NATIONAL SCIENTIFIC COUNCIL ON THE DEVELOPING CHILD

EARLY EXPOSURE TO TOXIC SUBSTANCES DAMAGES BRAIN ARCHITECTURE

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THE ISSUE

Children develop in an environment of relationships[1]. They also develop in an environment of chemicals. Many of these chemicals, such as the nutrients in a well-balanced diet, are essential for good health. Others, such as lead in drinking water, are poisonous and can cause illness or death. Some chemicals that disrupt brain architecture are produced in our own bodies as a result of severe and prolonged stress[2]. Others enter through contaminants in the air that we breathe, the water that we drink, and the food that we eat.

Brain development begins well before birth and continues through the early adult years. The biology of that process is influenced by the genes that are passed on from the parents to the child, by the environment of the mother's womb, and by the world the child experiences during infancy and childhood, which can either weaken or strengthen the initial blueprint. Thus, brains are built over time, and the circumstances in which they are built are every bit as important as the initial architectural framework handed down by genetics.

Toxic substances have the capacity to disrupt the development of all of the body's organ systems. The nature and severity of that disruption depend upon the type of substance, the level and duration of exposure, and most important, on the timing during the developmental process. Early assaults can lead to a broad range of lifelong problems in both physical and mental health that impose devastating human and financial costs. This paper focuses on the effects of toxic exposures on the architecture of the developing brain. When it is relatively immature, the brain is particularly susceptible to adverse impacts on the formation of its basic circuits. During pregnancy, the developing brain is extremely sensitive to many chemicals. When certain substances reach dangerous levels at particularly sensitive points in time, they can disrupt that developmental process through toxic effects on the general health of brain cells as well as on their ability to perform specialized functions. These toxic influences can weaken the foundational structure of the brain and result in permanent impairment, thereby leading to a wide range of lifelong, adverse impacts on learning, behavior, and health.[3-12]

The magnitude of the challenge of potentially toxic exposures requires sustained review and responsible management of a wide array of potentially threatening substances. Each year 2,000 to 3,000 new chemicals are brought to the U.S. Environmental Protection Agency for review prior to their manufacture. Currently there are more than 15,000 chemicals that are produced in quantities greater than 10,000 pounds per year and 2,800 are produced in quantities that exceed one million pounds annually [13]. Reports indicate that only 43 per cent of these "high volume" chemicals have been tested for human toxicity, and only 7 per cent have been evaluated for their potential effects on development.[14, 15]

Neurotoxicity (i.e., the quality or state of having a poisonous effect on neurons or neural circuits) may produce changes in the architecture and function of the brain as a result of exposure to a variety of biological or chemical agents.[3, 4, 6, 8] Certain prenatal infections, such as rubella, cytomegalovirus, and toxoplasmosis, are examples of biological agents whose neurotoxic properties have been studied extensively. This paper will focus on the wide variety of chemical substances that can harm the developing brain, which we have subdivided into three categories: (1) environmental chemicals, such as lead, mercury, and organophosphates; (2) recreational drugs, such as alcohol, nicotine, and cocaine; and (3) prescription medications, such as anticonvulsants to control seizure disorders and selected drugs for treatment of severe acne. Within each of these categories, exposure that occurs either before or after birth can result in highly toxic effects on the immature brain.

The striking finding from extensive research on neurotoxins is the magnitude of devastation and lifelong impacts they can have on human brain development.[4, 16] An important message for policy makers, however, is the extent to which many scientific findings are not well understood by the general public and do not match popularly held beliefs about safety and risk. This is particularly problematic in the face of widely available substances, such as alcohol, mercury, and many prescription drugs that are highly damaging to the immature brains of embryos (first trimester of pregnancy), fetuses (second and third trimester of pregnancy), and young children at doses that are tolerated with minimal to no adverse effects in adults. Thus, greater public understanding of this often confusing scientific knowledge provides an important opportunity for evidence-based policies that can strengthen our capacity to protect the developing brains of all young children.

WHAT SCIENCE TELLS US

Neurotoxins interfere with the natural function of genes, proteins, and other small molecules that build brain architecture. Disruptions of brain development caused by toxic substances, both before and after birth, can result in disorders that are evident immediately after exposure as well as impairments that emerge much later in life.[5, 7, 12, 16] Because fully effective treatments have yet to be developed for many of these disabling conditions, children who are exposed to neurotoxins before or soon after birth often face a lifetime of difficulties, for which all of society pays a continuing price.

- Environmental influences can be positive or negative in very powerful ways, because they have the capacity to literally change the architecture of the brain as it grows. Although exposure to toxins can result in serious injury, the brain is also resilient as biology protects it over other organ systems and helps it resist the potentially negative impacts of outside threats. Moreover, when given the chance, the brain often demonstrates the capacity to recover from damage. This balance between vulnerability and resilience determines how different environmental conditions affect brain development over time.

- The immature brain is far more vulnerable to toxic exposures than that of an adult. Mature brains have a barrier of cells that restrict the entry of chemicals from the bloodstream into brain tissue, but that protective barrier is absent in the fetus and only reaches maturity in the first year after birth. Thus, the time of greatest brain growth and most intensive construction of brain architecture is also the period that is most vulnerable to the relatively free passage of toxins into its cells.[3, 8, 9, 17, 18] Similar to the impact of disrupting the construction of the foundation of a new house, early exposure to toxic substances has broader and more lasting effects on brain development than exposure later in life.

GLOSSARY

CELL MEMBRANE: the outer layer of a cell that controls the passage of chemicals between the external environment and the cell's interior

ENZYME: a protein produced by cells that initiates or controls specific biochemical reactions

GLIA: specialized cells that provide a protective and supportive environment for neurons and their connections in the brain

GROWTH FACTOR: a protein or other substance (like vitamins) that promotes the growth of cells

MYELINATION: the process by which specialized brain cells form insulation around nerve fibers, which aids in the more rapid and error-free transmission of signals from one neuron to another

NEURAL CELL MIGRATION: an important part of the early embryonic development of the brain characterized by the movement of nerve cells from the place where they originate to specific locations where they form specific brain structures

NEURAL CIRCUIT: a network of connections among neurons that performs a specific function (e.g., visual circuit)

NEURON: a specialized cell that serves as the fundamental information-processing unit of the nervous system

NEUROTOXICITY: the quality or state of having a poisonous effect on neurons or neural circuits

NEUROTRANSMITTER: naturally occuring chemical substances (such as serotonin or dopamine) produced and used by the nervous system to transmit information across a synapse from one neuron to another.

SYNAPSE: the junction between two neurons across which neurotransmitters pass in order to excite or inhibit the next neuron in line.

ENVIRONMENTAL AGENTS

- Chemicals classified as heavy metals, such as lead, mercury, and manganese, disrupt many of the normal biochemical processes that are necessary to build a sound and durable brain early in life. These substances come from many places, including contaminants in foods (e.g., mercury in fish), chemical waste that accumulates in water and plants, and synthetic materials (e.g., lead in paint, dust, or soil; manganese in unleaded gasoline). Generally speaking, heavy metals are present in complex chemical mixtures that break down over time, leading to the release of individual toxins that enter the bodies of children through eating, skin absorption, or inhalation, as well as through the placenta before birth.[10, 18, 19]

- At levels frequently measured in our environment, heavy metals interfere with the construction of the basic framework of the maturing brain as well as with its function. These toxic effects include disruption of neural cell migration from one part of the brain to another, as well as the formation of synapses (i.e., connections among cells), each of which is essential for building normal brain architecture. Heavy metals also interfere with neurotransmitters, which are the natural body chemicals that carry signals from one cell to another. These neurotransmitters are responsible for all brain functions, including learning, control of emotions, social interactions, and such fundamental processes as movement, vision, hearing, and touch. The most complex of these functions, which involve thinking and feeling, are the most susceptible to disruption by toxic exposures.[20]

- Lead can have adverse effects on several specific aspects of brain development. These include the formation and sculpting of neural circuits (i.e., the networks of connections among brain cells) as well as the process by which fatty tissue forms insulation around nerve fibers (known as myelination) like the insulation around the electrical wires in a house, which facilitates more rapid transmission of signals among brain cells. The disruptive effects of lead are due largely to interference with the normal function of several important neurotransmitters, including dopamine, glutamate, and acetylcholine. The primary functional deficits resulting from lead exposure, which have been demonstrated through repeated studies in both humans and animals, include a range of problems in learning, behavior, and the ability to focus and sustain attention.[3-5, 21-27]

- Mercury disrupts brain development by inhibiting important enzymes and preventing certain cells from dividing to produce more neurons and support cells (called glia). Research shows that mercury also increases the vulnerability of the brain to the adverse effects of other toxins at levels that are otherwise thought to be below dangerous thresholds, thereby producing a so-called "double hit." As for all neurotoxins, the degree to which developing brain architecture is disrupted by mercury ultimately depends upon the timing and level of exposure, each of which is influenced by the source of the toxin. Currently, emissions released by coal-fired power plants are the most important source of environmental mercury in the United States.[28-30] This chemical is deposited into rivers, streams, and lakes where it is transformed by bacteria into a substance called methyl mercury, which is considered one of its most toxic forms. In recent years, the level of this dangerous chemical has been rising in the food chain, with the highest recordings found in contaminated fish (such as swordfish and tuna) as well as some shellfish, which are now the most significant sources of mercury exposure in the country and the

most harmful to the developing fetus and young child. Direct exposure to other forms of mercury, through contaminated soil or air near industrial sites, is a relatively smaller contributor. Exposure to elemental mercury, through broken thermometers or switches, is also much less common and much less toxic than to methyl mercury.[3-5, 27-33]

- Exposure to organophosphates (also called "OPs"), which are common ingredients in insecticides used widely in agricultural regions and by professionals for control of insect infestation in homes and commercial facilities, can cause mild to severe disruption of brain development. The most widely investigated of the organophosphates, chlorpyrifos (CPF), kills neurons, causes defects in neural cell migration, and reduces connections among brain cells. Other organophosphates also affect the production of neurons, supporting cells, and neurotransmitters. Thus, organophosphates disrupt a wide range of processes that are essential for the formation and function of brain circuits. Although animal research demonstrates that organophosphates produce microscopic changes that are difficult to detect, studies of functional outcomes in both animals and children demonstrate that modest changes in brain architecture caused by exposure to CPF can lead to measurable problems in learning, attention, and emotional control.[4, 5, 10, 16, 18, 24, 34-36]

RECREATIONAL DRUGS

- Both legal and illicit recreational neurotoxins, such as alcohol, nicotine and cocaine, interfere with chemicals that are necessary for the formation of normal brain architecture. Extensive human and animal research indicates that each agent causes different functional deficits that are influenced by the level, duration, and timing of the exposure. Recreational neurotoxins are most damaging during pregnancy because of the heightened susceptibility of the embryonic and fetal brain to developmental disruption. Research designed to pinpoint the precise biological impacts of parental substance abuse on fetal brain development, however, is quite challenging, given the high prevalence of multiple exposures (e.g., cocaine users often smoke cigarettes and consume alcohol) and the difficulties in conducting careful studies of individuals who are addicted to illegal substances. Even more important, it is often difficult to separate the biological impact of fetal exposure to toxic recreational drugs before birth from the physiological effects of environmental stresses facing children whose parents have a substance abuse problem, both of which can harm the developing brain.[2] Nevertheless, despite these research challenges, there is abundant scientific evidence that exposure to dangerous levels of recreational neurotoxins at particularly sensitive times in the developmental process can disrupt the architecture of the brain.[16]

- Of all the recreational neurotoxins studied to date, alcohol produces the most devastating disruptions of early brain development. These changes are most evident in the structure of cell membranes, which contain the proteins that are responsible for the ability of growth factors and neurotransmitters to perform their normal functions. The adverse impacts of alcohol are so powerful that they also can interfere with the development of organs that often are

spared by other toxic exposures, including those of the cardiovascular, digestive, and musculo-skeletal systems. Thus, high levels of alcohol exposure during pregnancy have been shown to produce a combination of problems that have been characterized as the "fetal alcohol syndrome," which is a serious medical condition involving multiple organ systems. Once again, the timing of the toxic exposure is most important. Alcohol exposure in the embryo and fetus can cause different kinds of disruptions of brain architecture by killing neurons or stalling their migration during critical developmental periods. The potential long term functional outcomes of such disruptions in both human and animal studies include cognitive deficits such as mental retardation, reduced emotional control, problems with attention, and hyperactivity.[3, 16, 27, 37, 38]

- Nicotine exposure from cigarette smoking during pregnancy also has a well documented adverse impact on the structure and function of the fetal brain. Nicotine binds to a membrane protein that is responsible for the function of acetylcholine, a naturally occurring neurotransmitter in the adult brain that also is present during fetal development. When pregnant women smoke, oxygen delivery to the fetus is reduced and high levels of nicotine exposure result in decreased overall growth. Both animal and human studies also have documented cognitive impairments associated with fetal nicotine exposure, although these effects are significantly milder than those resulting from alcohol or other toxic chemicals.[4, 10, 27, 39]

- Cocaine, methamphetamine ("speed"), and methylphenidate (Ritalin) are psycho-stimulant substances that have been shown to cause functional impairments in animals and humans who experience prenatal exposure. However, unlike the adverse effects of alcohol and other neurotoxins that are noticeable in early childhood, the damage from prenatal psychostimulant exposure may not be apparent until later in life.[27] Moreover, the specific impact of exposure to psychostimulants in humans has been relatively difficult to investigate, because pregnant women who abuse cocaine or other psychostimulants typically use alcohol and nicotine as well. Psychostimulants act by interfering with the regulation of a class of neurotransmitters (the monoamines) whose activation and inactivation are important for normal function in fetal brain development. Animal studies demonstrate that psychostimulants such as cocaine cause changes in the maturation of brain cells located in specific circuits that affect the ability to focus attention and regulate emotion. Most prospective studies of prenatal cocaine exposure in humans report relatively modest developmental changes in infants and toddlers but measurable problems with attention, hyperactivity, and mood control as the children are followed into their early teen years.[16, 27, 40]

MEDICATIONS

- A variety of prescription drugs that are safe for adults can cause serious damage to an immature nervous system. For example, both human and animal studies indicate that prenatal exposure to valproate, which is used to treat seizure disorders, can cause neural tube defects (i.e., defects in the spinal cord, such as spina bifida) and substantial disruption of early brain growth and architecture. Moreover, studies of postnatal exposure in animals demonstrate both

destruction of brain cells and alteration in the formation of neural circuits involved in cognitive and behavioral functions. As expected from this type of developmental disruption, valproate exposure during pregnancy can cause mental retardation, other cognitive deficits, and impaired emotional control.[3, 41]

- The extent to which certain nutritional supplements can disrupt the development and function of the immature brain is highly influenced by both the timing and level of exposure. Vitamin A, for example, is a common example of a class of chemicals called retinoids, which are essential to a variety of chemical reactions that are important for normal brain development, including the activity of genes that are necessary for producing brain cells, promoting their specialization, and protecting their survival. Excessive exposure during embryonic or fetal development, however, results in impairments that can be major (e.g., spina bifida) or relatively minor (i.e., mild functional difficulties). Excessive levels of retinoids resulting from maternal use of a compound to treat severe acne during pregnancy can have particularly devastating effects. This provides a striking example of a chemical that is highly neurotoxic for the immature brain of a fetus at doses that are tolerated without serious consequences by adults.[42, 43]

POPULAR MISREPRESENTATIONS OF SCIENCE

Popular beliefs about which chemical substances are more or less toxic to the developing embryo, fetus, infant, and child are most commonly related to their relative abundance and legal status in society. In this context, it is essential that we distinguish scientific facts from widespread misperceptions.

- It is generally assumed that illegal recreational drugs have the most damaging impacts on brain development and function. In fact, extensive research indicates that alcohol is one of the most dangerous neurotoxins that can affect the brain during the period between conception and birth.[3, 37, 38]

- It is generally assumed that the adverse impact of toxic substances on the developing architecture of the brain is an all-or-none phenomenon. In fact, neurotoxins can produce a range of outcomes, from mild to severe impairment, which often lead to confusing conclusions about the linkage between exposure to a specific substance and its consequences.[5-7, 9, 12, 27, 28, 40]

- It is generally assumed that the absence of cognitive or behavioral problems in childhood indicates that an early exposure to a neurotoxin had no adverse effect on brain development. In fact, studies in both animals and humans have demonstrated that some substances cause damage to the brain that is manifested in the delayed onset of learning problems, attention deficits, and changes in emotional regulation, which can have long term consequences into the teenage and adult years.[3, 5, 7-9, 12, 27]

- It is generally assumed that the determination of a dangerous level of exposure to a potentially neurotoxic substance is a straightforward scientific question. In fact, this can present a complicated challenge because the developing brain of a young child is typically more susceptible to damage than the mature brain of an adult, and the immature nervous system of an embryo or fetus is even more vulnerable to toxic exposures than is that of an infant. Therefore, there is no credible way to determine a safe level of exposure to a potentially toxic substance without explicit research that differentiates its impact on adults from the greater likelihood of its adverse influences on the developing brain during pregnancy and early childhood.[4, 6, 7, 9, 11, 12, 16, 24, 26, 36, 44]

- There is a popular misperception among some groups that vaccines containing thimerosal (which has been added as a preservative) are linked to the development of autism in susceptible children. In fact, extensive and repeated studies by highly reputable scientific groups have failed to confirm this claim.[45]

THE SCIENCE-POLICY GAP

There is no question that exposure to certain chemical substances during the period from conception through the early years of life causes significant and irreversible damage to the developing architecture of the brain. Nevertheless, the importance of determining which substances are safe and specifying thresholds of exposure for those that are dangerous is not yet incorporated into public policy. These tasks are complicated by the fact that policy initiatives in this area are driven largely by popular beliefs, which are influenced primarily by advocacy groups and media reports that often are not updated as new science becomes available. Moreover, these folk beliefs prove especially stubborn to dislodge as they are not subject to rigorous scientific review. Although much remains to be learned about the full breadth of risk during pregnancy and early childhood, there is much that can be done based on what we know now about how to reduce the number of children whose brains are harmed by neurotoxins.

Over the past few decades, effective public policy has been developed to reduce exposure to some of the most widely recognized neurotoxins. The decreased prevalence of lead poisoning is a prominent example.[4, 18, 46] Efforts to educate the public about the harmful effects on children of second hand cigarette smoke provide another example. Between 1994 and 1999, the percentage of homes with a child under age 7 in which someone smoked regularly dropped from 29% to 19%. Consequently, median blood levels of cotinine (a breakdown product of nicotine) were 56% lower in the five year period from 1999 to 2000 compared to levels reported between 1988 and 1991.[18] In 1999-2000, the U.S. Environmental Protection Agency imposed new restrictions on the use of organophosphate pesticides, largely because of concerns about the potential exposure of young children. Subsequently, the percentage of food samples with detectable residues of these pesticides declined from 29% in 1996 to 19% in 2001.[18]

Although progress has been made in reducing selected toxins, policies that could restrict the exposure of embryos, fetuses, and infants to other chemicals whose neurotoxicity is well documented, such as mercury and other industrial organic compounds, have been less well formulated.[10, 13, 18, 19, 47] Beyond the moral responsibility to reduce known threats to the health of young children, there are persuasive economic arguments for greater attention to the value of prevention, both as an investment in sound development and as strategy for reducing the continuously escalating treatment costs of disease and disability.[13, 29, 38, 48] The gap between what we know about the potentially devastating effects of neurotoxins and what we do through public policies and programs to protect the developing brain from harm in the early years of life is illustrated by the following examples.

- Because of the highly complex nature of the processes that build brain architecture in the earliest years, the immature brain of an embryo, fetus, or infant is often susceptible to significant damage from exposure to chemicals at levels that appear to be harmless for adults. Despite this well established scientific fact, policy makers generally establish safe levels of exposure to prescription drugs and known neurotoxins through a process that is guided by research findings from studies of mature animals and adult humans.[4, 11, 16]

- The absence of overt cognitive and behavioral deficits in infants and toddlers who have been exposed to neurotoxic substances often has a strong influence on establishing priorities for regulatory controls. However, long-term impacts of some early toxic exposures, which can include a so-called "silent period" of normal functioning prior to the appearance of functional deficits, are not well understood. This typically results in public policies that fail to protect developing brains during pregnancy and early infancy.[3, 5, 7-9, 12, 27]

- An illustrative example of the science-policy gap can be found in a recent study by the U.S. Environmental Protection Agency which estimated that 8 per cent of women of childbearing age in the United States have dangerously high blood levels of mercury. After concluding that "there is no safe level of methyl mercury in the blood" (p. 59), the report went on to state that 50 per cent of women of childbearing age have blood levels of mercury that reach or exceed 1 part per billion.[18] With these data as a backdrop, research shows that mercury levels in the food chain are increasing, with the greatest concern focused on popular fish such as swordfish and tuna. What makes the science-policy gap particularly striking is evidence that the source of this increasing toxic chemical burden is well known and preventable. The largest production of environmental mercury comes from the emissions of coal-burning power plants and incinerators, despite the fact that technology is available to reduce its atmospheric release.[18, 29, 30] Other sources of contamination are related to inadequate disposal of mercury-containing products, which could be ameliorated through greater public education and the provision of convenient and appropriate mechanisms for recycling and waste management.[30, 32]

IMPLICATIONS FOR POLICY AND PROGRAMS

Beyond the importance of individual responsibility for the care and protection of children, public policies can have a significant impact on promoting health and preventing disease or disability in the entire population. When fluoride is added to public water supplies, children have fewer dental caries. When foods eaten by infants and toddlers are fortified with iron, the prevalence of anemia decreases, and the risk of associated developmental problems goes down. In contrast, when mercury enters the food chain or when young children play in gardens that have been sprayed with neurotoxic insecticides, individual behavior cannot guarantee safety and the resulting disruptions of early brain development that lead to lifelong disabilities could have been prevented by informed public policies.[4, 5, 47, 49]

To this end, the basic science of how early brain development can be disrupted by toxic substances is now sufficiently detailed to inform more effective policies to protect the well-being of human embryos, fetuses, and young children.

- **The costs of ignoring the danger of neurotoxins are high.** The moral costs of preventable disability and public expenses for special education, medical care, and lost economic productivity incurred for individuals with disabilities that were caused by early chemical damage to the developing brain are considerable. The costs of cognitive impairments due to lead poisoning alone, for example, have been estimated to approach $43 billion per year, and the costs of mental retardation, autism, and cerebral palsy due to environmental pollutants have been estimated at $9 billion annually.[13] The magnitude of this financial burden indicates that the prevention of brain damage by neurotoxic exposures should be assigned a higher priority for policies focused on public health, education, human capital development, and environmental protection.[5, 13, 48, 50]

- **The establishment of safe levels of exposure to toxic substances should be based on scientific data that recognizes the critical link between vulnerability and age.** In view of the well-established scientific fact that embryonic, fetal, and early childhood brain development is considerably more susceptible to damage from toxic substances than the mature brain of an adult, the establishment of thresholds for toxic exposures should focus primarily on the best data available for the youngest children.[4, 6, 7, 11, 12, 16, 26, 36]

- **Public awareness campaigns should be grounded in state-of-the-art science.** Knowledge about the potential adverse impacts of prescription drugs and nutritional supplements when used by pregnant women and nursing mothers should be updated continuously and communicated to health care personnel and the general public. The fact that toxic exposures can be most damaging in the earliest weeks of pregnancy, before many women are aware that they are pregnant, underscores the importance of broader public education on this issue. Current efforts to strengthen the ability of nurses to play this important role can be seen in the Environmental Health Nursing Initiative launched by the Agency for Toxic Substances and Disease Registry in the U.S. Department of Health and Human Services (http://www.atsdr.cdc.gov).

- **Scientific information should be disseminated more extensively through warning labels and proactive controls on toxic exposures.** Information on the toxic effects of organophosphates could be disseminated in a more effective manner by a requirement for clearer warning labels on the packaging of commonly used insecticides. This would enable pregnant women and families with young children to make more informed choices about the products they use. In an effort to move beyond sole reliance on individual behavior, Michigan enacted legislation in 2004 that prohibits the use of any pesticides at a school or child care center unless it has adopted an integrated pest management program that focuses on non-pesticide alternatives to chemical controls. Both the Michigan law and recent legislation in Rhode Island require schools and child care centers to notify parents in advance before pesticides are used on school grounds.[50] More proactive education programs also should be provided for employees of childbearing age who are exposed to substances in the workplace that are not harmful to adults but can be highly toxic to the immature brain. In such cases, chemicals can be transmitted through the placenta of a pregnant woman or brought home on the clothing of a mother or father of a young child.

- **Marketing campaigns provide opportunities for enhanced public education.** The significant neurotoxicity of prenatal alcohol exposure calls for a focused re-examination of the marketing of alcohol to young adults and other vulnerable populations. This should include efforts targeted at low income neighborhoods and populations with less education, college campuses where alcohol abuse is common, and work sites that have high concentrations of employees of childbearing age.

- **The chemical and interpersonal impacts of adult addictive behaviors on child well-being require greater public attention.** Routine prenatal care should be augmented by the incorporation of state-of-the-art practices for identifying and treating women who are addicted users of both legal (e.g., alcohol and tobacco) and illegal (e.g., cocaine) substances. This could be reinforced through community-based counseling, targeted education programs in the workplace, and comprehensive therapeutic interventions as needed. Central to such efforts is the need to focus on the fact that parental substance abuse threatens the development of healthy brain architecture through the effects of two kinds of chemicals: (1) abused substances that are taken by the mother and cross the placenta during pregnancy; and (2) elevated stress hormones that are produced by young children themselves who experience highly stressful interactions in the absence of stable and supportive caregiving relationships.

- **Increased investments in environmental surveillance are needed to strengthen our capacity to prevent damage to young children's brains.** There is a compelling need for greater public efforts to track developmental disorders that are linked to environmental exposures in order to identify disease clusters and determine the causes of disrupted brain architecture.[51] Examples of recent state-level legislation include the California Health Tracking Act of 2003 and the Illinois Children's Environmental Health Officer Act of 2005.

The protection of young children requires a balanced approach to both individual and public responsibility. Extensive research shows that preventive public health measures are most effective

when they do not depend primarily on individual behavior.[4, 5, 18, 19, 46, 47] Well studied examples include safety caps on medications that decrease child ingestions; lowered hot water temperatures that prevent scalding burns; the removal of lead from gasoline, food cans, and residential paint products which leads to lowered blood lead levels in children; and the fortification of bread, flour, and grain products with folic acid to reduce the incidence of neural tube defects such as spina bifida.

In the final analysis, the prevention of brain damage to embryos, fetuses, and young children as a result of toxic exposures will depend largely on the extent to which effective controls are implemented to lower the levels of known neurotoxins in the environment. Maryland demonstrated such a commitment in 2000 with the creation of a children's environmental health protection advisory panel, which reviews existing regulations, statutes, and proposed regulations to assess whether they provide sufficient protection for children and makes specific recommendations accordingly. The challenge for policy makers and civic leaders is to build working relationships with leading research and public health agencies, educate the general public about the science of neurotoxicity, confront popular misunderstandings and active distortions of that science, and use currently available knowledge to design and implement policies to reduce preventable injuries to the brains of young children, both before and after birth.

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CONTRIBUTING MEMBERS

Susan Nall Bales
President
The FrameWorks Institute

W. Thomas Boyce, M.D.
Professor of Epidemiology and Child Development
Division of Health and Medical Sciences
University of California, Berkeley

James Heckman, Ph.D.
Henry Schultz Distinguished Service Professor of Economics
Director
Economics Research Center, Department of Economics
University of Chicago

Arthur J. Rolnick, Ph.D.
Senior Vice President and Director of Research
Federal Reserve Bank of Minneapolis

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THE HELLER SCHOOL, BRANDEIS UNIVERSITY
MS 077 · Waltham, MA 02454-9110 · 781-736-3822 · fax 781-736-3773 · www.developingchild.net

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