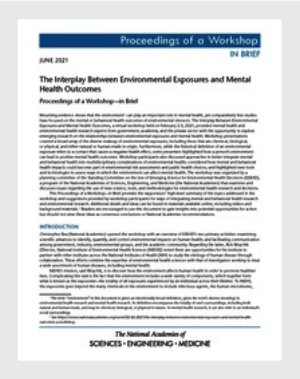

The Interplay Between Environmental Exposures and Mental Health Outcomes: Proceedings of a Workshop—in Brief (2021)

DETAILS

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Proceedings of a Workshop

IN BRIEF

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The Interplay Between Environmental Exposures and Mental Health Outcomes

Proceedings of a Workshop—in Brief

Mounting evidence shows that the environment[1] can play an important role in mental health, yet comparatively few studies have focused on the mental or behavioral health outcomes of environmental stressors. The Interplay Between Environmental Exposures and Mental Health Outcomes, a virtual workshop held on February 2-3, 2021, provided mental health and environmental health research experts from government, academia, and the private sector with the opportunity to explore emerging research on the relationships between environmental exposures and mental health. Workshop presentations covered a broad array of the diverse makeup of environmental exposures, including those that are chemical, biological, or physical, and either natural or human-made in origin. Furthermore, while the historical definition of an environmental exposure refers to a contact that causes a negative health effect, some presenters highlighted how a person's environment can lead to positive mental health outcomes. Workshop participants also discussed approaches to better integrate mental and behavioral health into multidisciplinary considerations of environmental health; considered how mental and behavioral health impacts could become part of environmental risk assessments and public health choices; and highlighted new tools and technologies to assess ways in which the environment can affect mental health. The workshop was organized by a planning committee of the Standing Committee on the Use of Emerging Science for Environmental Health Decisions (ESEHD), a program of the National Academies of Sciences, Engineering, and Medicine (the National Academies) that examines and discusses issues regarding the use of new science, tools, and methodologies for environmental health research and decisions.

This Proceedings of a Workshop—in Brief provides the rapporteurs' high-level summary of the topics addressed in the workshop and suggestions provided by workshop participants for ways of integrating mental and behavioral health research and environmental research. Additional details and ideas can be found in materials available online, including videos and background materials.[2] Readers are encouraged to use this document to gain insights into potential opportunities for action but should not view these ideas as consensus conclusions or National Academies recommendations.

INTRODUCTION

Christopher Rea (National Academies) opened the workshop with an overview of ESEHD's two primary activities: examining scientific advances to identify, quantify, and control environmental impacts on human health; and facilitating communication among government, industry, environmental groups, and the academic community. Regarding the latter, Rick Woychik (Director, National Institute of Environmental Health Sciences [NIEHS]) noted there are opportunities for his institute to partner with other institutes across the National Institutes of Health (NIH) to study the etiology of human disease through collaboration. These efforts combine the expertise of environmental health sciences with that of investigators working to treat a wide assortment of human diseases, including mental health.

[1] The term "environment" in this document is given an intentionally broad definition, given the term's diverse meanings in environmental health research and mental health research. Its definition encompasses the totality of one's surroundings, including both natural and human-made, and may be chemical, biological, or physical in nature. In mental health research, it can also refer to an individual's social surroundings.

[2] See https://www.nationalacademies.org/event/02-02-2021/the-interplay-between-environmental-exposures-and-mental-health-outcomes-a-workshop.

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NIEHS's mission, said Woychik, is to discover how the environment affects human health in order to promote healthier lives. Complicating this task is the fact that the environment includes a wide variety of components, which together form what is known as the exposome—the totality of all exposures experienced by an individual across their lifetime. To NIEHS, the exposome goes beyond the many chemicals in the environment to include infectious agents, the human microbiome, prescription drugs, food, and lifestyle factors such as nutrition, smoking, and stress, which individually and in total may affect human physical or mental health depending on an individual's genetic and biological makeup. Woychik noted the increasing awareness that studies on environmental impact need to go beyond examining one exposure at a time and take a more holistic approach, given that everyone is exposed to a complex array of environmental agents. Reflecting this idea, the environmental health sciences community now embraces the concept of an exposome framework, the idea that it is important to study the totality of environmental exposures over the life course.

Woychik also explained that in taking this broader, more holistic view of the exposures one experiences across the life course, NIEHS's interests include understanding the genetic, epigenetic, and overall biological basis for why individuals have differential responses to various environmental exposures. By studying those differential responses, NIEHS hopes to gain new insights into the molecular basis of toxicity.

The concept that environmental exposures can affect mental health outcomes comes as no surprise to those who study human behavior. In fact, said Joshua Gordon (Director, National Institute of Mental Health [NIMH]), understanding the impact of the environment on mental health has long been part of psychiatry and psychology efforts to develop interventions for mental health conditions. He noted that environmental exposures can serve as risk factors for adverse mental health outcomes, while others can serve as protective elements that build resilience to adverse outcomes. NIMH's research efforts aim to uncover the various inputs that alter mental health and to explore the mechanistic relationship between those environmental exposures and mental health, both in terms of risk and resilience. Developing that mechanistic relationship, said Gordon, requires collaborative studies across many institutes at NIH.

> "Working together has the potential to improve our ability to study, treat, and most importantly, prevent the onset of human disease and to promote high-quality human health." —Rick Woychik

BACKGROUND

A Mental Health Paradigm in Environmental Health Research and Decision Making

Erika Manczak (University of Denver) proposed the question of whether environmental policies would change if the regulatory paradigm considered the effects of exposures on mental as well as physical health. After all, challenges to mental health can affect every domain of life given that psychopathology can lower academic and professional achievement, lead to greater interpersonal dysfunction and economic challenges, and adversely affect physical health. Consistent with Woychik's broad definition of the environment, Manczak noted that the holistic environment, beyond exposures to chemicals, pollutants, and other discrete factors, can have adverse effects on mental health. As examples, she cited how the COVID-19 pandemic, recent natural disasters, the potential for calamitous threats from climate change, and the degradation of beneficial natural spaces can all affect mental health, particularly among U.S. populations and communities that have been historically marginalized.

> "Acknowledging the ways in which our physical environments and exposures can contribute to mental health has the potential to actually reduce stigma around mental illness. By highlighting the ways in which external forces can act on mental health, I believe we have the opportunity to change these problematic narratives in ways that can reduce shame and burden." —Erika Manczak

In Manczak's opinion, highlighting the interplay of mental health and the environment can increase awareness of the scope, interconnection, and impact of these processes; catalyze cutting-edge science to understand mechanisms, outcomes, and interventions; and inform decision making at scientific, policy, and individual levels. The greatest tool for doing so, she added, will be to create and bridge multidisciplinary perspectives. She also suggested that looking at the effects of the environment on mental health as a whole, rather than on individual mental health issues, would help to detect environmental impacts on mental health and understand the scope and interconnection between the environment and mental health.

An Intersectional Perspective on the Breadth of Environmental Considerations in Mental Health Research and Public Health Practice

Sandro Galea (Boston University) reminded workshop participants that mental health disorders are fundamentally brain disorders and the brain is an organ whose normal and abnormal functions are influenced by the environment. However, most studies of the biological basis of mental health disorders, including the largest genome-wide analysis of major depressive disorder, fail to produce replicable findings because they neglect to factor in the environment's influence on the brain.

Galea discussed the evidence supporting the link between environmental factors and mental health in terms of environmental pathogens, environmental destruction, and environmental form. "Environmental form" is a term he used to describe the built, social, cultural, and political environment in which one lives. One strong piece of evidence regarding

environmental pathogens comes from studies showing an association of childhood blood lead levels at age 11 with psychopathology in adults at age 38. Other studies have found significant associations between mental health issues and daily exposure to air pollutants, particularly particulate matter, and links between suicide and exposure to specific pesticides.

Environmental disasters—earthquakes, hurricanes, floods, and others—influence mental health through the experience of traumatic events that cause emotional, psychological, or physical distress or harm. The COVID-19 pandemic fits this definition of a traumatic event, and is relentlessly affecting mental health. Galea pointed to studies showing that environmental disruptions can have consequences for mental health that far outlast the disruption itself.

Regarding environmental form, research has found a robust association between the amount of green space available and mental health, including psychological distress, depression, and anxiety. Environmental form also includes segregation and other effects of redlining, the discriminatory practice of systematically denying goods and services, including home mortgage loans, to residents of a certain geographic area based on race or ethnicity. Research shows these effects correlate with poor mental health. Equity, a component of environmental form, is key when considering the links between the environment and mental health, with populations of lower socioeconomic status experiencing poorer mental health than those of higher status. For example, stressors exacerbated by the COVID-19 pandemic, such as housing or income instability, further increase the prevalence of depression and would be expected to prolong the course of poor mental health. Personal relationships; social support systems; interactions with neighborhoods, schools, and communities; social policies; and other aspects of an individual's environment also affect mental health.

With this many environmental factors influencing mental health, the challenge is to make every study as simple as possible, but no simpler, said Galea. By that he meant that studies should include enough factors to make meaningful conclusions, but not so many factors that they overcomplicate the study and obscure key conclusions. While doing so poses methodological issues, it also makes the intersection of environmental health and mental health more intellectually interesting and the science involved more consequential.

> "I do not think that we can have a discussion in 2021 around environmental considerations in mental health without thinking about equity."
> —Sandro Galea

EMERGING TRENDS AT THE INTERSECTION OF POLLUTION EXPOSURES AND MENTAL HEALTH

Interplay of Air Pollution Exposure and Mental Health

Growing up in an urban environment, said Joanne Newbury (University of Bristol), doubles the risk for experiencing psychosis compared to living in a rural setting and increases the chances of developing Alzheimer's disease and other dementias, depression, and anxiety. While researchers have suggested various possibilities for this association, including prenatal infection, poverty, and low social cohesion, the role of air pollution has been largely ignored until recently. A growing number of studies report correlations between air pollution and psychotic and mood disorders, but these studies have lacked information on correlated factors that might also be detrimental to mental health, such as population density and deprivation. In addition, air pollution data are most often collected at the city or county level, which only provides a rough estimate of an individual's exposure.

Newbury described her research comparing the mental health of twins while tracking outdoor levels of four common air pollutants: nitrogen oxide, nitrogen dioxide, and fine and coarse particulate matter. Psychotic experiences were more common among teens with the highest exposures to the four pollutants. These associations were significant and robust, with exposure to nitrogen oxide and nitrogen dioxide explaining 60 percent of the association. Research in London found that higher exposure to nitrogen oxide and nitrogen dioxide (which correlates with heavy urban traffic) was associated with increased utilization of inpatient and community mental health services.

In another study, Newbury found that genetics might play a role in the link between environmental exposures and mental health; those with higher genetic risk of developing a psychiatric disorder also experienced higher exposure to air pollution, poverty, residential mobility, and related conditions during their upbringing. However, this genetic correlation to environmental exposures, said Newbury, was much weaker than the direct correlation between environmental exposures and psychiatric disorders.

Taken together, this research suggests that reducing air pollution could improve mental health trajectories and also reduce the high health care costs associated with long-term chronic mental illness.

Interplay of Pesticide Exposure and Mental Health

Virginia Rauh (Columbia University) discussed neurotoxicity mechanisms that link environmental exposures to outcomes over time. She noted that over 5,000 new synthetic chemicals are introduced to the environment annually, at least 25 percent of which may be neurotoxic, and that the developing brain is highly vulnerable to being affected by neurotoxic substances. Organophosphate pesticides such as chlorpyrifos are neurotoxic, both systemically and developmentally. Developmental neurotoxicity occurs at lower doses than systemic toxicity, which Rauh said suggests that systemic toxicity may not be the correct biomarker for establishing safety standards for these chemicals.

Rauh discussed a prospective cohort study in which she and her colleagues follow urban Black and Dominican mothers who enrolled during pregnancy between 1998 and 2006 and have been assessed, along with their offspring, ever since. The researchers measured chlorpyrifos levels in maternal and cord blood at birth and have tracked neurological, psychological, and brain structure and function outcomes. Results from the children's first 7 years showed that cord blood levels of chlorpyrifos were inversely associated with birth weight, motor and mental development as measured by the Bayley developmental score,[3] working memory deficits, and IQ. Cord blood levels were positively associated with increased behavior and developmental problems. Rauh noted that other studies have produced similar results in different populations and different biomarkers of exposure.

Finer-grained analysis found that those children with the highest cord blood levels of chlorpyrifos had deficits in auditory attention and finger dexterity. Results of brain imaging studies found that overall brain size was not affected, but there were volumetric differences and deformations in specific brain regions. These brain structure alterations were most notable in brain regions generally associated with attention, language, executive function, reward, and emotion. Imaging studies also found alterations in brain regions associated with fine motor control, consistent with the observation that children in the highest exposure group had higher rates of clinically meaningful tremors. Rauh noted that occupational exposure to chlorpyrifos in adults has been linked to Parkinsonism.

Interplay of Metal Exposure and Mental Health

Aaron Reuben (Duke University) discussed the impacts of lead on children to illustrate how metal exposure can impact mental health. Average blood levels in the United States and other industrialized nations dropped precipitously following the phase-out of leaded gasoline that began in 1973, while current exposures in low-income countries remain three to six times higher than the current level of concern.

Lead is a proven neurotoxin that impairs brain development by mimicking calcium, causing a disruption to neuronal signaling, proliferation, and differentiation. Consequently, children exposed to lead develop lower cognitive ability, fine motor skills, and emotional and behavioral regulation capacity, though the long-term consequences for mental health across the lifespan are still poorly characterized. A longitudinal study conducted in Dunedin, New Zealand, assessed children born in 1972 repeatedly for mental health and personality disorders. High blood lead levels occurred across social strata, enabling researchers to evaluate long-term impacts of lead exposure without having to disentangle correlated socioeconomic disadvantages.

A major finding from this study was that children with high blood lead levels experienced more psychiatric problems throughout adulthood, with higher blood levels correlating with higher levels of general psychopathology. Reuben stressed that the association is modest, which means that lead is a contributor to, but not likely a primary cause of, mental illness. The components of psychopathology in adults most strongly associated with lead exposure were internalizing disorders and thought disorders, including depression and anxiety, while children's lead exposure manifested more strongly in terms of externalizing problems, particularly hyperactivity and conduct disorder. A 30-year follow-up of this initial study found that children with high blood lead levels experienced more psychiatric problems across adulthood, with internalizing and thought disorder symptoms driving the association between childhood lead levels and mental health challenges. Though the effect size was modest, Reuben noted that psychopathology associations with lead exposure are of a similar magnitude to, although smaller than, well-known risk factors such as childhood maltreatment and having a family history of mental illness. The strongest effect was on conscientiousness, an important finding given that conscientiousness has been associated robustly with important life outcomes, including educational and occupational attainment, as well as health, wealth, and happiness.

Panel speakers commented on the importance of funding and conducting long-term longitudinal studies such as the one described by Reuben. Workshop participants noted the need to pay special attention to creating cohorts, and to address questions about how race, ethnicity, language, and gender play out in the studied exposures. Rauh and others also pointed to the importance of studying exposures in adolescents, given that adolescence is a critical developmental period, particularly regarding brain plasticity. Bruce Lanphear (Simon Fraser University) added that this is a good time to begin longitudinal studies given the new approaches that researchers have developed to characterize environmental exposures more accurately and to examine particular outcomes.

Patrick Ryan (Cincinnati Children's Hospital Medical Center), who moderated this panel session, pointed out that none of the environmental exposures occur in isolation, but rather with other environmental exposures that make up an individual's exposome. Lanphear stressed that too much research focuses on one environmental risk at a time, rather than the exposome, and thus tends to overemphasize specific risk factors. This comes at the expense of understanding the risk from other factors in the exposome and the synergies that can exist between two or more risk factors. Reuben said the same was true of outcomes, where they are studied individually rather than in total. At the same time, said Ryan, studies of one or two exposures are more practical to conduct and can yield results that lead to regulatory action or other interventions.

Jennifer Manly (Columbia University Irving Medical Center) noted that her work on understanding the mechanisms behind the racial disparities in cognitive aging and dementia and the work that others are doing to understand environmental

[3] Additional information on the Bayley scales of infant development is available at https://www.sciencedirect.com/topics/medicine-and-dentistry/bayley-scales-of-infant-development.

exposures and how they relate to health throughout the life course are converging in an interesting way. She recommended that researchers in these areas would benefit from collaborating with one another, and along with Rauh and Lanphear, she also recommended funding life course research similar to the long-term study Reuben discussed. Rauh remarked that studying early childhood exposure and exposure during adolescence would be particularly important given the developing brain's sensitivity to chemical exposure during early childhood and its plasticity during adolescence. Ryan pointed out that late childhood is also when anxiety disorders and depression first start to emerge and when personal behaviors begin to change, making that an interesting time to look at exposures.

EMERGING TRENDS AT THE INTERSECTION OF ENVIRONMENTAL DISRUPTIONS AND MENTAL HEALTH

The Interplay of Disasters and Mental Health

Joshua Morganstein (Uniformed Services University of the Health Sciences) discussed that when thinking about how the environment affects human health, it is important to consider environmental disruptions such as natural disasters, climate change, and human-generated disasters, including the levee failure following Hurricane Katrina, the terrorist attacks on September 11, 2001, and the many mass shootings over the past decade. In fact, much of what is known about the well-studied effects of trauma on mental health, whether in the form of posttraumatic stress disorder (PTSD) or other psychological disorders, comes from research on disasters, which are becoming more frequent and more severe worldwide and creating a greater burden on the mental health of affected communities. Historically, in nearly all disasters, more people, over a greater geography, and across a much longer period of time, experience psychological and behavioral effects more than all other medical issues combined.

The mental health burdens triggered by disasters often start with distress reactions that lead to behaviors such as insomnia, substance use, family conflict, and feeling a decreased sense of safety that can negatively affect mental health. While most people who experience these difficulties during or after a disaster will recover—some will even come out better at managing future stressors—others will develop more severe mental and behavioral outcomes.

The COVID-19 pandemic, Morganstein noted, is a disaster that has generated protracted uncertainty, fear of shortages, isolation and quarantine, and confusion over evolving information on recommended health behaviors. All of these alter how people perceive and assess risk, which influences how they behave. In general, and particularly during ongoing public health emergencies such as the COVID-19 pandemic, it is the ability to alter perceptions of risk that influences the public's willingness to engage in health behaviors required to respond effectively and recover from a disaster.

Grief is an important but often overlooked example of how disasters affect communities, with bereavement over the loss of a loved one being particularly impactful. In fact, estimates indicate that approximately nine people are affected by every COVID-19 death, suggesting that the impact of this pandemic on bereavement is likely to be profound, said Morganstein. He also noted that disasters are not simply local events but are felt broadly through society. For example, Hurricane Katrina claimed nearly 2,000 lives, but it also displaced 1.5 million people, many of whom relocated and brought their burden of community distress with them.

Communities pass through phases that unfold over time following disasters, though protracted public health emergencies such as the COVID-19 pandemic disrupt these phases. Whereas most communities will feel stronger connections over a shared adversity such as a hurricane or a tornado, COVID-19 has led to conflict within communities, leaving some people feeling more isolated. The prolonged uncertainty of this event has also made it difficult to plan, and the ability to plan in the present is important to help people feel a sense of hope for the future.

In the aftermath of a disaster, the risk of experiencing poor mental health outcomes results from the interaction of pre-event factors, event characteristics, and recovery variables that create a cumulative exposure. Though each disaster is unique, they often share aspects of risk, particularly feelings of social isolation and reduced access to health care. Disaster-associated risk is not distributed equitably across society, said Morganstein, which has been consistently demonstrated during the COVID-19 pandemic, the Flint water crisis, and Hurricane Katrina. In fact, research into the adverse mental health effects of disasters has revealed that certain communities have been identified consistently as being at increased risk to many different disaster types.

Community-level interventions that reduce stress and improve functioning following a disaster comprise five essential elements: (1) enhancing a sense of safety, (2) calming the local population, (3) developing self- and community efficacy, (4) promoting social connectedness, and (5) fostering hope and optimism. Together, these elements constitute psychological first aid, an evidence-based framework for supporting resilience in individuals, communities, and organizations. Morganstein explained that interventions to enhance these elements are most effective when they consider the unique cultural and contextual factors within a community. He also noted that an important finding from a study of Florida Department of Health workers following the devastating 2004 hurricane season was that respondents who reported living in communities that displayed these elements had lower overall rates of PTSD. Morganstein said efforts are ongoing to develop structured programs to teach psychological first aid in the same way the public learns cardiopulmonary resuscitation. He noted that the likelihood that an individual will encounter someone in acute cardiopulmonary arrest is infinitely small, while a majority of people will encounter someone experiencing some measure of trauma.

Morganstein noted that one challenge in providing aid for communities during disasters is helping people use media wisely. While media is an important source of health information and can help shape public perceptions, it also transmits fear and distress. Research shows that increasing exposure to disaster-related media is associated with an increased risk of adverse effects, including lower rates of perceived safety and elevated rates of insomnia, depression, alcohol use, PTSD, and general psychological distress. Grief leadership—a range of leadership behaviors around grief and loss—can ameliorate those risks and improve functioning and recovery within affected communities. Effective grief leaders promote healing and recovery within their communities by communicating openly to acknowledge and address issues of grief, facilitate processes that honor losses, and help people look toward a hopeful future.

Environmental Disruption with Mental Health Impacts and Disparities: Lessons from the Flint Water Crisis

C. Debra Furr-Holden (Michigan State University) discussed the Flint water crisis, which started in April 2014 when the city of Flint, Michigan, switched its water source from the Detroit Water and Sewerage Department to the Flint River. As Furr-Holden discussed, a series of mistakes and disregarded engineering standards caused lead to leach from city water pipes, contaminated the city's water supply with other hazardous chemicals, and allowed levels of multiple waterborne pathogens to rise. Though the water source was switched back to the Detroit water supply in October 2015, irreparable damage had been done to the mental and behavioral health of the city's residents. As Furr-Holden noted, some of that damage was biological in origin, but much of it was linked to the social and political determinants of health.

Furr-Holden noted that people often talk about race as a predictor of health, but in an equity framework, inequities are more about unfairness in dealing with systems and structures. In that context, inequities, racism, and experiences of racism are upstream contributors to adverse mental and behavioral outcomes. This concept of examining upstream contributors fits with the idea of thinking about cumulative or holistic exposures—the exposome—rather than just individual exposures.

Furr-Holden discussed survey results from Flint and Genesee County showing that mental and behavioral health problems increased two- to three-fold during the water crisis. In addition, she said, results of these studies also showed a disproportionate impact on Flint's Black population compared to others living in the same community. This disproportionate impact has persisted, with significant overlap with other long-standing, chronic effects resulting from the legacy of Jim Crow era policies that have increased poverty among Black communities.

While this workshop focused on exploring relationships between environmental factors and mental health, Furr-Holden and several speakers stressed that mere characterization of their association is not sufficient. They called for research to identify evidence-based solutions that address the biological and mental health consequences of disasters and other environmental conditions. It is important for that research, said Furr-Holden, to engage the community and be equitable in terms of power, control, and decision making to also address challenges with trust, relationship building, respect, and transparency in order to promote change. Furr-Holden further expounded on the need for policy interventions that mandate and promote equity. While data can help drive those policies, political will is the ultimate fuel for policy change. She further argued that there is a business case that supports equity, both in terms of dollars and cents and human potential. As an example, Morganstein cited modeling studies that estimated it would cost about $12.5 billion to screen for and treat the three most common mental disorders that occurred among the residents of New Orleans most affected by the flooding that accompanied Hurricane Katrina. This was on top of the $14 billion it cost to repair the levees that were the source of the damage and suffering.

Emily Freeman (Lundbeck Pharmaceuticals LLC), who moderated the second panel session, pointed out that the primary driver of mental health outcomes following an environmental disaster tends to be the socioeconomic interactions in response to the disaster and not necessarily the disaster itself. Farris Tuma (NIMH) said there is great leverage in knowing before a disaster hits what some of the socio-behavioral factors and stressors in a community are, such as housing and food insecurity. That knowledge, he said, should allow for planning responses to address related situations, such as people having to move from one temporary housing arrangement to another, so that communities do not have to suffer from unnecessarily prolonged stressors and exacerbations of problems. Along with that, said Richard Kwok (NIEHS), it is important to understand factors that can increase resilience in the face of a disaster, something NIEHS in collaboration with the National Library of Medicine is studying as part of its Disaster Research Response program.

Leveraging Other Disciplines and Technologies to Understand and Address the Link Between the Environment and Mental Health

Panelists discussed opportunities for other disciplines and emerging technological approaches to contribute to the understanding of links between the environment and mental health. For example, Margaret Sugg (Appalachian State University) said the Crisis Text Line, a confidential service used to deliver mental health interventions to adolescents, is a good longitudinal data source and she has used it to measure and track different types of mental health conditions. She also noted that disasters can be thought of as a threat multiplier with regard to mental health, and new technological approaches may lead to ways of disentangling the multiple factors involved in the complex relationship between mental health and the environment.

Gregory Wellenius (Boston University) pointed to social media and Google searches as a means to study how the COVID-19 pandemic will affect population mental health in a manner that is not possible to observe through mental health surveys. He noted that the Delphi group at Carnegie Mellon University[4] has been analyzing these so-called "big data" sources for signals related to the COVID-19 pandemic that may be useful to inform population mental health. On the other hand, Morganstein expressed concern that relying on technological approaches could further increase disparity gaps, given that access to technology is not ubiquitous across all communities.

Freeman said that while she has heard a great deal in the discussions about access and disparities, she wondered how it would be possible to connect interventions and available tools to the communities that need them the most. She also questioned if community-based participatory research might identify the challenges that a community faces and then use the resulting information to deploy resources, technologies, or even trusted voices in the community to address disparities. Morganstein and Furr-Holden both noted the importance of identifying and engaging trusted community leaders in any effort to conduct research and implement community solutions. Along those lines, Tuma said researchers have developed and implemented methodologies for working in communities to identify those key influencers. He noted that behavioral economists may be able to identify the types of behaviors that need to be leveraged to promote community resilience against the negative socio-behavioral impacts of environmental disasters. Furthermore, Kwok said NIEHS is looking to fund dissemination and implementation science, something that Furr-Holden said is needed, given that researchers tend to follow the money.

MENTAL HEALTH BENEFITS OF A HEALTHY ENVIRONMENT

Structural Racism, Urban Nature, and Why Place Matters for Community Mental Health

When it comes to determinants of human health, the places where people live and spaces around them matter, said Eugenia South (University of Pennsylvania). She discussed how research shows that a person's zip code has a greater impact on their health than their genetic code. This link between place and health is a key contributor to the pernicious effect structural racism plays in adversely affecting mental health. South displayed and discussed a conceptual framework linking macro-level societal structures of neighborhoods segregated by race and socioeconomic status to the micro-level effect of individual health outcomes, driven by the impact that segregation and resource inequalities have on neighborhood environments.[5]

The neighborhood environment, both physical and social, serves as an input for how an individual experiences stress and behaves in response to that stress, explained South. She detailed how a history of structural racism resulted in race and place being intertwined. For example, resources and investments have flowed into predominantly white neighborhoods, while Black families and neighborhoods were denied similar resources. Black-owned homes and predominantly Black communities deteriorated and lost value, resulting in many of those communities having an incredible amount of blighted space today. In addition, many of those same communities have the lowest amount of green space, a factor that can promote positive mental health when present.

> "We really cannot talk about the environment without talking about structural racism."
> —Eugenia South

Housing discrimination and segregated neighborhoods are examples of structural racism, South said, and identify dimensions of U.S. history and culture that have allowed privileges associated with "whiteness" and disadvantages associated with "color" to endure over time. Detailed examination of contemporary physical neighborhood space in segregated cities, including blighted and green spaces in predominantly Black or white neighborhoods, can highlight the result of structural racism. This is important because structural racism can sometimes be difficult to identify and can often be invisible, but nonetheless is embedded into the fabric of U.S. society.

South expounded that blighted spaces adversely affect mental health as they tend to fracture ties between neighbors, reduce social connections, increase crime, and may trigger negative emotions, including feeling stigmatized and neglected by society. South then turned to the subject of urban nature, defined as any outdoor space with vegetation, as a mental health equity tool. Vacant lot greening is a proven approach for increasing the amount of urban nature, as it increases the amount of green space in urban environments and addresses a major contributor to urban blight. As one example, the Pennsylvania Horticultural Society (PHS), in collaboration with local community contractors, converts blighted spaces in Philadelphia into clean, green spaces and maintains them with attractive wooden fences, trees, and grass.

Working with the PHS and its local collaborators, South has been conducting a city-wide, controlled trial in which over 500 vacant lots were randomized to receive either the full greening treatment, a trash-only cleanup, or no intervention. Following either of the two interventions, gun assaults decreased 29 percent, residents felt safer when going outside, and people reported going outside more and socializing with their neighbors. People living near the greened lots reported feeling less depressed and experiencing overall improvement in self-reported mental health. The main takeaway, said South, is that

[4] See https://delphi.cmu.edu.

[5] For additional reading and information on this framework, please see Diez Roux, A. V., and C. Mair. 2010. Neighborhoods and health. *Annals of the New York Academy of Sciences* 1186(1):125-145.

targeted, simple, low-cost interventions can address legacies of structural racism and have a profound impact on mental health. She added that Philadelphia is now including vacant lot greening and abandoned house remediation in its violence prevention plan. Furthermore, she designed a program in which postpartum women received coaching and interventions that led them to spend more time in green spaces, which resulted in fewer reports of postpartum depression as compared to a control population.

The Impact of Resiliency on Communities' Exposure to Environmental Disruptions and Disasters

Maureen Lichtveld (University of Pittsburgh) said the combination of historic disparities, disasters, climate change, and environmental health threats can create unique vulnerabilities and mental health consequences for communities. To illustrate this, she recounted the series of environmental disasters that hit southern Louisiana, starting with Hurricane Katrina in 2005 and then the *Deepwater Horizon* oil spill in 2010 that cost the local economies over $8 billion. That income loss led to increases in anxiety and depression and was negatively associated with both individual and community resilience. Exposure to media that continually reminded residents of the losses they were incurring led to hyper arousal, behavioral disengagement, and symptoms of PTSD in a sizable number of people (similar to what is happening during the COVID-19 pandemic).

The study of resiliency enhances understanding of how environmental disasters and disruptions affect mental health. As part of a National Academies effort[6] to explore community resilience, Lichtveld and her colleagues visited several Gulf Coast communities, as well as communities in New York, North Dakota, and South Dakota that had also suffered multiple disasters. They studied resiliency plans developed by communities that received funds to implement those plans. Plans included elements such as property acquisition for rebuilding, public gathering spaces for community coherence, action plans to address needs of vulnerable populations, affordable housing creation, and decision support tools to help manage a flooding river. With NIEHS funding, she and several collaborators developed a resilience activation framework. In this framework, individual resilience attributes influence community resilience attributes. A disaster can have a negative effect on human, economic, social, and political capital that in turn can influence the inherent resilience in individuals and the community and affect individual mental health. The model also posits that activation of resilience attributes occurs in sociocultural settings that can be measured.

Initiatives to Improve the Environment to Improve Mental Health

Amy Bohnert (Loyola University Chicago) spoke about a Chicago initiative being conducted by Space to Grow, an organization that focuses on greening schoolyards.[7] This cross-sector partnership involves the city's water department, schools, and private funders, and is generating promising data in terms of children's mental health. Another effort, run by the Children & Nature Network, aims to disseminate research showing the benefits children get from exposure to nature.[8]

Amber Pearson (Michigan State University) discussed the partnership between the Detroit Audubon and the City of Detroit Parks & Recreation Department to convert unmaintained parks into native grassland meadows with opportunities for recreation and socialization in high-vacancy neighborhoods. This is different from other greening interventions in that it does not require expensive park equipment, has low maintenance needs, and is unlikely to greatly affect nearby home prices and push residents out of the neighborhood. In her opinion, this program provides a feasible option for post-industrial cities that face decisions about the use of vacant land while balancing low tax revenues and reductions in city services.

Pearson also pointed out that a number of cities around the world are using the COVID-19 pandemic to rethink their use and value of public spaces. Barcelona, Spain, for example, has a new 10-year plan to reclaim open spaces for people and reduce automobile-generated air pollution. Paris, France, has been converting roads to bike- and pedestrian-only paths, and Bangkok, Thailand, created a new park on a long-vacant rail line.

Both Dawn Morales (NIMH) and Rebecca White (Arizona State University) pointed to the fact that not all interventions to improve the lived environment as a means of promoting better mental and physical health have been successful. Morales said she wants to see more research to better understand how to empower communities to create health equity, and White noted that some greening projects and environmental restoration projects have created issues around gentrification and end up pushing long-time residents out of the improved neighborhoods. On the other hand, mural projects designed and painted by local community members have given communities of color the opportunity to portray people who look like them in a positive light, engendering a sense of belonging and empowering them to have positive mental health, particularly for adolescents in these communities.

Margarita Alegría (Massachusetts General Hospital), the session moderator, noted the need to move from finding associations between the environment and mental health to developing causal mechanisms, perhaps using new research methodologies. South agreed with this idea, adding that funding to conduct studies in a neighborhood context has to be prioritized to do just that. Lichtveld said that taking an exposome approach and looking for changes in metabolomics and the microbiome on a population scale could yield causal mechanisms, though she acknowledged such studies would be difficult and costly.

[6] This report is available at https://www.nap.edu/catalog/25383.

[7] See https://www.spacetogrowchicago.org.

[8] See https://www.childrenandnature.org.

Alegría suggested that there is a need for measures of the environment at the neighborhood level to better identify causal mechanisms, and Pearson said that there are new, promising approaches for quantifying a neighborhood's greenness and disorder using Google Street View and satellite imagery, as well as efforts to measure neighborhood soundscapes. Recent analyses, she said, have pointed to the mental health benefits of natural sounds. In addition, there are now a number of proxies for positive social environments that foster cohesion, trust, a sense of safety, and a sense of support.

REFLECTION ON EMERGING OPPORTUNITIES FOR THE PATH AHEAD

Opportunities to Advance Emerging Tools and Technologies

Jonathan Hollander (NIEHS), reflecting on the main themes he heard over the course of the workshop, commented on the available opportunities to conduct impactful research on environmental chemicals and mental health. As an example, he said there is a great deal of potential and opportunity to begin to study how chemicals in the environment could have an effect on mental health. At the same time, the workshop's discussions gave him a new appreciation for the complexity of that task, both in terms of the difficulty in sorting out the effects of different mixtures of chemicals in the environment on mental health and regarding the assessment of mental health in the face of coexisting health conditions.

A number of tools are available for conducting exposure assessments and characterizing the exposome over multiple scales. Among these tools are geographic information systems,[9] remote sensing technologies, laser ablation/inductively coupled mass spectrometry, and mobile phone–based monitoring of personal exposures and activity tracking. As an aside, Hollander noted that these tools could be particularly useful for advancing the understudied area of adolescent exposures; adolescence is when many mental health disorders first emerge.

Hollander mentioned the Human Health Exposure Analysis Resource (HHEAR),[10] a partnership involving NIEHS; the National Cancer Institute; the National Heart, Lung, and Blood Institute; and the NIH Environmental Influences on Child Health Outcomes program. HHEAR enables researchers to measure environmental exposures and integrate their data with other data sets, including data on the relationships between exposures and human health across the lifespan, by providing access to laboratory, statistical, and data science analysis services. He also noted the Powering Research Through Innovative Methods for Mixtures in Epidemiology (PRIME) program, through which NIEHS is developing innovative statistical methods that incorporate toxicological information into statistical models for studying chemical mixtures.[11] He concluded his remarks by noting two funding opportunities at NIEHS, which are summarized in Box 1.

BOX 1 NIEHS Recent Funding Opportunities

Environmental Risks for Psychiatric Disorders: Biological Basis of Pathophysiology, PAR-19-385[a] and PAR-19-386.[b] The goal is to stimulate research to understand the biological basis by which environmental exposures increase the risk for psychiatric disorders with symptom onset in late childhood, adolescence, and early adulthood.

Virtual Consortium for Translational/Transdisciplinary Environmental Research (ViCTER, R01), RFA-ES-18-007.[c] The goal is to create new partnerships to foster transdisciplinary collaboration and promote translational research efforts in the field of environmental health.

[a] See https://grants.nih.gov/grants/guide/pa-files/par-19-385.html.
[b] See https://grants.nih.gov/grants/guide/pa-files/par-19-386.html.
[c] See https://grants.nih.gov/grants/guide/rfa-files/rfa-es-18-007.html.

Opportunities to Advance the Convergence of Research Disciplines

Sarah Lowe (Yale University) commented that much of the work discussed at the workshop was likely conducted by interdisciplinary teams despite persistent barriers and challenges involved in working in an interdisciplinary team. Such challenges include the limit to what each team member knows about the other fields involved in a study, being vulnerable enough to work in a field in which one is not an expert, and relinquishing control and deferring to the expertise of others involved in a collaboration. Other barriers include not knowing who to collaborate with and how to talk to possible collaborators given that the same words can have different meanings to people in disparate fields. Clear communication without technical jargon is key to successfully working in an interdisciplinary team, said Lowe.

[9] See https://www.nationalacademies.org/our-work/leveraging-advances-in-remote-geospatial-technologies-to-inform-precision-environmental-health-decisions-a-workshop.
[10] See https://hhearprogram.org.
[11] See https://www.niehs.nih.gov/research/supported/exposure/mixtures/prime_program/index.cfm.

An additional challenge involves how different fields conduct science, particularly in a world where productivity and funding are valued in terms of career trajectories. Involving researchers from other fields in a smaller or community-based study can be difficult if they do not perceive a benefit to their careers. Toward that end, institutions and departments need to show patience with faculty who become involved in interdisciplinary projects given that they often take time to develop and flourish and might not result in the highest level of initial productivity. According to Lowe, institutions and departments should enable cross-disciplinary training opportunities for graduate students and postdoctoral researchers as a means of preparing the next generation of investigators to work in interdisciplinary teams. In addition, said Lowe, it can be hard to procure funding for interdisciplinary research when the team members do not have a history of working together. She applauded the funding programs that Hollander mentioned and their emphasis on funding interdisciplinary teams.

Opportunities to Enhance Public Health Policy

According to Gina Solomon (University of California, San Francisco), anyone, including herself, who has done environmental health work in communities has seen that environmental health policy does not incorporate mental health issues very well. Too often, she said, researchers and decision makers will consider mental health to be less relevant than physical health, a notion that this workshop should put to rest. In fact, mental health issues are often central to the effects that the environment can have on health, and policy decisions involving environmental health issues need to include mental health.

For Solomon, one key takeaway from the discussions was the importance of evaluating the neurological effects of environmental chemicals and how those can affect mental health. Another was that psychological first aid is something that should be taught as part of both disaster preparedness and general community environmental preparedness. The importance of engaging with communities to determine how they want to increase their own self-efficacy was another important lesson from the workshop.

Solomon noted that advancing equity and environmental and social justice are foundational to this area of work, including mental health. She added that while there are many steps to take to enhance mental health at the community level, there is a need to figure out how to fund such efforts, implement them at scale, and measure the effects they have on enhancing community resilience. These are all areas that should be considered from a health policy perspective, said Solomon.

Synthesis of Themes into the Context of Decision Making

Patrick Breysse (Centers for Disease Control and Prevention) began the final session by talking about the Agency for Toxic Substances and Disease Registry (ATSDR), which works with local health departments and the local medical community to respond to environmental health emergencies, investigate emerging environmental health threats, and conduct research on the health effects of hazardous waste sites. A unique aspect of this program is that communities can petition the agency to become involved when there is an environmental hazard affecting the community. In recent years, the program has recognized the importance of addressing the psychosocial stressors affecting communities. To address that concern and the fact that communities may already be experiencing mental health effects by the time they request ATSDR's involvement, Breysse and his colleagues have created a resource center that provides guidance and tools for community stress assessment by public health professionals.[12]

Solomon, the session moderator, remarked that much of the data discussed at the workshop came from observational studies and that she has heard little about toxicology or other approaches to study if specific chemicals might affect mental health, as is done with physical health. She noted that regulatory and what she called action-oriented agencies do not know what to do with observational data, even when those data are compelling. Tina Bahadori (National Academies) acknowledged that while there is an increasing awareness of the connection between environmental health and mental health, little is happening in terms of actual action, perhaps because of the point Solomon raised. For example, even in the aftermath of the Flint water crisis, decision makers were pushing back against IQ decrement as a measure of mental health when considering the most recent rule limiting lead and copper levels in water.

With the Biden administration's focus on disparities and racial justice as they pertain to policy decisions, Bahadori agreed this was the time to push for integrated, collaborative, multiagency efforts to characterize the exposome and begin to develop integrated markers of adversity that would provide information on the degree to which an individual has experienced environmental insults. She also noted the opportunity to use new in vitro developmental models of the fetal brain to understand how environmental chemicals affect neural development.

Regarding research investments, Bahadori highlighted the need for better baseline data on the occurrence and prevalence of environmental stressors and the health outcomes of interest. She also suggested designing studies that would map findings from observational, prospective, and clinical studies to the measures characterized in regulatory statutes. This translational research has to come from the research community rather than the regulatory community, which can provide the information needed to identify what is actionable in the regulatory and policy space, noted Bahadori.

[12] See http://www.atsdr.cdc.gov/stress.

Solomon noted that substance abuse was not a topic discussed much at the workshop, and yet it is extremely important given that it is something seen in communities affected by stressors, including environmental stressors, and after disasters. Nora Volkow (National Institute on Drug Abuse [NIDA]) remarked that her institute wants to understand how genes affect diseases, including substance use disorders, and that involves understanding how genes influence the way an individual responds to the environment because that response can provide protection or result in disease. She noted that drug addiction has been increasing over the past decades, and it is important to understand what is driving this increase. In this case, the distress triggering drug use and addiction is likely coming from the environment writ large rather than shifting genetics. Understanding the diversity of responses to the environment is crucial for advancing the science of drug addiction, and that requires integrating other disciplines into behavioral sciences. She noted that in 2016, NIDA launched a study to follow close to 12,000 U.S. children as they transition into adulthood and begin to correlate brain development, characterized with imaging, and environmental and social exposures. Volkow said this will be NIDA's most ambitious effort to understand how the environment influences brain development.

Lowe noted that the perception of risk from living near a contaminated site can have as big of an effect on mental health as actual exposure to toxic substances. As such, it is important to validate the experience while also helping people critically evaluate whether the perceptions are grounded in reality. Doing so requires accurately communicating the risks of given exposures in order to be fully transparent so that community members are aware of what they have been exposed to and to generate trust among community members, leaders, and the research community. Volkow seconded the importance of perception, adding that research has shown that children's perceptions of their socioeconomic status—not their actual status—have a direct effect on how they perform cognitively. Breysse and Volkow cautioned that when working in a community to address stress related to environmental contamination (e.g., to support stress management or to provide mental health first aid), it is important to avoid actions that may be perceived as avoiding or sidelining community members' primary health concerns. They recommended sharing information about stress along with resources about environmental exposures and related health risks that may be affecting the community. Breysse noted that ATSDR's new Community Stress Resource Center is designed to help environmental health professionals address stress as part of public health responses to environmental contamination.[13]

When asked what their policy and research priorities would be given the large number of environmental issues that the nation is facing, Lowe said she would prioritize enacting policies that achieve environmental justice among communities that are most affected by climate change and environmental toxins and that have contributed least to those problems. Bahadori commented that the nation is still far from achieving environmental justice given that disparities have not yet been quantified. Research that would quantify the magnitude of the disparities that communities are experiencing would inform these gaps. She also said that the Environmental Protection Agency has been funding research aimed at developing prevention interventions that will address the issue of disparities, poverty, and education. Volkow mentioned that providing a high-quality education could be the single most important intervention. Studies have shown that providing the training and education to parents that help their children receive a good education is a protective factor against substance use and negative mental health outcomes. Daniel Geschwind (University of California, Los Angeles) noted the importance of including diverse populations in any of the suggested studies.

Concluding the workshop, Gary Miller (Columbia University) remarked that now is a good time for initiatives funded jointly across NIH institutes that have an interest in mental health to tease out the influences that environmental exposures have on the various diseases that affect the brain and behavior. They could partner with NIEHS, which has the expertise to measure the environmental factors that would drive disease-oriented research aimed at understanding how modifying the environment might serve to prevent behavioral and mental health disorders. In his opinion, enough is known about how enhancing the environment can improve mental health at a population scale. The challenge is getting that information into the hands of the decision makers.

[13] See http://www.atsdr.cdc.gov/stress.

DISCLAIMER: This Proceedings of a Workshop—in Brief was prepared by **Joe Alper**, **Alexandra Andrada**, **Andrew Bremer**, and **Marilee Shelton-Davenport** as a factual summary of what occurred at the workshop. The statements recorded here are those of the individual workshop participants and do not necessarily represent the views of all participants, the workshop planning committee, the Standing Committee on the Use of Emerging Science for Environmental Health Decisions, or the National Academies of Sciences, Engineering, and Medicine.

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