NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD

Place Matters:

The Environment We Create Shapes the Foundations of Healthy Development

WORKING PAPER 16

Center on the Developing Child
HARVARD UNIVERSITY

NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD

SPONSORS

Anonymous

The Ballmer Group

Buffett Early Childhood Fund

Chan Zuckerberg Initiative

Conrad N. Hilton Foundation

The Dayton Foundation/ Scarlett Feather Fund

Esther A. and Joseph Klingenstein Fund, Inc.

Genentech Philanthropies

Imaginable Futures

J.B. and M.K. Pritzker Family Foundation

LEGO Foundation

Tikun Olam Foundation

William S. Benjamin and Kerri Benjamin

MEMBERS

Jack P. Shonkoff, M.D., Chair
Julius B. Richmond FAMRI Professor of Child Health and Development, Harvard T.H. Chan School of Public Health and Harvard Graduate School of Education; Professor of Pediatrics, Harvard Medical School and Boston Children's Hospital; Research Staff, Massachusetts General Hospital; Director, Center on the Developing Child, Harvard University

Pat Levitt, Ph.D, Science Co-Director
Chief Scientific Officer, Vice President, and Director, The Saban Research Institute; Simms/Mann Chair in Developmental Neurogenetics, Program in Developmental Neuroscience & Neurogenetics, Children's Hospital Los Angeles; W.M. Keck Provost Professor in Neurogenetics Department of Pediatrics, Keck School of Medicine, University of Southern California

Nathan A. Fox, Ph.D., Science Co-Director
Distinguished University Professor, Department of Human Development and Quantitative Methodology, Program in Neuroscience and Cognitive Science; Director, Child Development Lab, University of Maryland

Judy L. Cameron, Ph.D.
Professor of Psychiatry, Neuroscience, Obstetrics-Gynecology Reproductive Sciences, Clinical and Translational Science, and Behavioral and Community Health Sciences, University of Pittsburgh; Director, Pitt Science Outreach; Director, Working for Kids: Building Skills; Senior Scientist, Affiliate Scientist and Professor of Behavioral Neuroscience, Oregon National Primate Research Center

Greg J. Duncan, Ph.D.
Distinguished Professor, School of Education, University of California, Irvine

Damien Fair, PA-C, Ph.D.
Redleaf Endowed Director, Masonic Institute for the Developing Brain; Professor, Institute of Child Development, Department of Pediatrics, University of Minnesota Medical School

Philip A. Fisher, Ph.D.
Director, Stanford Center on Early Childhood; Excellence in Learning Chair & Professor, Graduate School of Education, Stanford University

Megan R. Gunnar, Ph.D.
Regents Professor and Distinguished McKnight University Professor, Institute of Child Development, University of Minnesota

Takao K. Hensch, Ph.D.
Professor, Molecular and Cellular Biology, Harvard Faculty of Arts and Sciences; Professor, Neurology, Harvard Medical School at Boston Children's Hospital; Director, Child Brain Development; Director, WPI-IRCN (UTIAS); Director, NIMH Silvio Conte Center for Brain Science, Harvard University

Fernando D. Martinez, M.D.
Regents Professor and Swift-McNear Professor of Pediatrics; Director, Asthma and Airway Disease Research Center; Director, Clinical and Translational Science Institute; Director, BIO5 Institute; Professor, Genetics - GIDP, The University of Arizona

Patrícia Pelufo Silveira, M.D., Ph.D.
Scientific Director, Genomics and Epigenetics Pillar Ludmer Center for Neuroinformatics and Mental Health; Associate Professor, Department of Psychiatry, Faculty of Medicine and Health Sciences, McGill University

David R.Williams, Ph.D., M.P.H.
Norman Professor of Public Health and Chair, Department of Social and Behavioral Sciences, Harvard T.H. Chan School of Public Health; Professor of African and African American Studies, Harvard University

ACKNOWLEDGMENTS

We gratefully acknowledge the significant contributions to this paper made by:

Gloria Corral, M.P.P., Parent Institute for Quality Education

Iheoma Iruka, **Ph.D.,** The University of North Carolina at Chapel Hill

Gabriela Lopez, Chan Zuckerberg Initiative

Al Race, Communications Consultant

Aaliyah Samuel, Ed.D. CASEL

Natalie Slopen, Sc.D., Harvard T.H. Chan School of Public Health

Nat Kendall-Taylor, Ph.D., FrameWorks Institute

Wendy Viola, William Julius Wilson Institute

Donna Wilson, Ph.D., National Conference of State Legislatures

About the Authors
The National Scientific Council on the Developing Child, housed at the Center on the Developing Child at Harvard University, is a multi-disciplinary collaboration designed to bring the science of early childhood and early brain development to bear on public decision-making. Established in 2003, the Council is committed to an evidence-based approach to building broad-based public will that transcends political partisanship and recognizes the complementary responsibilities of family, community, workplace, and government to promote the well-being of all young children. In collaboration with the Council, Lindsey Burghardt, M.D., M.P.H., FAAP, Chief Science Officer at the Center, also played a critical role in the production of this working paper. For more information, go to www.developingchild.harvard.edu.

Please note: The content of this paper is the sole responsibility of the authors and does not necessarily represent the opinions of the sponsors.

Suggested citation: National Scientific Council on the Developing Child. (2023). *Place Matters: The Environment We Create Shapes the Foundations of Healthy Development: Working Paper No. 16.* Retrieved from www.developingchild.harvard.edu

© 2023, NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD, CENTER ON THE DEVELOPING CHILD AT HARVARD UNIVERSITY

THE ISSUE:

The Physical Environments Where Children Live Affect Their Development and Health

We all experience a continuous stream of influences from the physical and social environments in which we live, beginning before birth and continuing throughout our lives. These include a wide range of conditions in the places where children live, grow, play, and learn that get "under the skin" and affect the developing brain and other biological systems—including the immune and metabolic systems—with potential effects in childhood and well into the adult years.[1] Beyond the critically important impacts of caregiver-child relationships on early childhood development, *the places where people live* affect what they are exposed to, which then affects maturing biological systems—positively or negatively. In short, *place matters*.

Scientists categorize the physical environment in at least two ways, both of which are shaped by human actions, including intentional decisions around policies that shape the environment in which we live. One category—the *natural environment*—includes the quality and temperature of our air, the purity and availability of our water supply, and the ways that climate change affects the prevalence and magnitude of natural disasters like floods, hurricanes, and wildfires. Another—the *built environment*—includes the residences in which families live; the density of surrounding buildings; the types of local businesses (and whether they offer job opportunities, access to nutritious food, etc.); the availability of green spaces; the upkeep of roads, bridges, and sidewalks in the neighborhood; and the transportation that people can access to get to where they need to go.[2]

The qualities of the conditions in which people live are not evenly or randomly distributed. They are shaped by and deeply rooted in public policies and social history. Extensive research demonstrates how zoning regulations, real estate and banking practices, and government actions—both through historic discrimination and current practices—have discriminated against minoritized racial and ethnic groups. These influences, past and present, continue to shape the natural and built environments where Black and Indigenous individuals, along with other people of color (BIPOC), live today.

> **The qualities of the conditions in which people live are not evenly or randomly distributed. They are shaped by and deeply rooted in public policies and social history.**

For example, policies described as "redlining"—a federally backed program that for nearly 40 years denied mortgage loans and other financial services for residents of areas that were marked on maps as "hazardous" for investment based on residents' race or ethnicity— resulted in neighborhoods that remain predominantly populated by Black residents and other people of color. This segregation has led to unequal access to wealth (through lack of access to high-paying jobs and favorable mortgages), lack of access to high-quality health care and schools, and unequal access to reliable transportation. These previously redlined neighborhoods often lack resources to oppose the building of highways, manufacturing plants, and toxic waste disposal sites in or near their communities. As a result, today, these racially segregated communities are far more likely than predominantly white neighborhoods to experience increased exposure to high levels of air pollution, toxic chemicals, excessive noise, and higher temperatures, while also having less access to healthy foods, high-quality health care facilities, safe areas to play or exercise, and green spaces.[3,4,5] Families struggling with the hardships of intergenerational poverty and with limited political power in rural areas are also more likely to live in close proximity to contaminated groundwater and be exposed to toxicants (i.e., artificial, human-made toxic products such as pesticides or industrial waste) that can have serious consequences for pregnancy outcomes and the subsequent health of their children.[6,7,8]

Understanding the powerful effects that natural and built environments have on the early foundations of health and development calls for increased attention to important influences that fall well beyond the traditional boundaries of the early childhood field.

In 2004, the National Scientific Council on the Developing Child described the effects of early life experiences on the developing brain in its first Working Paper, *Young Children Develop in an Environment of Relationships*.[9] Over the ensuing two decades, this science-based concept has helped make the case for safe, stable, and nurturing relationships as the "active ingredient" in how environments can positively influence the architecture of the developing brain. More recently, as research on the early origins of health and illness has advanced, so has our understanding of how early experiences affect *multiple* biological systems in the body (e.g., immune, metabolic, and respiratory) and how those systems interact with and shape each other as well as the brain.[10,11] But this is not the whole picture. External exposures from the natural and built environments *also* affect the development of biological systems inside the body and *interact* with the more personal influences of adult-child relationships in a deeply interconnected way.

The implications of this rapidly growing science are clear. Understanding the powerful effects that natural and built environments have on the early foundations of health and development calls for increased attention to important influences that fall well beyond the traditional boundaries of the early childhood field. This demands the incorporation of a more intentional early childhood perspective within the current concerns of urban planning, rural development, environmental protection, climate change, and anti-discrimination policies, among others. Ensuring "fairness of place"—that vital conditions for well-being are available to all children, not just some—requires that a broader range of policy domains work together to redress racist and other discriminatory policies to achieve greater equity. Supporting healthy child development is *still* about caregiver-child relationships, and it's *also* about communities, businesses, and governments working together to assure a supportive and healthy environment for *all* young children—with particular attention to natural and built environments that fall far short of that goal.[12]

What Science Tells Us

The conditions of a place can have positive or negative influences on child health and development. Positive influences, beginning in pregnancy and continuing throughout childhood, include access to nutritious food, clean air and drinking water, safe green space in which to play, reliable transportation, and a home environment free of lead and other heavy metals. Negative influences include polluted air and water, extreme temperatures, a lack of safe green spaces, high rates of crime and violence, excessive environmental noise that can disrupt normal sleep patterns, lack of access to affordable nutritious food, and a home environment containing toxicants from asbestos, lead, or secondhand smoke.[13]

An environment that provides many positive influences is more likely to support healthy development, and an environment that imposes many negative influences is more likely to result in a higher prevalence of disease and impairment. For example, access to safe green spaces—such as parks, playgrounds, and recreation areas—is associated with better physical and mental health, lower stress, and lower rates of obesity and type 2 diabetes, among many other benefits.[14] Access to safe green space during pregnancy is associated with decreased risk for low birth weight, which is a known risk factor for a range of health conditions across the life course.[15] More frequent exposure to green spaces during childhood is related to lower risk of both obesity and neurodevelopmental problems such as inattentiveness.[16] Based on available evidence, it is reasonable to hypothesize that these benefits can be explained by higher levels of physical activity, calming effects of exposure to nature, mitigation of extreme heat, and reduction of air and noise pollution.

As our knowledge of the health effects of green space grows, the unequal distribution of these spaces demands greater attention. In many cities across the United States, neighborhoods with higher percentages of residents of color, as well as people with lower levels of education and income, have less access to green space and experience higher average temperatures than neighborhoods with higher percentages of white and higher-income residents.[17,18] Moreover, the geography of these differences closely mirrors the boundaries created by legalized, discriminatory zoning and real estate investment practices (described above) that began almost a century ago and have played a major role in creating the racially segregated neighborhoods and subsequent unequal exposures to adverse environmental conditions that continue to this day.[19] Current zoning practices that place restrictions on minimum lot sizes, building height, and construction of multifamily homes perpetuate unequal types and quality of housing across neighborhoods. These historically discriminatory practices, as well as their modern-day policy counterparts, result in neighborhoods with fewer positive conditions and more harmful environmental influences, and thereby contribute to persistent racial disparities in health, such as higher rates of obesity and diabetes in Black populations compared to white.[20]

Many factors contribute to the early foundations of health and development. That said, abundant research evidence shows that as the number of adverse exposures increases, it becomes less likely that any individual will "weather the storm" and avoid experiencing some negative effects.[21] As the demand for deeper understanding of neighborhood influences on child well-being has increased, researchers across disciplines have become more precise about quantifying both positive and negative environmental conditions and their impacts. One of the most prominent examples, the Childhood Opportunity Index (COI), provides a comprehensive tool for evaluating assets and risk factors at the neighborhood level, based on data collected from 72,000 census tracts in the 100 largest metropolitan areas in the United States.[22]

TABLE 1

Neighborhood indicators in the Child Opportunity Index 2.0

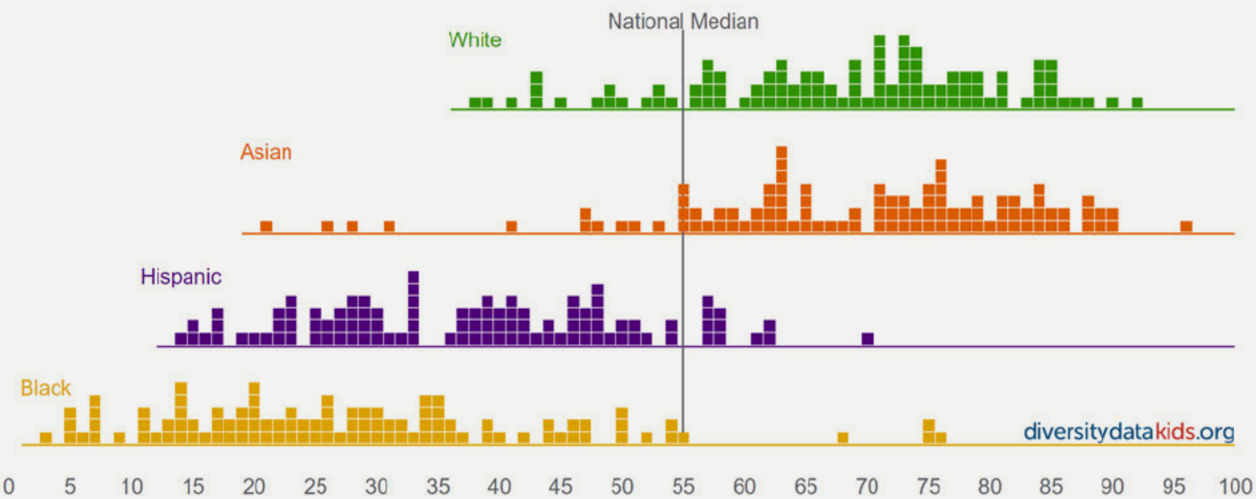
Education	Health and Environment	Social and Economic
Early childhood education • Early childhood education centers • High-quality early childhood education centers • Early childhood education enrollment **Elementary education** • Third grade reading proficiency • Third grade math proficiency **Secondary and postsecondary education** • High school graduation rate • Advanced Placement course enrollment • College enrollment in nearby institutions **Educational and social resources** • School poverty • Teacher experience • Adult educational attainment	**Healthy environments** • Access to healthy food • Access to green space • Walkability • Housing vacancy rate **Toxic exposures** • Hazardous waste dump sites • Industrial pollutants in air, water or soil • Airborne microparticles • Ozone concentration • Extreme heat exposure **Health resources** • Health insurance coverage	**Economic opportunities** • Employment rate • Commute duration **Economic and social resources** • Poverty rate* • Public assistance rate* • Homeownership rate* • High-skill employment* • Median household income* • Single-headed households

*These five indicators are combined into an economic resource index.

The COI considers the types of resources and conditions in neighborhoods where children live, and the corresponding access to opportunities—or lack thereof—that can support healthy development. The 29 elements quantified by the COI include proximity to assets like educational resources (including high-quality early care and education), green spaces, employment opportunities, and healthy foods, as well as exposure to risk factors like hazardous waste, air pollution, and extreme heat.[23] Analyses of COI data show significant geographical differences across the United States, with New England and the Great Plains states containing metro areas with the highest scores, while the Central Valley of California and Southern states have metro areas with some of the lowest opportunity scores in the country.

Within these regions, the COI lays bare dramatic differences between neighborhoods populated predominantly by white residents and those that are home to mostly Black and Hispanic residents (see sidebar). Black and Hispanic children across the US are more than seven and five times more likely, respectively, to live in "very low opportunity" neighborhoods compared to white children.[24] Analysis of COI data shows that children are highly segregated by race/ethnicity, and opportunities are significantly less available to those who identify as Black or Hispanic compared to those who identify as white or Asian. In the Milwaukee metro area, for example, the typical white child lives in a neighborhood with a Child Opportunity Score of 85 (out of 100), while the typical Black child lives in a neighborhood with a score of only 6.

Underinvestment Leads to Wide Racial Disparities in Access to Opportunity



The figure above shows the distribution of Child Opportunity Scores across the 100 largest US metro areas by race/ethnicity. The green bars at the top show wide variation in opportunity scores for white children across metro areas, but the distribution is generally above the national median. In other words, in the vast majority of metro areas, the typical white child enjoys neighborhood opportunity higher than the national median. The distribution for Asian children is similar. In contrast, the typical Hispanic or Black child lives in a neighborhood with an opportunity score that is well below the national median. In fact, **for the 100 largest metro areas combined, the average Child Opportunity Score is 73 for white children and 72 for Asian children, in sharp contrast to 33 for Hispanic children and 24 for Black children.**[25]

Environmental exposures early in life can cause lasting changes in developing biological systems. The brain and other biological systems in the body (e.g., immune, metabolic, and respiratory), as well as the microbiome (i.e., bacteria that develop in the gut and play an important role in health and illness), each have periods when they are most sensitive to environmental influences. During prenatal development, billions of cells are produced that become specialized for different organ systems or functions—each establishing unique properties that allow them to function as part of the brain, lungs, immune system, or as hormone-producing cells, among many other types. In the immune system, for example, these specialized cells are deployed throughout the body and develop molecular "memories" that are essential elements of the body's defense against infection throughout childhood and adolescence.[26]

Ensuring the environments that surround pregnant people are safe, supportive, and free of toxicants is a critical investment in the future health and well-being of all children.

Ensuring the environments that surround pregnant people are safe, supportive, and free of toxicants is a critical investment in the future health and well-being of all children. Exposure to a subset of specific infections or toxic substances, as well as poor nutrition (e.g., scarcity or overabundance of calories), during the prenatal period can have lifelong impacts on developing biological systems and even prime these systems to be more susceptible to similar stressors later in life. For example, undernutrition during critical periods of fetal development may cause lasting changes in metabolic and endocrine regulation that increase the likelihood of obesity and cardiovascular disease later in life. Some toxic substances absorbed during pregnancy can enter the placenta and affect its function, as well as cross into the fetus and disrupt its development directly. Significant adversity or trauma may also speed up the opening and closing of critical periods in the development of specific brain circuits.[27] This can have negative consequences for both physical and mental health by contributing to earlier onset of puberty and the development of anxiety.[28]

The effects of early exposure to air pollution on the developing brain and respiratory system have been studied extensively and are well understood. Significant air pollution comes from the burning of fossil fuels, including emissions from cars, as well as poorly ventilated wood-burning stoves, and forest fires. Airborne pollutants can be absorbed in a variety of ways and cause problems in specific developing organs as well as entire systems.[29] The nature and severity of these effects vary according to when they occur over the course of development. For example, exposure to air pollution prenatally, when the lungs and immune system are especially sensitive to environmental influences,[30] is associated with lower lung volume in early childhood[31] and decreased lung function in the preschool years.[32] Exposure to air pollution in the prenatal period is also associated with increased rates of restricted growth in utero, prematurity, and low birth weight in full-term infants.[33,34,35,36] Children who are exposed to higher rates of outdoor air pollution during the first year after birth may have diminished functional lung capacity as teenagers.[37] Similar exposures throughout early childhood increase the risk of developing pediatric leukemia, elevated blood pressure, and asthma or chronic obstructive pulmonary disease in adolescence or early adulthood.[38,39,40] Because Black children are exposed to air pollution more often than white children, it is not surprising that they are twice as likely to have asthma and four times as likely to die from it.[41]

There is also evidence that some types of air pollutants can activate the body's stress response by stimulating the hypothalamic-pituitary-adrenal (HPA) axis, triggering the release of stress hormones such as cortisol.[42] Many developing biological systems, including the brain, are more sensitive to the effects of excessive amounts of stress hormones than more mature systems, particularly in the prenatal period and early years after birth. When the stress response is chronically elevated, it can produce what is known as a "toxic stress response," creating structural irregularities in the brain and negative effects on cognition and mental health,[43] as well as broader wear and tear effects across multiple organ systems over time.[44] Moreover, the full range of health outcomes that are affected by early environmental influences such as air pollution may not be apparent until much later in life.

Racism influences multiple dimensions of the natural and built environments that affect the foundations of child development and lifelong well-being. In the first decade of the 21st century, the Human Genome Project (an international collaboration that generated the first sequence of the full set of human DNA) demonstrated once and for all that there are no distinct biological boundaries that indicate where one racial category begins and another ends. Racial distinctions, as we know them, are inventions created by societies—and there are no validated genetic criteria for differentiating these categories.[45] Given this scientific consensus, when we study racial and ethnic disparities in health status across groups (as defined by census data or other means of self-identification), these comparisons reflect variation in lived experiences within and across generations, not underlying genetic differences. Stated simply, although *race* is not an objective biological categorization, the experience of *racism* gets into the developing body, with significant biological consequences that can begin in the prenatal period.

Many people think of racism as overt bigotry or personally experienced discrimination in the context of everyday social interactions, including implicit bias, microaggressions, and harassment. The full manifestations of its effects, however, are embedded in a much wider range of conditions, experiences, and exposures that are experienced by families of color with young children.[46] *Cultural racism*, for example, is experienced as a pervasive ideology that is reflected in the language, symbols, media, and assumptions of the larger society that values whiteness as the desirable standard. Stereotype threat, which occurs when an individual's awareness of a negative stereotype results in worry that their behavior could reinforce that stereotype about their culture, and the internalized racism that it produces, are often invisible to those who do not experience them first-hand.[47]

Structural (or systemic) racism, which is reflected in both the natural and built environments, includes multiple manifestations of how political, economic, and social inequities become deeply embedded in where people live—particularly but not exclusively in racially segregated communities—and how systems and institutions operate in ways that provide an advantage to some racial/ethnic groups and perpetuate an unfair disadvantage to others. These biases have been built deeply into an array of public policies and institutional practices that have been either prescribed explicitly by law (e.g., Jim Crow segregation) or perpetuated implicitly by customary practices (e.g., racial disparities in the criminal justice system as illustrated by unequal sentencing patterns). Many adverse effects of systemic racism have deep historical roots whose impacts continue to the present day, and many present-day policies continue to perpetuate these inequities and their ongoing effects. These include the placement of hazardous waste sites close to communities of color (see box below) and the construction of the US interstate highway system beginning in the 1950s, which located urban routes largely through communities of color and neighborhoods that were previously redlined.[48] Current policies that perpetuate inequities through ongoing discrimination in the housing market include requirements for minimum lot sizes and restrictions on the construction of multi-family homes.[49]

The cumulative effects of systemic racism, compounded by cultural racism and the everyday personal indignities and threats of individualized discrimination, contribute to a complex mix of physical, social, and economic conditions and experiences that impose substantial hardships on BIPOC families raising young children.[50] In the natural environment, structural racism leads to segregated communities in which minoritized children are exposed to more excessive heat and toxicants (e.g., air pollution,[51] industrial waste,[52] insecticides in the case of migrant farm workers[53]) and have less access to clean drinking water[54,55] and violence-free green space.[56,57] In the built environment, structural racism affects the type and quality of residential housing and leads to diminished access to nutritious foods, high-quality health services and child care, educational resources, and economic opportunity.

In the built environment, structural racism affects the type and quality of residential housing and leads to diminished access to nutritious foods, high-quality health services and child care, educational resources, and economic opportunity.

The causal mechanisms that explain how the effects of racism can be built into the body and lead to disparities in the development and health of young children continue to be the focus of extensive research. Like other types of early life adversity that trigger excessive activation of the stress response system, the stresses of racism can lead to biological disruptions that increase the risk for negative impacts on learning, behavior, and both physical and mental health. Some scientists have documented how different forms of adversity affect different parts of the brain;[58] many have focused on the common effects of excessive stress activation inside the body, independent of its causes.[59] Although the biological disruptions caused by racism may be due to its effects on the stress response system, disparities in health outcomes associated with systemic racism can also be explained by profoundly disproportionate exposures to environmental toxicants such as air pollution and contaminated drinking water. Further research will shed greater light on the complex interactions among multiple sources of adversity and resilience that affect the well-being of children and the adults who care for them, particularly in the prenatal and early childhood periods, when developing biological systems are most susceptible to environmental influences.

The timing of environmental experiences and exposures can influence both short- and long-term effects.[60] As noted earlier, humans differ in their sensitivity to influences from the environment at various points in the life course. The sensitivity of the brain and other biological systems is typically greater in the prenatal period than in young children; young children are more susceptible to most adverse exposures than adolescents; and adolescents are more vulnerable to many exposures than adults.[61] Immature biological systems in an embryo or fetus develop at an extremely fast pace, and their development is powerfully shaped by interactions with the environment around them. These systems read conditions in the womb as predictors of what they will encounter after birth and adapt accordingly. This makes these developing systems more susceptible to positive and negative environmental influences, as compared to when they have matured and stabilized.[62]

Beginning immediately after birth, the protective function of the placenta and uterus is replaced by responsive caregiving, but the external environment also affects babies and toddlers directly through the air they breathe, the water they drink, and the sound level and temperature of the conditions in which they sleep—all of which can either promote or disrupt the development of their brain circuits, the maturation of their immune system, and the regulation of their metabolism.[63]

Although the first "place" that affects development directly is the intrauterine environment during pregnancy, the nature and extent of these effects may not be fully apparent until years or decades later.[64] Inadequate or excessive nutrition, unmanageable levels of stress, extreme heat, and chemical exposures (e.g., lead) are particularly dangerous during the prenatal period.[65] Over- or under-nutrition is associated with greater risk of obesity, hypertension, and heart disease in adulthood.[66] These and other environmental influences (e.g., specific infections, tobacco smoke, pesticides) during pregnancy are also connected to very low or very high birth weights, which can have implications across the lifespan, including greater risk for cardiovascular disease, type 2 diabetes, and mental health conditions.[67]

One example of how the timing of exposures affects their impact is the effects of lead, an extensively studied toxicant. This heavy metal can be absorbed at any age by the gastrointestinal system through ingestion, in lesser amounts through the respiratory system by inhalation, or in small amounts through skin absorption—and there is no safe level of lead in the blood. A high-profile instance of widespread lead exposure through contaminated water in Flint, Michigan, was identified in 2014, when nearly a quarter of the children in that city showed increased blood lead levels[68] —double the previous rate[69]—in the months following Flint's switch in public water suppliers. Young children, fetuses, and pregnant individuals absorb lead through the gastrointestinal system at substantially higher rates than the general population. As a result, exposure during these sensitive periods can result in a range of negative impacts on health and learning (including increased risk of preterm birth, miscarriage, decreased fetal growth, learning and behavioral difficulties later in childhood, and increased blood pressure in adulthood[70]), while exposure to the same level of lead in an adult is much less likely to have significant effects.[71]

> **Although the first "place" that affects development directly is the intrauterine environment during pregnancy, the nature and extent of these effects may not be fully apparent until years or decades later.**

Lead exposure provides a striking example of the effects of discriminatory housing and economic policies on the built environment, which in turn affects child outcomes. Structural racism, through redlining and neighborhood disinvestment, has resulted in children of color living, on average, in older homes that are more likely to contain lead in pipes, paint, and the surrounding soil. Regulatory policies that require landlords of rental properties to abate lead are inconsistently enforced, and when the safeguards around these policies break down, residents are left with limited options for lead abatement. Moreover, these safeguards fail more often in neighborhoods where families living in poverty have fewer resources to put toward lead abatement in their homes.[72] In Flint, long-term impacts cannot yet be measured, but research to date has documented a 15% increase in babies born at low birth weight to women who were pregnant when the crisis began and a nearly 20% increase in low birth weight among children born to Black mothers in the area.[73]

The consequences of exposure to environmental tobacco smoke (ETS) during pregnancy also illustrate increased sensitivity in the prenatal period. Extensive studies have demonstrated that prenatal exposure to ETS—even when the expectant parent does not smoke—leads to higher risk of low birth weight, birth defects, and stillbirth.[74] While there is abundant evidence that adults also experience negative health effects from tobacco exposure, those effects (e.g., elevated blood pressure and increased risk of lung cancer and heart disease) are different from those observed early in life. As noted above, air pollution during the prenatal period can directly affect the developing lungs and immune system, increase the risk of low birth weight or neurodevelopmental outcomes like autism, and be a trigger for asthma in susceptible children during childhood (see below). Exposure to air pollution in adulthood does not lead to the same outcomes.[75,76]

Individuals respond differently to the physical environment, but there are clear patterns of risk that can inform universal action. Even within the same home, or in the face of similar experiences or exposures in a broader context, individual children react differently to both adversity and support. Some are highly sensitive to changes in their environment while others "go with the flow" in difficult situations. Scientists refer to this concept of individual differences as heterogeneity. As a core principle of 21st century biology, it is explained by extensive evidence that all aspects of development and health over the life course are determined by complex *interactions* among genes, environments, and developmental timing ("GxExT").[77]

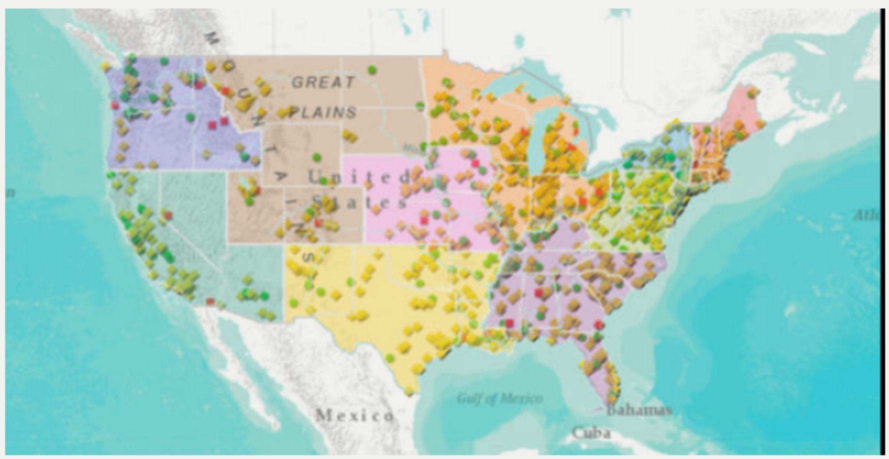
In the case of asthma, each child is born with a unique genetic profile that reflects differential susceptibility to the disease—but whether and how those genetic instructions are carried out is affected by experiences and exposures.[78] A fetus in utero or a developing child after birth may be exposed to a range of environmental triggers for asthma (including air pollution—as noted above—but also dust, chemicals, viruses/bacteria, vermin, and stress).[79] How that fetus or baby is affected by these triggers, however, depends on the magnitude and frequency of the exposures, how specific exposures interact with individual genetic variation, and whether they occur during critical periods of development. All three factors interacting with each other will determine whether a child is likely to develop asthma, how severe the symptoms might be, and whether the condition becomes chronic.[80]

Population-level *rates* of asthma, on the other hand, paint a clear picture of identified risk factors in the broad environment that can be addressed to lower its prevalence across an entire community. For example, multiple studies have shown that higher rates of asthma exist in neighborhoods with more pollution and lower-quality housing.[81,82] Programs such as the Community Asthma Initiative in Boston, which provides expanded access to better health care and addresses sources of environmental triggers that are most prevalent in neighborhoods with high rates of this illness, have been shown to reduce rates of asthma across the community. Such programs do not eliminate asthma entirely, because of the complex interaction of factors described above, but by reducing its environmental causes and improving medical treatment, they have been effective in significantly reducing the human and economic burdens of this costly disease at a population level.[83,84]

Looking at how environmental threats to health play out across a range of contexts and diseases reveals common underlying principles that underscore the way toxic exposures, genetic variation in susceptibility, and developmental timing interact to shape outcomes. In the case of Toms River Township (formerly Dover Township), a predominantly white, middle class, suburban region in New Jersey, public health officials investigated a significant increase in the incidence of childhood cancers and found a link to hazardous chemicals in the local drinking water and soil from a nearby manufacturing site.[85] In another example from the Appalachian region of West Virginia known as Chemical Valley, the release of a chemical known as MCHM polluted the local drinking water, groundwater, and soil, leading to increases in preterm births and low birth weights in full-term newborns, many of whom required complex medical care.[86]

Without minimizing the serious (and fully preventable) consequences of these toxic exposures, not all children who drank the affected water in the Toms River area developed cancer, and not all fetuses exposed to contaminated drinking water in Chemical Valley were born prematurely. Differences in individual genetic makeup, levels of exposure, and developmental timing explain most, if not all, of the reasons for the variable health effects. Regardless of this predictable variation in population-level risk, a broad public health approach combined with a tailored response to address differential needs is most likely to protect the health and development of all children in a community. In the case of lead, this approach can include housing policies that ensure high-quality pipes and clean water for everyone, mitigation efforts in neighborhoods most likely to have high concentrations of lead paint and soil, and frequent surveillance combined with individualized monitoring and treatment as needed for children with detectable blood levels.

Human-Made Toxicants Affect Childhood Development



EPA Map of Superfund National Priorities List. Explore this interactive map and additional details here.

While the impacts of adverse environmental influences fall disproportionately on individuals living in poverty, people of color, and other marginalized groups as a result of historical and current discriminatory policies, all communities are potentially susceptible to the health effects of unfavorable environmental conditions. The Toms River Township of Ocean County, New Jersey, is a suburban, predominantly white, middle-class region. Between 1979 and 1999, 102 children under the age of 19 who lived in that area were diagnosed with cancer, an incidence rate that is one-third greater than expected. Rates of brain cancer, leukemia, and other nervous system cancers were particularly high.[87] The state of New Jersey subsequently conducted a study that linked prenatal exposure to two specific sources of contamination in the township's water and air to an increased risk of leukemia in girls.[88] The identification of these contaminants resulted in the closure of two business sites, payment of fines for criminal penalties by the companies involved, financial settlement with families whose children developed cancer, an expanded treatment system for the water supply, and the development of a new water sampling and analysis method that allows for measurement of radioactivity. Despite these efforts, cleanup of the site and disputes about ways to restore its natural resources remain ongoing.[89, 90] Environmental hazards can disrupt developing biological systems in a variety of ways beginning very early in life, leading to a range of adverse effects on physical and mental health. News headlines from Wilmington, Massachusetts; Camp Lejeune, North Carolina;

Flint, Michigan; and Jackson, Mississippi, have captured ways that residents have been exposed to toxicants as dramatic examples of preventable tragedies, but they are far from the only ones. As of fall 2022, there were more than 1,300 locations in the US officially designated by the Environmental Protection Agency as National Priority Superfund sites (i.e., locations that contain high levels of hazardous material contamination that require long-term cleanup funded by federal legislation), with another 43 awaiting this formal designation.[91] While contaminated sites can be found in every state and in both rural and urban areas, as well as on hundreds of former military installations,[92] they are not evenly distributed. In 2015, a national analysis of hazardous waste sites found that toxic facilities are usually placed in locations where residents lack social, economic, or political power—and these are disproportionately areas where people of color and people living in poverty reside.[93] The Superfund program, instituted by federal legislation in 1980, is one example of a policy response to understanding our shared responsibility for—and benefit from—cleaning up environmental toxicants. Yet, just like exposure to toxicants, our response to these conditions is uneven across groups. For example, in Flint, Michigan, where residents are predominantly Black, it took 79 lawsuits[94] and two years of community activism after several major outbreaks of disease due to contaminated water to initiate a public response that eventually brought lead levels below the toxic range.

Implications for New Directions in Policy

All children, regardless of where they grow up, should be able to live in an environment that supports their healthy development. And, all communities have natural and built dimensions of their environment that have been constructed and designed through decisions made over time. Just as these dimensions of the environment have been designed over time, they can be re-designed to support healthy development.

All children, regardless of where they grow up, should be able to live in an environment that supports their healthy development.

Every environment is infused with a combination of positive and negative influences on health and development, but levels of exposure to hazards and access to opportunity are not distributed equally. Equalizing such environmental opportunities so that all children can grow up in neighborhoods free of toxicants and rich in access to high-quality education and health care will require confronting the causes and consequences of systemic racism, intergenerational poverty, and other structural inequities that lead to preventable disparities in child development and lifelong physical and mental health.

When we respond as a society to a devastating hurricane, wildfire, flood, or blizzard, we target greater support to the communities that have been most severely affected. Similarly, directing greater attention to community conditions where they present the greatest threats to the well-being of young children reflects our shared commitment to a healthy and sustainable society. Securing the opportunity for all children to develop in an environment that helps them to thrive requires attention to universal needs *and* investment in places that face the greatest hardships and obstacles. Deeply embedded inequities where people live disproportionately undermine the life prospects of children of color and children living in poverty, beginning before they are born. There is an urgent need to address these inequities and provide all children with the opportunity to reach their full potential.

The benefits of high-quality health care, child care, and early education are well-documented. Yet these child-focused programs are situated in a broader environment of risk and protection that also requires focused attention in order to achieve the promise of population-wide improvements in educational achievement, health, and well-being. All sectors of the early childhood ecosystem, including policymakers, service providers, advocates, and private philanthropists, must direct increased attention to and investment in the prevention and reduction of adverse environmental conditions and exposures that get built into the developing body early in life. Strategic investments at the population and community levels, beginning in the earliest periods of development, represent a critical yet currently under-addressed dimension of science-informed early childhood policy that demands fresh thinking.

To succeed in this mission, we must broaden the list of policy domains that are viewed as affecting the foundations of early childhood development and lifelong physical and mental health. Prominent examples include environmental protection, climate change policies and mitigations, housing, zoning, urban planning, economic development, criminal legal reforms, and anti-discrimination policies, among others. All of these areas are interdependent. Each policy domain must focus on its capacity to dismantle structural factors that lead to the disproportionate exposure of minoritized children to adverse environmental influences. Re-examining policies and their associated systems through an anti-racist, early childhood lens will advance our ability to connect the dots among:

- strengthening community assets that support healthy development;
- preventing, reducing, and/or mitigating environmental conditions that threaten human well-being, with particular attention to the most affected communities; and
- understanding how both assets and threats are built into the body, beginning prenatally and in the early childhood period, and result in either a strong or weak foundation for all the learning, behavior, and health that are necessary for a thriving and sustainable society.

These challenges will not be addressed by working within the current boundaries of early childhood policy and practice. The future of science-informed investment in young children and their families—and the path to greater impacts at scale—requires a coordinated strategy that builds on the current ecosystem of child- and family-focused supports and moves "upstream" to incorporate a broader range of policy domains that influence the natural and built environments that affect families raising young children. Through such a coordinated strategy, we can create a society that supports the health and development of all children, one where equal access to opportunity assures a sustainable future for us all.

→ **For more specific policy implications, ideas, and examples, visit developingchild.harvard.edu in 2023 and beyond.**

References

1 National Scientific Council on the Developing Child. Connecting the brain to the rest of the body: early childhood development and lifelong health are deeply intertwined: Working paper no. 15. 2020. https://developingchild.harvard.edu/resources/connecting-the-brain-to-the-rest-of-the-body-early-childhood-development-and-lifelong-health-are-deeply-intertwined/

2 U.S. Environmental Protection Agency. Basic Information About the Built Environment. Updated March 10, 2022. Accessed May 12, 2022. https://www.epa.gov/smm/basic-information-about-built-environment

3 Sistrunk C, Tolbert N, Sanchez-Pino MD, et al. Impact of federal, state, and local housing policies on disparities in cardiovascular disease in Black/African American men and women: from policy to pathways to biology. *Front Cardiovasc Med.* 2022;18(9):756734. doi:10.3389/fcvm.2022.756734

4 Santaliz CA, Lee A, Teteh D, Madak EZ, Treviño L. Endocrine-disrupting chemicals and breast cancer: disparities in exposure and importance of research inclusivity. *Endocrinology*. 2022;163(5):bqac034. doi:10.1210/endocr/bqac034

5 Abdi FM, Andrews K. Redlining has left many communities of color exposed to lead. Child Trends. February 13, 2018. https://www.childtrends.org/blog/redlining-left-many-communities-color-exposed-lead

6 Collins MB, Munoz, I, JaJa J. Linking 'toxic outliers' to environmental justice communities. *Environ. Res. Lett*. 2016;11:015004. doi:10.1088/1748-9326/11/1/015004

7 Gochfeld M, Burger J. Disproportionate exposures in environmental justice and other populations: the importance of outliers. *Am J Public Health*. 2011;101 Suppl 1(Suppl 1):S53-S63. doi:10.2105/AJPH.2011.300121

8 Nardone A, Casey JA, Morello-Frosch R, Mujahid M, Balmes JR, Thakur N. Associations between historical residential redlining and current age-adjusted rates of emergency department visits due to asthma across eight cities in California: an ecological study. *Lancet Planet Health*. 2020;4(1):e24-e31. doi:10.1016/S2542-5196(19)30241-4

9 National Scientific Council on the Developing Child. Young children develop in an environment of relationships: working paper no. 1. 2004. https://developingchild.harvard.edu/resources/wp1/

10 Boyce WT, Levitt P, Martinez FD, McEwen BS, Shonkoff JP. Genes, environments, and time: the biology of adversity and resilience. *Pediatrics*. 2021;147(2):e20201651. doi:10.1542/peds.2020-1651

11 National Scientific Council on the Developing Child. 2020.

12 Shonkoff J. Re-envisioning early childhood policy and practice in a world of striking inequality and uncertainty. Center on the Developing Child at Harvard University. January 2022. https://developingchild.harvard.edu/re-envisioning-ecd/

13 Center on the Developing Child at Harvard University. The foundations of lifelong health are built in early childhood. 2010. https://developingchild.harvard.edu/resources/the-foundations-of-lifelong-health-are-built-in-early-childhood/

14 De la Fuente F, Saldías MA, Cubillos C, et al. Green space exposure association with type 2 diabetes mellitus, physical activity, and obesity: a systematic review. *Int J Environ Res Public Health*. 2020;18(1):97. Published 2020 Dec 25. doi:10.3390/ijerph18010097

15 Islam MZ, Johnston J, Sly PD. Green space and early childhood development: a systematic review. *Rev Environ Health*. 2020;35(2):189-200. doi:10.1515/reveh-2019-0046

16 Islam MZ, Johnston J, Sly PD. 2020.

17 Hoffman JS, Shandas V, Pendleton N. The effects of historical housing policies on resident exposure to intra-urban heat: a study of 108 US urban areas. *Climate*. 2020;8(1):12. https://doi.org/10.3390/cli8010012

18 Nesbitt L, Meitner MJ, Girling C, Sheppard SRJ, Lu Y. Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning*. 2019;181:51-79.

19 Roberts JD, Dickinson KL, Hendricks MD, Jennings V. "I can't breathe": examining the legacy of American racism on determinants of health and the ongoing pursuit of environmental justice. *Curr Environ Health Rep*. 2022;9(2):211-227. doi:10.1007/s40572-022-00343-x

20 De la Fuente F, et al. 2020.

21 Hamby S, Elm JHL, Howell KH, Merrick MT. Recognizing the cumulative burden of childhood adversities transforms science and practice for trauma and resilience. *Am Psychol.* 2021;76(2):230-242. doi:10.1037/amp0000763

22 Acevedo-Garcia D, Noelke C, McArdle N, et al. The geography of child opportunity: why neighborhoods matter for equity. First findings from the Child Opportunity Index 2.0. January 21, 2020. Accessed July 20, 2022. https://www.diversitydatakids.org/sites/default/files/file/ddk_the-geography-of-child-opportunity_2020v2_0.pdf

23 Acevedo-Garcia D, McArdle N, Hardy EF, et al. The child opportunity index: improving collaboration between community development and public health. *Health Aff (Millwood)*. 2014;33(11):1948-1957. doi:10.1377/hlthaff.2014.0679

24 Acevedo-Garcia D, et al. 2020.

25 Acevedo-Garcia D, et al. 2020.

26 Dietert RR, Etzel RA, Chen D, et al. Workshop to identify critical windows of exposure for children's health: immune and respiratory systems work group summary. *Environ Health Perspect*. 2000;108 Suppl 3(Suppl 3):483-490. doi:10.1289/ehp.00108s3483

27 Tooley UA, Bassett DS, Mackey AP. Environmental influences on the pace of brain development. *Nat Rev Neurosci*. 2021;22(6):372-384. doi:10.1038/s41583-021-00457-5

28 Callaghan BL, Richardson R. The effect of adverse rearing environments on persistent

memories in young rats: removing the brakes on infant fear memories. *Transl Psychiatry*. 2012;2(7):e138. doi:10.1038/tp.2012.65

29 Brumberg HL, Karr CJ, et al. Ambient air pollution: health hazards to children. *Pediatrics*. 2021;147(6):e2021051484. doi:10.1542/peds.2021-051484.

30 Krusche J, Basse S, Schaub B. Role of early life immune regulation in asthma development. *Semin Immunopathol*. 2020;42(1):29-42. doi:10.1007/s00281-019-00774-z

31 Mudway IS, Dundas I, Wood HE, et al. Impact of London's low emission zone on air quality and children's respiratory health: a sequential annual cross-sectional study. *Lancet Public Health*. 2019;4(1):e28-e40. doi:10.1016/S2468-2667(18)30202-0

32 Morales E, Garcia-Esteban R, de la Cruz OA, et al. Intrauterine and early postnatal exposure to outdoor air pollution and lung function at preschool age. *Thorax*. 2015;70(1):64-73. doi:10.1136/thoraxjnl-2014-205413

33 Brumberg HL, et al. 2021.

34 Stieb DM, Chen L, Eshoul M, Judek S. Ambient air pollution, birth weight and preterm birth: a systematic review and meta-analysis. *Environ Res*. 2012;117:100–111. doi: 10.1016/j.envres.2012.05.007

35 Srám RJ, Binková B, Dejmek J, Bobak M. Ambient air pollution and pregnancy outcomes: a review of the literature. *Environ Health Perspect*. 2005;113(4):375–382. doi: 10.1289/ehp.6362

36 Dadvand P, Parker J, Bell ML, et al. Maternal exposure to particulate air pollution and term birth weight: a multi-country evaluation of effect and heterogeneity. *Environ Health Perspect*. 2013;121(3):267–373. doi: 10.1289/ehp.1205575

37 Schultz ES, Hallberg J, Bellander T, et al. Early-life exposure to traffic-related air pollution and lung function in adolescence. *Am J Respir Crit Care Med*. 2016;193(2):171-177. doi:10.1164/rccm.201505-0928OC

38 Boothe VL, Boehmer TK, Wendel AM, Yip FY. Residential traffic exposure and childhood leukemia: a systematic review and meta-analysis. *Am J Prev Med*. 2014;46(4):413–422. doi:10.1016/j.amepre.2013.11.004

39 Kelishadi R, Poursafa P, Keramatian K. Overweight, air and noise pollution: universal risk factors for pediatric pre-hypertension. *J Res Med Sci*. 2011;16(9):1234–1250.

40 Guarnieri M, Balmes JR. Outdoor air pollution and asthma. *Lancet*. 2014;383(9928):1581–1592. doi:10.1016/S0140-6736(14)60617-6

41 Holsey CN, Collins P, Zahran H. Disparities in asthma care, management, and education among children with asthma. *Clin Pulm Med*. 2013;20(4):172-177. doi:10.1097/CPM.0b013e3182991146

42 Thomson EM. Air pollution, stress, and allostatic load: linking systemic and central nervous system impacts. *J Alzheimers Dis*. 2019;69(3):597-614. doi:10.3233/JAD-190015

43 National Scientific Council on the Developing Child. Excessive stress disrupts the architecture of the developing brain: working paper no. 3. Updated 2014. https://developingchild.harvard.edu/resources/wp3/

44 McEwen BS. Stress: Homeostasis, rheostasis, reactive scope, allostasis and allostatic load. 2017. doi:10.1016/B978-0-12-809324-5.02867-4

45 Yudell M, Roberts D, DeSalle R, Tishkoff S. SCIENCE AND SOCIETY. Taking race out of human genetics. *Science*. 2016;351(6273):564-565. doi:10.1126/science.aac4951

46 Williams DR, Mohammed SA. Discrimination and racial disparities in health: evidence and needed research. *J Behav Med*. 2009;32(1):20-47. doi:10.1007/s10865-008-9185-0

47 Shonkoff JP, Slopen N, Williams DR. Early childhood adversity, toxic stress, and the impacts of racism on the foundations of health. *Annu Rev Public Health*. 2021;42:115-134. doi:10.1146/annurev-publhealth-090419-101940

48 Archer, D. White men's roads through black men's homes: advancing racial equity through highway reconstruction. *Vanderbilt Law Review* 73;5:1259-1330.

49 Racial Residential Segregation in Greater Boston. Harvard Chan-NIEHS Center for Environmental Health. Updated July 18, 2022. Accessed January 25, 2023. https://storymaps.arcgis.com/stories/bd15a5eb9eae49cda09bfa7368272f89

50 Center on the Developing Child at Harvard University. Moving upstream: confronting racism to open up children's potential. 2021. https://developingchild.harvard.edu/resources/moving-upstream-confronting-racism-to-open-up-childrens-potential/

51 Chakraborty J, Zandbergen PA. Children at risk: measuring racial/ethnic disparities in potential exposure to air pollution at school and home. *J Epidemiol Community Health*. 2007;61(12):1074-1079. doi:10.1136/jech.2006.054130

52 Mohai P & Saha R. Which came first, people or pollution? Assessing the disparate siting and post-siting demographic change hypotheses of environmental injustice. *Environ. Res. Lett*. 2015;10:115008. doi:10.1088/1748-9326/10/11/11500

53 Mills PK, Dodge J, Yang R. Cancer in migrant and seasonal hired farm workers. *J Agromedicine*. 2009;14(2):185-191. doi:10.1080/10599240902824034

54 Roberts JD, Dickinson KL, Hendricks MD, Jennings V. "I can't breathe": examining the legacy of American racism on determinants of health and the ongoing pursuit of environmental justice. *Curr Environ Health Rep*. 2022 Jun;9(2):211-227. doi:10.1007/s40572-022-00343-x

55 Masten SJ, Davies SH, McElmurry SP. Flint water crisis: what happened and why? *J Am Water Works Assoc*. 2016;108(12):22–34. doi:10.5942/jawwa.2016.108.0195

56 Locke DH, Hall B, Grove JM, et al. Residential housing segregation and urban tree canopy in 37 US cities. *npj Urban Sustain*. 2021;1(15):1–9. doi:10.1038/s42949-021-00022-0

57 Rowland-Shea J, Doshi S, Edberg S, Fanger R. The nature gap: confronting racial and economic disparities in the destruction and

protection of nature in America. Center for American Progress. 2020.

58 McLaughlin KA, Sheridan MA. Beyond cumulative risk: a dimensional approach to childhood adversity. *Curr Dir Psychol Sci*. 2016;25(4):239-245. doi:10.1177/0963721416655883

59 Smith KE, Pollak SD. Rethinking concepts and categories for understanding the neurodevelopmental effects of childhood adversity. *Perspect Psychol Sci*. 2021;16(1):67-93. doi:10.1177/1745691620920725

60 Boyce WT, et al. 2021.

61 Boyce WT, et al. 2021.

62 Fleming TP, Watkins AJ, Velazquez MA, et al. Origins of lifetime health around the time of conception: causes and consequences. *Lancet*. 2018;391(10132):1842-1852. doi:10.1016/S0140-6736(18)30312-X

63 Boyce WT, et al. 2021.

64 Dunkerton S & Aiken C. Impact of the intrauterine environment on future reproductive and metabolic health. *The Obstetrician & Gynaecologist*. 2022;24(2):93-100. doi:10.1111/tog.12797

65 Center on the Developing Child at Harvard University. 2010.

66 Portella AK, Silveira PP. Neurobehavioral determinants of nutritional security in fetal growth-restricted individuals. *Ann N Y Acad Sci*. 2014;1331:15-33. doi:10.1111/nyas.12390

67 Fernandez-Twinn DS, Hjort L, Novakovic B, Ozanne SE, Saffery R. Intrauterine programming of obesity and type 2 diabetes. *Diabetologia*. 2019;62(10):1789-1801. doi:10.1007/s00125-019-4951-9

68 Ezell JM, Bhardwaj S, Chase EC. Child lead screening behaviors and health outcomes following the Flint water crisis [published correction appears in *J Racial Ethn Health Disparities*. 2022 Mar 10.]. *J Racial Ethn Health Disparities*. 2023;10(1):418-426. doi:10.1007/s40615-022-01233-6

69 DeWitt RD. Pediatric lead exposure and the water crisis in Flint, Michigan. *JAAPA*. 2017;30(2):43-46. doi:10.1097/01.JAA.0000511794.60054.eb

70 United States. Agency for Toxic Substances and Disease Registry. Toxicological profile for lead. August 2020. doi:10.15620/cdc:95222

71 Yeter D, Banks EC, Aschner M. Disparity in risk factor severity for early childhood blood lead among predominantly African-American Black children: The 1999 to 2010 US NHANES. *Int J Environ Res Public Health*. 2020;17(5):1552. Published 2020 Feb 28. doi:10.3390/ijerph17051552

72 Muller C, Sampson RJ, & Winter AS. Environmental inequality: The social causes and consequences of lead exposure. *Annual Review of Sociology*. 2018;44(1), 263-282. doi:10.1146/annurev-soc-073117-041222

73 Wang R, Chen X, Li X. Something in the pipe: the Flint water crisis and health at birth. *J Popul Econ*. 2022;35:1723-1749. doi:10.1007/s00148-021-00876-9

74 Salmasi G, Grady R, Jones J, McDonald SD; Knowledge Synthesis Group. Environmental tobacco smoke exposure and perinatal outcomes: a systematic review and meta-analyses. *Acta Obstet Gynecol Scand*. 2010;89(4):423-441. doi:10.3109/00016340903505748

75 Volk HE, Lurmann F, Penfold B, Hertz-Picciotto I, McConnell R. Traffic-related air pollution, particulate matter, and autism. *JAMA Psychiatry*. 2013;70(1):71-77. doi:10.1001/jamapsychiatry.2013.266

76 von Ehrenstein OS, Aralis H, Cockburn M, Ritz B. In utero exposure to toxic air pollutants and risk of childhood autism. *Epidemiology*. 2014;25(6):851-858. doi:10.1097/EDE.0000000000000150

77 Boyce WT, et al. 2021.

78 National Scientific Council on the Developing Child. Early experiences can alter gene expression and affect long-term development: working paper no. 10. 2010. https://developingchild.harvard.edu/resources/early-experiences-can-alter-gene-expression-and-affect-long-term-development/

79 National Scientific Council on the Developing Child. 2020.

80 Martinez FD. Asthma as a developmental disorder. *Annu Rev Dev Psychol*. 2021;3:229-48. doi:10.1146/annurev-devpsych-030221-020950

81 Lemire E, Samuels EA, Wang W, Haber A. Unequal housing conditions and code enforcement contribute to asthma disparities in Boston, Massachusetts. *Health Affairs*. 2022;41(4): 563-572. doi:10.1377/hlthaff.2021.01403

82 Alexander D & Currie J. Is it who you are or where you live? Residential segregation and racial gaps in childhood asthma. NBER Working Paper 23622. National Bureau of Economic Research. July 2017. https://www.nber.org/papers/w23622

83 Woods ER, Bhaumik U, Sommer SJ, et al. Community asthma initiative: evaluation of a quality improvement program for comprehensive asthma care. *Pediatrics*. 2012;129(3):465-472. doi:10.1542/peds.2010-3472

84 Bhaumik U, Walker SP, Sommer SJ, et al. Social return on investment from an asthma community-based care management intervention program. American Public Health Association Annual Meeting. Denver, CO. November 8, 2010.

85 State of New Jersey Department of Public Health. Toms River Township childhood cancer investigation. Accessed October 4, 2022. https://www.state.nj.us/health/ceohs/environmental-occupational/hazardous-waste-sites/ocean/dovertwp.shtml

86 Parsons E & Diamond E. Dirty the waters: mothers' experience of a chemical disaster in West Virginia, USA. WIT *Transactions on the Built Environment*. 2019;190:79-90. doi:10.2495/DMAN190071

87 Mansnerus L. Community; Dover Township's cancer cluster. *The New York Times*. February 7, 1999. Accessed May 18, 2022. https://www.nytimes.com/1999/02/07/nyregion/community-dover-township-s-cancer-cluster.html

88 Toms River Township Childhood Cancer Investigation. State of New Jersey Department of Health. Accessed May 18, 2022. https://www.state.nj.us/health/ceohs/environmental-occupational/hazardous-waste-sites/ocean/dovertwp.shtml

89 Childhood cancer incidence update: a review and analysis of cancer registry data, 2001-2005. U.S. Department of Health and Human Services Public Health Service, Agency for Toxic Substances and Disease Registry, Division of Health Assessment and Consultation. 2008.

90 NJ Families Blast Deal Over Polluted Toms River Site After Child Cancer Epidemic. NBC10 Philadelphia.

Accessed February 1, 2023. https://www.nbcphiladelphia.com/news/local/toms-river-families-blast-deal-over-polluted-site/3483258/

91 Superfund: National Priorities List (NPL). United States Environmental Protection Agency. Accessed October 5, 2022. https://www.epa.gov/superfund/superfund-national-priorities-list-npl

92 Reuben SH. *Reducing Environmental Cancer Risk: What We Can Do Now*. National Cancer Institute, National Institutes of Health, U.S. Department of Health And Human Services. DIANE Publishing; 2010.

93 Mohai P & Saha R. 2015.

94 AG looks to settle Flint suits; Worthy joins criminal probe. *Associated Press*. February 21, 2019. Accessed October 5, 2022. https://apnews.com/article/8e645ecb0acf42bebeebb3595007c934

WORKING PAPER SERIES

Working Paper 1 *Young Children Develop in an Environment of Relationships (2004)*

Working Paper 2 *Children's Emotional Development is Built into the Architecture of their Brain (2004)*

Working Paper 3 *Excessive Stress Disrupts the Architecture of the Developing Brain (2005, updated 2014)*

Working Paper 4 *Early Exposure to Toxic Substances Damages Brain Architecture (2006)*

Working Paper 5 *The Timing and Quality of Early Experiences Combine to Shape Brain Architecture (2007)*

Working Paper 6 *Establishing a Level Foundation for Life: Mental Health Begins in Early Childhood (2008, updated 2012)*

Working Paper 7 *Workforce Development, Welfare Reform, and Child Well-Being (2008)*

Working Paper 8 *Maternal Depression Can Undermine the Development of Young Children (2009)*

Working Paper 9 *Persistent Fear and Anxiety Can Affect Young Children's Learning and Development (2010)*

Working Paper 10 *Early Experiences Can Alter Gene Expression and Affect Long-Term Development (2010)*

Working Paper 11 *Building the Brain's "Air Traffic Control" System: How Early Experiences Shape the Development of Executive Function (2011)*

Working Paper 12 *The Science of Neglect: The Persistent Absence of Responsive Care Disrupts the Developing Brain (2012)*

Working Paper 13 *Supportive Relationships and Active Skill-Building Strengthen the Foundations of Resilience (2015)*

Working Paper 14 *Understanding Motivation: Building the Brain Architecture That Supports Learning, Health, and Community Participation (2018)*

Working Paper 15 *Connecting the Brain to the Rest of the Body: Early Childhood Development and Lifelong Health are Deeply Intertwined (YYYY)*

REPORTS

The Science of Early Childhood Development: Closing the Gap Between What We Know and What We Do (2007)

A Science-Based Framework for Early Childhood Policy: Using Evidence to Improve Outcomes in Learning, Behavior, and Health for Vulnerable Children (2007)

Early Childhood Program Evaluations: A Decision-Maker's Guide (2007)

The Foundations of Lifelong Health Are Built in Early Childhood (2010)

Building Core Capabilities for Life: The Science Behind the Skills Adults Need to Succeed in Parenting and in the Workplace (2016)

From Best Practices to Breakthrough Impacts: A Science-Based Approach to Building a More Promising Future for Young Children and Families (2016)

Applying the Science of Child Development in Child Welfare Systems (2016)

Three Principles to Improve Outcomes for Children and Families (2017)

Center on the Developing Child HARVARD UNIVERSITY NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD

50 Church Street, 4th Floor, Cambridge, MA 02138
617.496.0578
www.developingchild.harvard.edu