetic resonance imaging scans.

Acquisition

- Clearly define and capture sociodemographic information.
  - Use validated questionnaires that capture diversity.
  - Ensure that the collected demographic data can easily be harmonized.
- Ensure that data acquisition methods are appropriate and inclusive.
- Provide adequate support to participants.
- Ensure participant safety and comfort during data acquisition.

Analysis

- Report sociodemographic information.
  - Clearly describe sample characteristics across sociodemographic categories.
  - Use existing guidelines when reporting sociodemographic data (for example, Nature Portfolio reporting summary).
  - Acknowledge any limitations that exist because of a lack of representation.
- Choose appropriate analytical strategies.
  - Avoid using strict quality control metrics that may disproportionately exclude specific groups.
  - Ensure the generalizability of results across different groups where possible.
- Consider the influences of sociodemographic variables.
  - Perform group-aggregated analyses or consider the influence of specific variables.
  - Avoid the use of covariates. Do not regress out meaningful signals associated with sociodemographic variables. Test for relationships between sociodemographic variables and biological or behavioral variables of interest.
  - Avoid using sociodemographic variables as a proxy for other factors[117] (that can influence the brain, behavior and psychiatric illness).
- Carefully interpret the results to prevent harm to communities.
  - Recognize limitations in sample, data and analytical strategies.
  - Avoid oversimplification of findings leading to essentialist claims.
  - Use inclusive language in the communication of findings.

precision. These innovations have led to monumental advances in our understanding of how aspects of the brain are associated with behavioral traits. However, the field is still struggling with the inclusion of representative study populations. Conventional practices have resulted in the exclusion of many groups from research. Even when diverse groups are included, the influences of intersectional identities have been ignored. Here, we highlighted these issues to stimulate introspection, discussion and progress in the field. As scientists and researchers in a globalized world, we should embrace inclusive research practices and recognize that it is a necessity to establish accurate and generalizable brain–behavior relationships. To support researchers in their efforts to engage in and implement inclusionary research practices, we provide a summary of actions they can take in their research studies (Box 2).

An understanding of the complex interplay between sociodemographic factors, the brain and mental health is crucial for accurate diagnosis and treatment of psychiatric illnesses. Here, we reviewed (1) exclusionary practices in neuroimaging research, (2) intersectional influences of sociodemographic factors on the brain and behavior, and (3) key considerations regarding recruitment, acquisition and analysis to facilitate inclusive research. We encourage all researchers to consider their research practices and implement changes in their laboratories to be more inclusive of individuals across all sociodemographic identities. In doing so, we can eliminate health disparities and improve global health outcomes.

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Acknowledgements

E.D. is supported by a Northwell Health Advancing Women in Science and Medicine (AWSM) Career Development Award and Educational Achievement Award, as well as the Feinstein Institutes for Medical Research Emerging Scientist Award. J.A.R. is supported by the Stanford University Knight–Hennessy Scholars Program, as well as the National Academies of Sciences, Engineering and Medicine's Ford Foundation Predoctoral Fellowship. L.Q.U. is supported by R21HD111805 from the National Institute of Child Health and Human Development and U01DA050987 from the National Institute on Drug Abuse. L.A.M.G. is supported by the Treliving Family Chair in Women's Mental Health at the Centre for Addiction and Mental Health, Canadian Institutes for Health Research (PJT-173554), Cure for Alzheimer's Fund and Natural Sciences and Engineering Research Council of Canada (2018-04301). E.G.J. is supported by the Ann S. Bowers Women's Brain Health Initiative and R01AG063843. S.W.Y. is supported by R01DA053301 and R01DA050636. B.T.T.Y. is supported by the National University of Singapore Yong Loo Lin School of Medicine (NUHSRO/2020/124/TMR/LOA), the Singapore National Medical Research Council (NMRC) LCG (OFLCG19May-0035), NMRC CTG-IIT (CTGIIT23jan-0001), NMRC STaR (STaR20nov-0003), NMRC OF-IRG (OFIRG24jan-0030), Singapore Ministry of Health (MOH) Centre Grant (CG21APR1009), the Temasek Foundation (TF2223-IMH-01) and the US National Institutes of Health (R01MH120080 and R01MH133334). M.M.C. is supported by the Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council Canada, Toronto Dominion Bank, McGill University's Healthy Brains for Healthy Lives (a Canada First Research Excellence Fund) and TRIDENT (supported by the New Frontiers in Research Fund). M.M.C. also receives research and salary support from the Fonds de recherche du Quebec—Santé. A.J.H. is supported by the National Institute of Mental Health (R01MH123245 and R01MH120080). Any opinions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funders.

Competing interests

The authors declare no competing interests.

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Peer review information *Nature Neuroscience* thanks Janine Bijsterbosch and Timothy Brown for their contribution to the peer review of this work.