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A Neuroecosocial Perspective on Adolescent Development

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Abstract

Adolescence is a period of life that encompasses biological maturation and profound change in social roles. It is also a period associated with the onset of mental health problems. The field of developmental cognitive neuroscience has advanced our understanding of the development of the brain within its immediate social and cultural context. In a time of rising rates of mental health problems among adolescents across the globe, it is important to understand how the wider societal, structural, and cultural contexts of young people are impacting their biological and social-cognitive maturation. In this article, we review the landscape of youth mental health and brain development during adolescence and consider the potential role of brain research in understanding the effects of current social determinants of adolescent mental health, including socioeconomic inequality, city living, and eco-anxiety about the climate crisis.

Contents

1. INTRODUCTION

Adolescence (roughly ages 10–24 years; Sawyer et al. 2018) is a period of life that encompasses profound biological and social maturation. These developmental processes are shaped by the social, structural, and cultural environments in which individuals are embedded. As rates of substance abuse, addiction, anxiety, and depression in adolescents rise across the globe, it is important to understand how the broader social contexts of young people influence their brain and social development and, in turn, their mental health. Our focus here is on identifying key areas of investigation and setting an agenda for the contribution of developmental cognitive neuroscience in uncovering mechanisms associated with the social determinants of brain development. We begin by discussing the increasing prevalence of mental health difficulties in young people worldwide in the context of these challenging social conditions and new global crises. We then briefly review existing findings on the brain's sensitivity to social context in adolescence at a microenvironment level and raise questions about the ways in which studies of the developing brain may shed light on the processes mediating the relationship between youth mental health and the social world at the macroenvironment level. We then explore three current social determinants of youth mental health: social inequality, city living, and the ecological crisis. We finish with a call for more interdisciplinary engagement between the social sciences and neurosciences to innovate both theory and methods that can characterize neuroecosocial interactions during adolescence. We argue that a youth-driven approach is crucial to investigating and mitigating the biological and mental health impacts of the social realities of adolescents today. We draw on neuroecosociality as an approach used to bring the neurosciences into critical dialogue with social theory and methods from the social sciences to investigate neurological, social, and ecological pathways and their interactions. Our premise is that by bringing these disciplines into conversation and their methods into engagement, we can begin to understand how inequity, injustice, and social contexts more broadly are inscribed in the human body and mind during development (Rose et al. 2022).

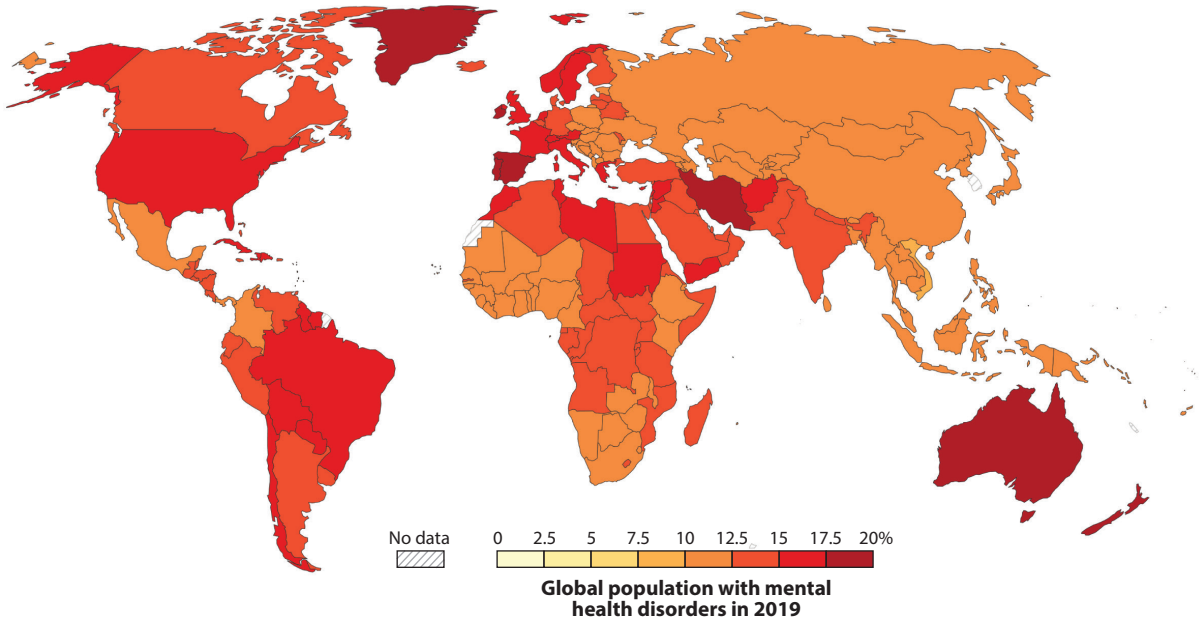

Figure 1

Share of the global population with mental health disorders in 2019. The map shows the percentage of the population in each country with any mental health disorder, including depression, anxiety, bipolar disorder, eating disorders, and schizophrenia. Image adapted from Dattani et al. (2023) (CC BY 4.0).

2. YOUTH MENTAL HEALTH: AN ECOSOCIAL RESPONSE TO AN ESCALATING GLOBAL CRISIS

The mental health of young people has been a growing international concern for many years, with rates of substance abuse, addiction, anxiety, and depression on the rise and further exacerbated by conditions related to the COVID-19 pandemic (Castelpietra et al. 2022, WHO 2022) (see **Figure 1**). According to UNICEF in 2019, up to 20% of adolescents globally experience mental health disorders, which are among the leading causes of disability and death for adolescents aged 10–19 (Carvajal-Velez et al. 2023). Additionally, both retrospective and prospective data demonstrate that the majority of adult mental disorders begin in late childhood and adolescence, with up to 50% of all mental health conditions emerging before the age of 14 (Carvajal-Velez et al. 2023, Solmi et al. 2022). Developmentally, adolescence is a period of enormous biological and psychosocial change; it is—by virtue of this fact—also a significant moment for prevention and intervention. Mitigating the scale of mental health challenges requires an integrative understanding of adolescence and an intersectional approach to the adolescent's social environment. Researchers have long characterized this life stage as a period of both vulnerability and opportunity (Dahl 2004), alluding to the heightened risk, but also to particular strengths and resilience, that mark adolescence.

Currently, 34% of adolescents aged 10–19 globally are at risk of developing depression, with female adolescents and adolescents from Africa, Asia, and the Middle East at an even higher risk than those from Europe, North America, and Oceania (Shorey et al. 2022). Suicide rates are also on the rise worldwide, with suicide being the third leading cause of global deaths among 15–19-year-old girls and women, behind tuberculosis and maternal conditions (WHO 2021).

For boys and men aged 15–19, suicide is the fourth leading cause of death worldwide, behind road injury, interpersonal violence, and tuberculosis (WHO 2021). UNICEF (2019) estimated that 15% of adolescents in low- and middle-income countries have considered suicide. Recent data revealed that, in the United States, firearm-related violence has become the leading cause of death in this age group (with deaths among Black youth remaining substantially higher than among any other group), a stark reminder of the structural and political determinants of youth mortality (Goldstick et al. 2022). Results from multiple international epidemiological surveys have demonstrated that anxiety disorders are the most prevalent class of mental disorders and lead to significant psychosocial and physical health concerns (Xiong et al. 2022, Merikangas et al. 2022). A meta-analysis of 41 studies conducted in 27 countries estimated a worldwide prevalence of any anxiety disorder to be 6.5% in children and adolescents (Polanczyk et al. 2015). In March 2022, the World Health Organization (WHO) released a scientific brief (WHO 2022) summarizing the available early evidence of the pandemic's impact on mental health, including findings from WHO-commissioned systematic reviews as well as estimates from the Global Burden of Disease (GBD) study. According to GBD estimates, the COVID-19 pandemic led to a 25.6% increase in cases of anxiety disorders and a 27.6% increase in cases of major depressive disorder worldwide. Additionally, it was noted that the greatest increase in these disorders was particularly seen in women and youth, especially those aged 20–24.

In light of the global social instability affecting young people, adolescent mental health has become a major new target for health research and social policy, and findings from neuroscience are being increasingly called upon to inform health and social policy interventions (Patton et al. 2016, Vergunst & Berry 2021). Key questions emerge from this mental health landscape: Why are some adolescents at risk from mental health problems while others are resilient? What social environmental factors influence the developmental trajectories of adolescent mental ill-health? How do these factors vary by gender and culture? What is the role of neurobiological mechanisms in mediating risk and resilience? The past 20 years of cognitive neuroscience research have demonstrated an important role of the social environment—for example, friendships and hierarchies among peers—in adolescent neurocognitive development. It would be fitting for the field to now widen its lens on the social world and consider how social systems and institutions—from socioeconomic inequality to the climate crisis—impinge on the brain and cognition during this period to influence or buffer the risk of mental illnesses.

3. ADOLESCENCE AS A SOCIALLY SENSITIVE PERIOD OF DEVELOPMENT

There are several lines of evidence from multiple disciplines pointing to the central role of social context in understanding behavior and mental health, not least in the definition of adolescence itself. Within psychology and related disciplines, adolescence is commonly understood as beginning with puberty and ending when the individual reaches a milestone associated with adulthood. In many modern industrialized contexts, adolescence is thought to end when the individual shows signs of attaining a more independent role in society: an endpoint that is clearly determined by multiple social and economic factors (Sawyer et al. 2018). For example, in modern North American and European settings, the developmental period understood as adolescence has been prolonged since the mid-twentieth century due to an increased possibility for young people to continue education and delay work and parenthood (Arnett 2014). The psychological and sociological literature that describes this shift in adolescence often refers to emerging adulthood as a new life stage, acknowledging the fact that many young people acquire stable jobs and property and have children later than they did a few decades ago (Arnett 2014). While this period of life has been proposed

to extend until around the age of 24 (Sawyer et al. 2018), the precise timing of the shift into adult status depends on a variety of factors such as culture and social class (Furstenberg 2016). The prolonged nature of adolescence in some cultures reminds us that this developmental stage may be distinct in many ways; though temporally constrained, it is not fixed but rather contingent on historical, economic, cultural, and societal factors (Worthman & Trang 2018).

Biologically, adolescence is marked by distinct changes, and recent developments in cognitive neuroscience have made strides in characterizing them. Just 25 years ago, it was largely believed that human brain development was mostly complete at some point in childhood. That dogma was challenged in the early 2000s with the discovery that major neural development continues to occur beyond late childhood into puberty, adolescence, and early adulthood (Giedd et al. 1999). Structural neuroimaging (magnetic resonance imaging) studies began to produce a wealth of data that suggested that puberty and adolescence are associated with heightened brain neuroplasticity and that the brain is fine-tuned to its environment. These specific cellular processes in the brain correspond to changes in cognition, focusing on the development of executive function, emotion regulation, and social cognition (Blakemore & Choudhury 2006). While neuroimaging studies have yielded detailed group-level maps of spatiotemporal patterns of brain development, pointing to changes in cortical gray and white matter volume during the second decade of life, these studies also demonstrate considerable interindividual variation (Foulkes & Blakemore 2018). The dynamic processes underlying brain–context interactions remain unclear, but it is evident that social-environmental contexts in health and adversity drive these variations to a large extent (Ferschmann et al. 2022). In other words, these studies of neuroanatomical restructuring, including recent evidence of specific shifts in the balance of the neurotransmitters GABA (gamma-aminobutyric acid) and glutamate in the frontal cortex (Perica et al. 2022), have generated new conceptual space for investigating the mechanisms through which the social world affects brain development.

There is now extensive evidence that has led investigators to conceptualize adolescence as a period of social reorientation when young people are exposed to shifting social environments (e.g., transitioning to secondary schools in many countries) and start to spend more time with their friends and larger peer groups (Blakemore & Mills 2014). Peer relationships and interactions take on heightened importance during adolescence, as do feelings of belonging and concerns about social status (Tomova et al. 2021). In line with this, neuroimaging and behavioral studies show that young people are better able to take the perspective of others, as well as use the perspective of others to make judgements about themselves and the social hierarchies they belong to (Somerville 2013, van der Graaff et al. 2014). Adolescents also show heightened activation in brain regions underlying socioemotional and reward processing when they are socially excluded or rejected (Cacioppo et al. 2015, Masten et al. 2011). This hypersensitivity to the social environment and its interaction with the neurobiological processes that occur during adolescence are proposed to contribute to heightened risk of developing mental health disorders during this period (Masten et al. 2011, Pickering et al. 2020). For example, some studies suggest that exposure to social adversity (e.g., family conflict or peer victimization) is related to accelerated brain development and lowered cortical plasticity, which in turn could increase vulnerability to psychiatric disorders (Belsky & Andersen 2022, Holz et al. 2023). Another example is the role of puberty in the relationship between the social environment and mental health difficulties, particularly in girls. Puberty, which is initiated approximately between ages 8 and 14 in females and between ages 9 and 15 in males, begins with the activation of the hypothalamic-pituitary-gonadal axis (Dorn et al. 2006) and results in sexual maturity and reproductive capability. Adolescent girls in more advanced stages of puberty typically experience higher levels of anxiety and depression, and this has been related to higher sensitivity to rejection (Mendle et al. 2020), estrogen and its role in

WINDOWS OF SOCIAL SENSITIVITY DURING ADOLESCENCE: THE CASE OF SOCIAL MEDIA

A recent study by Orben et al. (2022) showed that higher self-reported social media use predicted a decrease in life satisfaction a year later at different ages for males (14–15 and 19 years old) and females (11–13 and 19 years old). While the effects were small and bidirectional, they indicated the existence of distinct developmental windows of sensitivity to social media during adolescence. For example, social challenges related to pubertal development in early adolescence and to living independently for the first time in late adolescence might lead to increased social media use, which might in turn increase social pressures. This example highlights how the unique biological, psychological, and social changes that co-occur during adolescence might confer sensitivity to social determinants in their environment.

sensitivity to socio-affective information (Goddings et al. 2012, Albert & Newhouse 2019), and feeling different from same-aged peers (Hamlat et al. 2015).

Moreover, these interacting biological, psychological, and social processes have their own ecology. Networks of brain activity and connectivity are embedded in hierarchically nested sociocultural contexts. These larger contexts in which the brain functions might include family systems, schools, histories of migration, healthcare institutions, and political conflicts (Kirmayer 2019, Ramstead et al. 2016). As such, the lived experience of adolescents and their risk of mental illness are also significantly shaped by the wider social structural, economic, political, and cultural environments of the individual (Sawyer et al. 2018, Worthman & Trang 2018). In other words, developing brains are situated brains, shaped across life through the niches we inhabit, the affordances we respond to, and the way social meaning and biology interact. The impact of these wider social structures might be particularly important during adolescence, as the biological, psychological, and social changes that occur during this period might open windows of sensitivity to different aspects of the social world (e.g., harmful effects of social media; Orben et al. 2022) (see the sidebar titled Windows of Social Sensitivity During Adolescence: The Case of Social Media). This article is set within a broader trend being increasingly recognized: Transdisciplinary approaches are needed to address the interplay of social and biological realms in understanding development as well as the etiology, prevention, and management of illness. We apply this approach to adolescent brain development, drawing on a neuroecosocial view of mind, brain, and culture, which calls for a widening in perspective from a developmental science centered on brain circuitry toward one that recognizes social predicaments and social systems as crucial sites for experimental study, explanation, and intervention (Rose et al. 2022). This integrative neuroecosocial perspective elucidates the powerful effects of social inequality, city living, and the climate crisis as key determinants of mental health during a sensitive period of development.

4. SOCIAL DETERMINANTS OF BRAIN DEVELOPMENT AND MENTAL HEALTH

The phrase social determinants of health refers to features of the social context or environment that impact health. Research into the social determinants of health has produced a wealth of data on the impacts of social forces and inequities on human health. However, the role of the brain and effects on brain development are relatively understudied. It is clear that promoting healthy brain development and functioning depends on understanding the bidirectional interaction between neurobiological and social-environmental processes, and successful systemic interventions require us to address economic and social barriers to well-being. Social structural adversity can put

young people at risk for poor brain health, but social factors also can be powerful ingredients in improving resilience and recovery (Ferschmann et al. 2022, Tooley et al. 2021, van Harmelen et al. 2017). Neuroscience is at a crucial junction, poised to have a substantial impact on youth mental health, but the generalizability of findings is limited unless action is taken to systematically integrate an understanding of social and cultural context into the design of neuroscience experiments and knowledge translation to policy and practice. With this in mind, we suggest that the social determinants of health field has important insights for developmental cognitive neuroscience. This includes the built and ecological environment, social institutions, structures, interpersonal interactions, roles, and relationships. Neuroscience research itself demonstrates that high levels of interindividual variation will be more accurately characterized by taking into account the young person's social environment.

4.1. Social Inequality: Pathways Between Socioeconomic Disadvantage and Health

Socioeconomic inequality is on the rise globally with recent reports showing increasing income and wealth disparities within and between countries (Chancel et al. 2022). Research has consistently linked the experience of living with socioeconomic disadvantage during childhood and adolescence to pronounced differences in mental and physical health, educational attainment, and cognitive and socioemotional development (Reiss 2013, Van Oort et al. 2011, Vukojević et al. 2017). Studies point to a greater incidence of mental health problems such as depression in adolescents from poorer families (Thapar et al. 2012) such that children and adolescents from lower socioeconomic groups are two-to-three times more likely to develop mental health problems (Reiss 2013, Russell et al. 2016). Similarly, growing up in poverty is associated with differences in cognitive development, including lower academic attainment levels throughout education (von Stumm et al. 2020, Welsh et al. 2010) as well as heightened socioemotional problems later in life (Evans & Cassells 2014).

Neuroimaging studies over the last decade have shown that different markers of socioeconomic status (SES) are related to structural brain development, particularly in the hippocampus, amygdala, and prefrontal cortex (Brito & Noble 2014, Hanson et al. 2011, Hao & Farah 2020, Farah 2017, Noble et al. 2015) (see **Figure 2**). Studies where income and childhood SES markers (e.g., parental education and home conditions) have been used have demonstrated that children and adolescents from lower-SES families have smaller hippocampal volumes (Hanson et al. 2011, Luby et al. 2013, Noble et al. 2012a). In addition, subjective measures of SES (e.g., subjective social status) have been connected to reduced gray matter volume in the perigenual area of the anterior cingulate cortex for children with low SES (Gianaros et al. 2007). In line with this, it has been proposed that these neurodevelopmental processes might mediate the relationships between SES and mental health problems, for example, in contributing to greater symptoms of depression and anxiety (Merz et al. 2018, Čermaková et al. 2022).

Recent studies have indicated that the impact of socioeconomic factors on the brain might be more pronounced at different points in life; in other words, there are sensitive periods of development that confer heightened sensitivity to environmental (socioeconomic) stress (McDermott et al. 2019, Piccolo et al. 2016). Accordingly, some studies report differential age effects of SES on cortical thickness and surface area such that the period of late childhood and early adolescence was most impacted by SES (Piccolo et al. 2016) and possibly correlated with self-esteem (Khundrakpam et al. 2020). Another study reported an interaction between parental education/family income and age, such that higher parental education/family income was associated with greater volume in the left superior temporal gyrus and left inferior frontal gyrus of

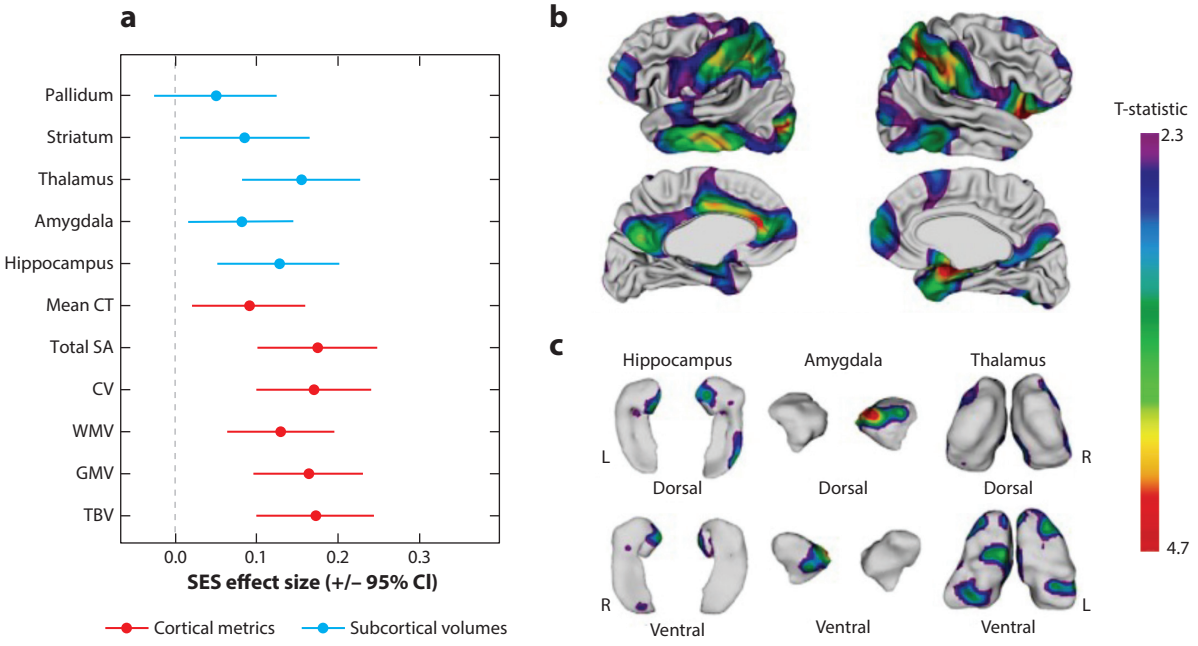

Figure 2

Results from an fMRI study investigating the association between childhood SES and brain measures in young people (5–25 years). (*a*) Standardized effect size of SES on each brain measure estimated using scaled variables. (*b*) Positive association between cortical SA and SES. (*c*) Positive association between subcortical SA and SES. Abbreviations: CI, confidence interval; CT, cortical thickness; CV, cortical volume; fMRI, functional magnetic resonance imaging; GMV, grey matter volume; L, left; R, right; SA, surface area; SES, socioeconomic status; TBV, total brain volume; WMV, white matter volume. Figure adapted from McDermott et al. (2019) (CC BY 4.0).

participants during adolescence (Noble et al. 2012b). Similarly, stressed ecologies during early life, in the form of low socioeconomic position, have been shown to impact the timing and events of the pubertal process such that stressful early life events cue individuals, both physiologically and behaviorally, to begin investment in reproduction sooner (Belsky & Andersen 2022, Worthman & Trang 2018). Therefore, it is possible that the onset of puberty and its relationship to the activation of the hypothalamic-pituitary-adrenal (HPA) axis might be important for the brain's contextual sensitivity, including to socioeconomic stress.

It will be important for researchers to carefully operationalize SES, as it is unclear how well SES markers capture the experience of social inequality as well as the adversity and precarity that come with living in poverty (Natl. Cent. Educ. Stat. 2012). SES is a multidimensional construct, usually pertaining to parental income, occupation, and/or education level, and sometimes subjective measures of social standing and neighborhood. This is distinct from measures of socioeconomic inequality, which measure the distance between the richest and poorest person in a group of people. In fact, research suggests that individuals from countries with more country-level wealth inequality experience worse outcomes, including lower life expectancy and worse mental health, than individuals from more equal societies (Elgar et al. 2015, Pickett & Wilkinson 2010). Similarly, the subjective experience of socioeconomic inequalities in one's proximate environment (e.g., friendship groups) has been found to predict mental health and interpersonal difficulties in adolescents who perceive themselves as poorer or as richer than their friends (Piera Pi-Sunyer

et al. 2023). This is distinct from the linear relationship traditionally hypothesized to exist between SES and health outcomes. A neurobiological understanding of how the brain is related to the experience of wealth inequalities in different environments (e.g., friendship groups, schools and neighborhoods, and countries) could shine light on how objective and subjective experiences of SES shape health outcomes (e.g., Douglass et al. 2017).

A cognitive neuroscience approach may prove valuable to both research and policy by demonstrating how the experience of living with social and material disadvantage leads to changes in the mind and brain, which, in turn, increase the risk of poorer educational attainment and mental disorders. Using large-scale longitudinal cohort studies, neuroscientists can begin to identify the links among hormones, social demographics, modifiable environments, and neurobiological markers. Future investigation comparing brain development in young people from families of varying socioeconomic positions could shed light on how socioeconomic disadvantage gets under the skin, illuminate potential sensitive periods for greatest vulnerability to adverse socioeconomic environments, and point to specific pathways of action and potential timing windows for prevention and intervention.

4.2. City Living, Chronic Stress Processing, and Mental Health

The second half of the twentieth century saw a global increase in the proportion of the population living in urban areas: less than 30% of the world's population lived in urban settings in 1950, compared with 55% of the current population (United Nations 2019). This upward trend is expected to continue into the mid-twenty-first century. Urbanicity is usually conceptualized as a combination of indices that characterize the physical environment, including a higher proportion of built-up environment and lower water and vegetation land cover (Xu et al. 2022) as well as particularities with respect to population density and social environments (Ventimiglia & Seedat 2019). City dwellers have easier access to the job market, higher salaries, easier access to health and social care services, better transportation systems, and higher-quality schools and childcare centers than people who live in rural settings. However, life in urban settings is also characterized by air and noise pollution (e.g., traffic and aircraft), less exposure to nature (e.g., green spaces and blue spaces), higher crime rates, greater living expenses, and, often, reduced social support (Ahern & Galea 2011, Dye 2008). In addition, urbanicity has been linked with increased and cumulative risk of mental health disorders. A meta-analysis reported that individuals living in urban cities are at greater odds of experiencing psychiatric disorders (38% higher), mood disorders (38% higher), and anxiety disorders (21% higher) compared with inhabitants of rural areas (Peen et al. 2010). Growing up in cities confers heightened risk: Children brought up in cities before mid-adolescence (around age 14) experience amplified risk of mental health disorders, for example, for nonaffective psychosis (Paksarian et al. 2018, Solmi et al. 2020), depression (Xu et al. 2022), and stress and anxiety disorders (Lambert et al. 2015).

The social environment of urban settings often includes low social cohesion, high socioeconomic deprivation, greater social inequalities, high population density, and limits to personal space (for a review, see Krabbendam et al. 2021). These factors have been related to increased difficulties in childhood and adolescence. For example, crime victimization and low neighborhood social cohesion during childhood predict psychotic symptoms (Newbury et al. 2016), and high neighborhood socioeconomic deprivation and inequalities have both been related to increased mental health disorders (Lambert et al. 2015, Visser et al. 2021). A mechanism proposed to contribute to the relationship between urban social environments and difficulties with mental health is the role of chronic social stress. Some studies suggest that urban city living is associated with increased activation of the HPA axis (measured through cortisol levels) (Tost et al. 2015), higher activation in

brain areas implicated in emotional processing (e.g., the amygdala and anterior cingulate cortex) in response to a cognitive-social stress task (Lederbogen et al. 2011), and increased activation in brain areas underlying reward processing and regulation (Krämer et al. 2017).

City living leads to more frequent experiences of social exclusion, sometimes referred to as social defeat. Social defeat stems from occasions of social subordination and humiliation, or the "negative experience of being excluded from the majority group" (Selten et al. 2013, p. 1180). These occasions of social exclusion are related to the subjective experience of social isolation and loneliness (Brandt et al. 2022, Kearns et al. 2015), which in turn amplifies and reproduces the negative perceptions and cognitive biases that lonely people have of their social environment (Matthews et al. 2019). Studies with rodents have demonstrated that prolonged and acute social isolation in early life produces disruptions in brain function, particularly in reward and stress processing (as reviewed in Matthews & Tye 2019, Novick et al. 2018). Some studies have started to investigate this association in human adolescents, suggesting that induced social isolation in young people constitutes a form of loneliness, causes stress and anxiety-related symptoms, and alters brain function (e.g., in the midbrain and amygdala) (Cacioppo et al. 2015, Tomova et al. 2020). However, less is known about the neurobiological effects of the social stress and loneliness created by living in large social structures. For example, young people in urban settings are more likely to have been racially bullied or bullied about money than young people in nonurban areas (e.g., outer city and rural areas) (Goldweber et al. 2013). These instances of aggression may have downstream neurobiological effects that increase the likelihood of mental health problems (Berger & Sarnyai 2015, Bowes et al. 2013, Henssler et al. 2020). In fact, ethnic minority status in urban areas has been associated with differential stress-related brain responses and increased cortisol levels (Akdeniz et al. 2014, Squires et al. 2012) as well as increased risk of developing psychosis (Solmi et al. 2020). The experience of urban social stress may also differ according to the intersecting social groups that people belong to. For example, exposure to crime and violence is higher in deprived neighborhoods, but the type of crime experienced may differ by gender, with females potentially being more exposed to sexual violence and males to gang and physical violence (Scorgie et al. 2017). The role of sociocultural identities in the experience of social stressors could further explain why the relationship between urbanicity, social exclusion, and mental health disorders might be more multidirectional in some societies, for example, those that are less unequal or are more multicultural (Heinz et al. 2020, Krabbendam et al. 2021, Plana-Ripoll et al. 2021).

In addition to the social characteristics of urban environments, urbanicity is often defined by particularities in the physical and built-up environment. A recent study developed an index to measure urbanicity called UrbanSat (Xu et al. 2022), which combines measures of population density, nighttime light, built-up environment, water and vegetation indices, and the percentages of land cover with respect to buildings, grassland, forest, and water. The study shows that the UrbanSat, and particularly the components of nighttime light and percentage of built-up environment, predicted differences in the structure and function of the medial prefrontal cortex and cerebellum (see **Figure 3**). A mediation analysis also showed that this relationship contributed to increased perspective-taking and more depressive symptoms in individuals growing up in areas with a higher UrbanSat (Xu et al. 2022). Other studies have also suggested that nighttime urban light exposure (Cho et al. 2015), road traffic and air pollution (Pujol et al. 2016, Roberts et al. 2019), and noise pollution (e.g., traffic and aircraft) (Beutel et al. 2016, Rautio et al. 2018) in urban environments are related to increased sensitivity to chronic stress, anxiety, and depressive symptoms. While the specific role of brain structure and function on these relationships is not well understood, some proposed mechanisms include brain hyperconnectivity in the default mode network (processing when not engaged in a task) (Costa e Silva & Steffen 2019) and between striatal and cortical regions (reward processing) (McCutcheon et al. 2019), as well as increased load on cognitive processing

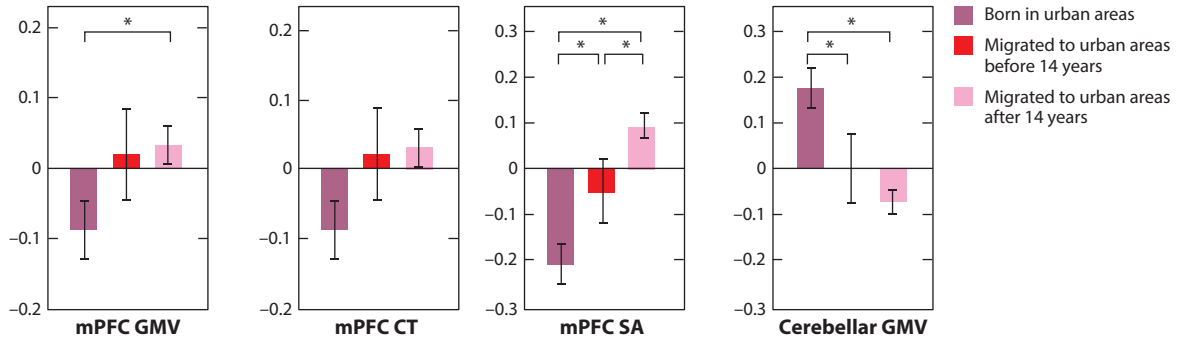

Figure 3

Results from an fMRI study investigating the relationship between an urbanicity index and brain measures. The graphs show that participants who were born in urban areas (*mauve*) or migrated to an urban environment before the age of 14 (*red*) had significantly smaller mPFC GMV and mPFC SA and greater cerebellar GMV than participants who migrated to urban environments after the age of 14 (*pink*). Error bars show means and standard errors. Asterisks indicate a p-value of <0.05. Abbreviations: CT, cortical thickness; fMRI, functional magnetic resonance imaging; GMV, grey matter volume; mPFC, medial prefrontal cortex; SA, surface area. Figure adapted with permission from Xu et al. (2022).

(e.g., attention, memory and cognitive control) (Bratman et al. 2012). These could be related to difficulties with goal-directed behavior and social and reward processing, which means that exposure to urban pollutants could be particularly harmful for youth who have diverse cognitive trajectories, have a predisposition for mental health problems, or live in areas that lack the spaces and infrastructure, such as parks and other green spaces, to mitigate the detrimental effects of urbanicity.

The availability of natural spaces in urban environments has been associated with lower risk of psychological conditions (e.g., depression and anxiety) and psychotic symptoms (Bezold et al. 2018, Gascon et al. 2015), improved physical health and immune function (Dadvand & Nieuwenhuijsen 2019), improved cognitive functioning (Dadvand et al. 2018), and reduced feelings of loneliness (for a review, see Astell-Burt et al. 2022). The main hypothesis for the mechanisms underlying the beneficial effects of green spaces (e.g., parks) on health is their role in cognitive restoration and stress reduction (Berto 2014). Studies have suggested that performance on cognitive processing tasks, including tasks related to working memory, attention, and social cognition, is enhanced in young people growing up or living in areas with more green spaces (for a review, see Vella-Brodrick & Gilowska 2022). This is also the case after being experimentally exposed to natural environments, which suggests that both short-term and long-term exposure to natural spaces could be beneficial for cognitive restoration (e.g., Bratman et al. 2012, Mason et al. 2021). In addition, exposure to green spaces is related to reduced stress (i.e., the stress reduction theory) (Ulrich et al. 1991), and this association has been found with both affective measures of stress (e.g., ecological momentary assessment) (Feda et al. 2015, Mennis et al. 2018) and physiological responses to stress (e.g., diminished heart rate) (Hystad & Cusack 2019). While some studies have looked at neurobiological differences that may underlie how natural spaces in urban environments are instrumental for cognitive restoration and stress reduction (e.g., Dadvand et al. 2018), there is a dearth of research in this area, and the neural pathways remain unclear.

It is important to acknowledge the role of developmental cognitive neuroscience in understanding how the social and physical conditions we inhabit in urban settings are inscribed in the mind and brain. In doing so, policy-directed research should consider how the brain is implicated

in the process through which urban settings might reproduce, amplify, or reduce health inequalities. One recent study showed that the association between neighborhood disadvantage and emotional disorders was twofold for adolescents living in urban settings as opposed to nonurban settings (Juengsiragulwit & Nikapota 2020). Notably, a greater percentage of adolescents living in disadvantaged neighborhoods were Hispanic or Black. Moreover, while young people from more disadvantaged backgrounds are the most likely to benefit from the health-related effects of natural spaces, they are also less likely to live in urban areas with more green spaces (affecting the frequency of use of these spaces) (Dadvand & Nieuwenhuijsen 2019). These considerations emphasize how the risk of mental health disorders might systematically reproduce for youth from less affluent and minority backgrounds. In contrast, some studies have not found a relationship between urbanicity and mental health. Some reasons for these null findings might be related to the prevalence of high SES in some samples (Evans et al. 2020), nonrepresentative access to health care and social cohesion in some wealthy neighborhoods (Ahern & Galea 2011), and selective migration to cities or disadvantaged neighborhoods by people who may have a predisposition to physical and mental disorders (Sariaslan et al. 2016). Future studies should employ ethnographic methods to examine the role of social experiences of city living and to characterize the affordances of different physical urban environments, combining them with methods that can be used to infer causal and multidirectional links with a range of genetic, neurobiological, and psychological factors.

4.3. Climate Crisis and the Rise of Youth Eco-Anxiety

Researchers have pointed out the disproportionate burden of the climate change crisis on young people (Wu et al. 2020). This vulnerability is argued to be biological, psychological, developmental, and social in nature due to a variety of factors, including that (*a*) the majority of young people globally live in regions that the United Nations has deemed to be at extremely high risk for climate disasters (Arora et al. 2022); (*b*) young people will live with the climate crisis for the rest of their lives and thus will experience the cumulative effects of intensifying associated disasters (Hickman et al. 2021, Meltzer et al. 2021); (*c*) due to their age and the climate crisis's growing impacts over time, young people will be responsible for mitigating the worst effects of the climate crisis (Wu et al. 2020); and (*d*) this is a sensitive period of neurobiological and emotional development, which may mean young people are especially susceptible to climate anxiety (Hickman et al. 2021, Pacheco 2020, Vergunst & Berry 2021, Wu et al. 2020). Negative effects on young people are compounded by their limited ability to adapt to high levels of chronic stress due to their less empowered social status and dependency on adults (Patel et al. 2021).

A growing body of scholarship points to the mental health impacts of climate change, showing how the crisis will worsen existing mental health problems and cause new ones for youth (Wu et al. 2020). It has been proposed that the climate crisis impacts adolescent mental health in three ways: direct experience of climate disasters; indirect consequences such as displacement, increased exposure to violence, and lack of social services; and overarching awareness of the magnitude of the threat, which is sometimes referred to as the vicarious effect (Clemens et al. 2020, Léger-Goodes et al. 2022). Most research to date has been focused on the direct and indirect effects, specifically the psychological effects of climate disasters, which are associated with a range of negative mental health outcomes for young people, including post-traumatic stress, depression, anxiety, and behavioral problems (Meltzer et al. 2021). Recent research has begun to focus on the vicarious effects, and, specifically, the phenomenon of climate anxiety. This has been termed eco-anxiety and is defined by the American Psychological Association as "chronic fear of environmental doom" (Clayton et al. 2017, p. 68). More generally, the term climate anxiety is used to describe "anxiety

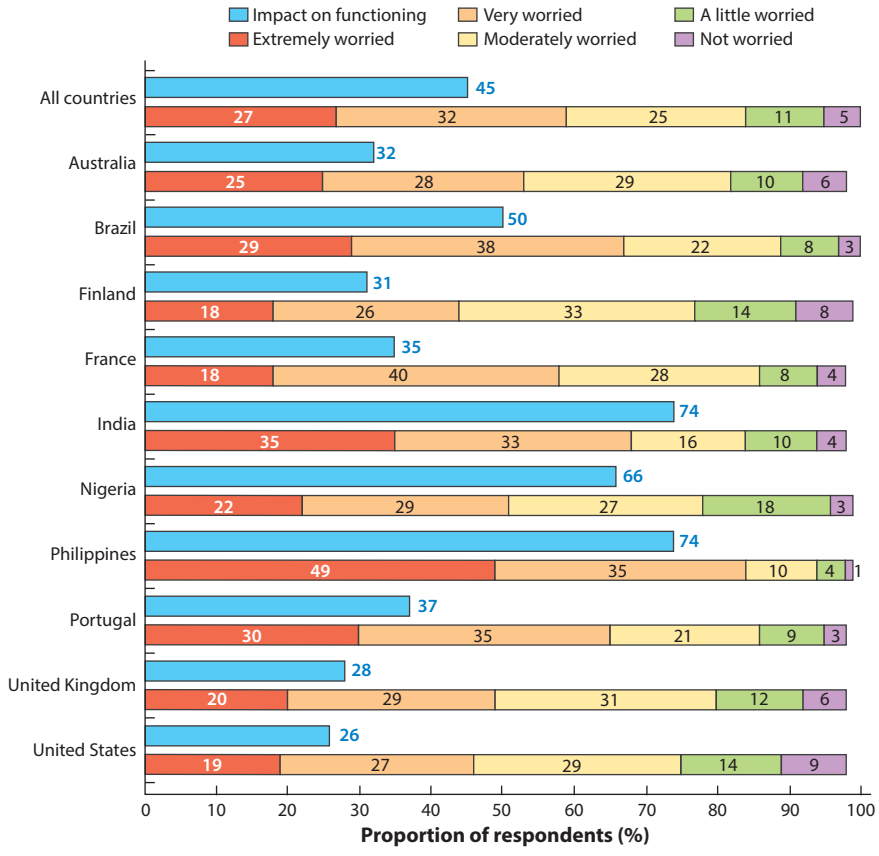

Figure 4

Results from a study showing the impact of worrying about climate change on functioning in young people (16–25 years). The plot shows the proportion of the study respondents reporting a negative impact on functioning (*blue*), as well as the proportion of respondents reporting being extremely worried (*dark red*), very worried (*orange*), moderately worried (*yellow*), a little worried (*green*), or not worried (*purple*). Data are shown for the whole sample ($n = 10{,}000$) and by country ($n = 1{,}000$ per country). Figure adapted with permission from Hickman et al. (2021) (CC BY-NC-ND 4.0).

related to the global climate crisis and the threat of environmental disaster" and has been linked to panic attacks, obsessive thoughts, and insomnia (Wu et al. 2020, p. e435). Research on the prevalence of eco-anxiety has found that, globally (across Australia, Brazil, Finland, France, India, Nigeria, Philippines, Portugal, the United Kingdom, and the United States), 84% of young people (ages 16–25) classified themselves as at least moderately worried about climate change, with almost half of all those surveyed saying that climate anxiety disrupted their daily functioning and three-quarters reporting being frightened of the future (Hickman et al. 2021) (see **Figure 4**). Research surveying child psychiatrists has echoed these rates, with a UK study reporting that 57% of clinicians are seeing young people distressed about environmental issues (as compared with 47% of clinicians treating adults) (R. Coll. Psychiatr. 2020). In a 2022 *New Yorker* article on Sunrise (a youth-led climate movement based in the United States), many young activists explicitly describe the climate crisis as "a source of profound anxiety" that has preoccupied them since childhood (Marantz 2022). Major media outlets such as the *Guardian*, the BBC, and the *New York Times* flag this growing anxiety as a crisis of hope and as a widespread concern for young people, parents,

and educators alike (Cook-Shonkoff 2020, Messenger Team 2021). Researchers have begun to document the multiple psychological impacts of the climate crisis, including not only eco-anxiety but also solastalgia (distress produced by environmental change), eco-guilt, and ecological grief, which encompass a range of emotional effects in response to the planetary catastrophe including anger, panic, sorrow, hopelessness, and grief (Pihkala 2020, Verlie 2020).

While the existing literature has demonstrated the extent to which young people are especially vulnerable to climate change, the impressive ability and capacity of youth to respond to and engage with this overwhelming challenge has also been well-documented (S. Choudhury & J.M.M. Moses, manuscript in preparation). Climate anxiety has spurred many young people to take remarkable political action and become involved in climate justice and activist movements (Marantz 2022). The climate crisis has led to demonstrations of developmentally appropriate interests in civic engagement, including high-profile platforms of resistance and action that reflect adolescents as exemplary agents of positive change and activism (Arora et al. 2022, Sanson & Bellemo 2021). In fact, researchers have pointed out that young people's climate anxiety leads to one of the most effective ways of engaging adults in climate action, namely young people motivating their parents to engage (Benoit et al. 2022). Young people's particular vulnerability due to their developmental stage is perhaps also a predisposition for active engagement with the climate crisis. Adolescents are less fatalistic than adults about climate change and are less likely to employ coping strategies such as avoidance or denial (Clemens et al. 2020).

Anxiety, powerlessness, and other challenging emotions about climate catastrophe are healthy responses to a planet in crisis that reflect young people's eco-awareness, compassion, and empathy (Galway & Field 2023, Hickman et al. 2021). However, these emotional responses require careful attention to mitigate their effects on everyday function and potential pathways to mental disorder (Bright & Eames 2022). Adolescents are developing their academic paths, shaping their sense of self, and forming their identity in relation to significant uncertainty about their warming planet, not to mention economic precarity and a host of other challenges due to the COVID-19 pandemic. Several calls to action raise avenues for future research toward mitigating the effects of eco-anxiety, grief, and solastalgia on youth. In what ways is climate-related anxiety distinct from other kinds of anxiety? What other kinds of emotions does climate change elicit (Galway & Field 2023)? What kinds of tools need to be developed to measure its effects on mental and physical health? Which groups are most affected and at what stage during the lifespan? How might new educational curricula be developed to respond to these climate emotions, and how should they be tailored to the neurodevelopmental particularities of this age group to engage young people in climate action, provide tools to reckon with climate catastrophes, and cultivate hope? Environmental educators have argued that a key strategy to manage eco-anxiety and empower young people is to develop curricula built to promote agency, empathy, and social action and to harness developing metacognitive capacities to support critical thinking (e.g., **https://sshean.ca/resources/**; Rae et al. 2022; S. Choudhury & J.M.M. Moses, manuscript in preparation). We suggest that findings from developmental psychology and cognitive neuroscience can supplement other important educational approaches (e.g., Indigenous frameworks and futures thinking) in the development of pedagogical responses that address the emotional impacts of uncertain ecological futures among youth. Specifically, developmental science may offer insights on trajectories to design educational tools that scaffold the competencies that are particularly salient to adolescence. This research might, for example, help us understand the time windows for the development of agency or of critical thinking capacities that enable young people to navigate exposure to climate misinformation and to analyze information and evidence in an already saturated, polarized (digital) media landscape.

5. ENGAGING ADOLESCENTS IN YOUTH-LED RESEARCH

The climate crisis is only one of the many arenas where youth are making themselves heard and manifesting leadership and creativity. While Greta Thunberg has become one major actor and voice of conscience in the climate movement internationally, many youth (including Greta) face both structural and institutional barriers in being both included and taken seriously in matters that affect them (Arora et al. 2022). Beyond climate activism, meaningful youth engagement is essential to the success of impactful decision-making in research and policy related to adolescent health and well-being. Global leaders in research and advocacy including UNICEF, the Lancet, and the WHO, as well as numerous nongovernmental and community-based organizations, have called for methods that prioritize youth voice in research and policy processes (Arora et al. 2022, Wong et al. 2021; see also **https://www.voicesofyouth.org/**). It is increasingly important to respond to the growing call for youth-engaged and youth-led models of research, which seek to center the multiple voices of youth and to draw on adolescents' valuable contributions as agents of change and action (Gasparri et al. 2021).

The concern is that the current evidence, crucial to the development of effective strategies, does not include the voices and realities of diverse and vulnerable populations such as youth with disabilities, LGBTQ+ youth, low-income youth, racialized youth, Indigenous youth, and youth in different cultures and contexts globally. For example, neuroscience research on the adolescent brain that is informing the design of clinical and psychiatric treatment has historically reflected particular populations in the global North, generally biased by class, education level, race, and ethnicity. Close consideration must be given to local context and the larger intersecting socio-ecological realities such as climate change, urbanization, social media, digital transformation, and globalization. To develop solutions, we urgently need to listen to youth with perspectives from a range of social, cultural, and economic backgrounds, engage across disciplines and sectors, and innovate in our research and policy processes.

Youth-led participatory action research (YPAR) methods offer equity-focused approaches—including quantitative surveys, focus group methods, arts-based methods, and photovoice—that draw on the expertise of adolescents and promote developmentally salient competencies such as agency and social connection. YPAR may offer a framework to psychologists and neuroscientists that acknowledges and has impacts on both the systemic and individual developmental contexts of youth (Ozer 2017). In other words, enabling young people to be participants in research design, data collection, and interpretation and sharing power with adult scientists and policy-makers not only makes ethical sense but also supports adolescent health and well-being in at least two interrelated ways: At a social-ecological level, it allows them to have a say in shaping the institutional and geographical contexts in which they grow, learn, and live (e.g., healthcare, urban infrastructures, schools), and at a psychological level, it fosters their growing autonomy, sense of responsibility, and identity at a particularly salient period of development. As we have emphasized throughout this article, the social systems that adolescents inhabit have direct impacts on their individual developmental trajectories; YPAR methods that promote their involvement in designing those systems therefore serve as positive interventions for their empowerment and well-being.

An example of youth engagement in mental health research is an innovative study examining the impact of different threads of cultural connection, that is, the effect of different dimensions of individuals' identity—including one's worldview, religion, sociocultural background, collective histories, and language—on youth mental health (D'Souza et al. 2021). Conducted in Canada and supported by the Wellcome Trust, this study resulted in the creation of a cross-Canada Youth Advisory Council (YAC) composed of youth with lived experience of depression and anxiety. This

YAC was comprised of Indigenous youth, sexual and gender minority youth, and youth from various ethnoracial minority groups, responding to growing concerns that mainstream scientific approaches overlook the diversity of youth, inadequately capture the role of the social ecology of the young person, and often undermine the subjective experience of the young person themselves. The project models how youth can be engaged not only in an advisory capacity but also in steering the research process, from reviewing the relevant literature to the interpretation of results using a participatory decision-making process known as Fuzzy Cognitive Mapping. This collaborative, youth-led process yielded the key finding that cultural connection is vital to fostering a secure cultural identity, healthy relationships, and a sense of belonging, particularly during adolescence. For example, communicating in one's native language and engaging in cultural practices with members of one's own ethnic group can reduce the risk of depression and anxiety among youth from certain minority groups. This unique research model demonstrates not only the integration of youth in mental health research but also the potential for youth-engaged research to empower adolescents in the process, allowing their perspectives and voices to shape and lead this initiative while also creating valuable learning opportunities for them.

6. CONCLUSION: A NEUROECOSOCIAL FRAMEWORK FOR THE DEVELOPING BRAIN

Policymakers are increasingly eager to understand how aspects of the environment—particularly those associated with broad ecological, institutional, and structural forces and inequalities such as the influence of social exclusion, climate change, and the experience of poverty—get under the skin and lead to changes in the mind and body that, in turn, raise the risk of mental disorder. Formulating policy-relevant science requires a neuroecosocial approach to studying the adolescent brain in the context of the body, the family, the social world, and the cultural and geographical setting. The central obstacle to addressing these questions is methodological; the challenge lies in developing ecologically valid methodologies that operationalize the social world and can measure the interactional relationships between the brain and social context. How do we unpack the black box of the environment? How do we operationalize context in the lab? Current forms of evidence remain siloed and require integration; youth-led researchers increasingly call for additional forms of data beyond quantitative, probabilistic, and decontextualized approaches to address youth mental health and illnesses in culturally and socially appropriate ways. An approach that truly recognizes the mutual relationships between social and biological processes of development, health, and disease and the value of acquiring data from lived experience within complex environments requires sustained collaboration between neuroscientists and social theorists (Rose et al. 2022). In order to understand pathways or mechanisms, whether they relate to stress, inflammation, neuroplasticity, or epigenetic processes, we need to turn to sociological and anthropological methods to characterize the environment or the ecological niche and their affordances for a particular individual to begin to grasp how environments as complex as neighborhoods and cities and contexts as abstract as inequality or planetary crisis affect individuals at the level of neurobiology, behavior, mental health, and recovery. This transdisciplinary, integrative approach can cast new light on the social and neurobiological pathways that connect lived experience and brain development and shape mental health during adolescence.

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