A BRIEFING PAPER FOR DELEGATES

Protecting the Developing Brains of Children from the Harmful Effects of Plastics and Toxic Chemicals in Plastics

Recommendations for Essential Policy Reforms in the New Global Treaty on Plastics

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As experts in the effects of toxic chemicals on neurodevelopment, and as scientists, clinicians, and children's health advocates in Project TENDR (Targeting Environmental Neuro-Development Risks), we are deeply concerned about mounting scientific evidence showing that plastics and toxic chemicals in plastics are contributing to neurodevelopmental disabilities and cognitive deficits in children.

In this briefing paper, we summarize the evidence of widespread fetal and early childhood exposures to plastics and resulting harm to children's brains and offer recommendations to strengthen the global treaty on plastics pollution to ensure it addresses the toxicity and proliferation of plastics and petrochemicals.

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Prevalence of Neurodevelopmental Disorders

One in six children in the United States has a developmental disability, including learning disabilities, intellectual impairment, autism, and attention deficit and hyperactivity disorder (ADHD), and the overall prevalence of most of these disorders increased from 2009-2017.[1] [2]

Children living in poverty have higher prevalence for all developmental disabilities.[3] [4] Prevalence rates by race and ethnicity vary by disorder, with Black children followed by White children having the highest rates for autism, and Black children followed by American Indian or Alaska Native children having the highest rates of learning disabilities. White children have the highest rate of ADHD, followed by Black children.[5]

Reported rates of developmental disabilities in children vary widely by country and region, and systematic reviews seeking to determine global prevalences often include data only for high income countries (HICs). A systematic umbrella review published in 2023 compared global rates for ADHD, autism, intellectual disability, and dyslexia with rates reported in the 2019 Global Burden of Disease (GBD) study, which included low- and middle-income countries (LMICs). The review rates (which largely exclude LMICs) compared to GBD rates are as follows: ADHD: 3.7% vs. 1.9%; autism: 0.6 – 1% vs. 0.4%; intellectual disability: GBD rate only, 3.1% overall, 1.5% for HIC. Dyslexia is not included in the GBD; the systematic umbrella review found a rate of 7.1% for both HICs and MICs.[6]

Learning, developmental, and intellectual disorders are complex, arising from multiple, interacting genetic and environmental factors. **While we cannot change our genes, we can reduce the onslaught of plastics and associated toxic chemicals that are contributing to lasting problems in cognition, behavior, and attention.**

Global Crisis of Plastics Production & Waste

Global production of plastics has grown exponentially since the 1950s, reaching 400 million metric tons in 2022.[7] Global production of plastics is projected to quadruple by 2050.[8] Oil and gas extraction that feeds plastics production is a major and rapidly growing source of air pollution and greenhouse gases (including CO_2 and methane). In 2019 alone, global plastics production generated 1.8 billion tons of greenhouse gases and led to 22 million tons of plastic entering the terrestrial and aquatic environment in the form of macroplastics (such as bottles), which can disintegrate in the environment into tiny particles known as microplastics (1nm to 5mm), and nano-plastics (<0.1µg).[9]

The United States generates more plastic waste per capita than any country in the world. According to the EPA, plastic waste in the U.S. grew from less than ten million tons in the 1980s to nearly 40 million tons today.[10] Globally, packaging accounts for the largest proportion of plastics waste, making up 40 percent of all plastic waste generated.[11]

Plastics and Petrochemical Additives

The vast majority of plastics in use today are refined from oil, natural gas, and coal into chemical monomers, the building blocks of plastic polymers. Packaging is commonly made of five polymers - polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC).[12]

Thousands of petrochemicals are added to plastic polymers —including fillers, plasticizers, colorants, stabilizers, lubricants, foaming agents, flame retardants, and antistatic agents—turning plastics into vectors that can deliver these chemicals into human bodies.[13] A 2024 report found there are 16,325 chemicals potentially used or present in plastic materials and products, with 25% of these classified as hazardous and 66% not yet assessed for safety. **The report determined that no plastic chemical can be classified as "safe."[14]**

In a recently compiled data set of 906 chemicals associated with plastic packaging, researchers declared 126 of the plastics additives as toxic, and many of those as neurotoxic.[15] For example, the chemical classes of ortho-phthalates, bisphenols, and polybrominated diphenyl ethers (PBDE) flame retardants are known neurotoxicants.[16] [17] [18] Other chlorinated and brominated flame retardants, organophosphate flame retardants, and chlorinated paraffins are likely neurotoxic.[19] [20] A class of high-volume chemicals in plastics, benzotriazole UV stabilizers, disrupt endocrine function, which in turn can impair brain development.[21]

Modes of Exposure

The body of evidence is growing that humans are exposed not only to the chemicals added to plastics but directly to plastic materials in the form of microplastics and nano-plastics; as many as 240,000 plastic particles (90% nanoparticles) have been found in a liter of bottled water.[22] Plastic particles and chemical additives can be ingested from food and water, inhaled from air and dust, absorbed through the skin, and are even injected via plastic intravenous tubing during medical procedures.

Diet is a particularly important exposure pathway for some compounds used in plastics such as phthalates, which leach into food from packaging materials, plastic equipment used in commercial dairy operations, lid gaskets, food preparation gloves, and conveyor belts.[23] Consumption of dairy and oily foods including fast food and packaged foods, are important dietary sources of phthalate exposures.[24] Furthermore, bisphenol A and replacement bisphenols also leach out of epoxy resin linings of food cans and bottle tops, as well as polycarbonate bottles.[25] [26]

Chemical additives also leach from plastics in our homes and concentrate in dust.[27] Relatively high levels of many of the compounds added to plastics, such as phthalates, organohalogen and organophosphate flame retardants, and phenols have frequently been measured at concentrations above 1000 ng/g dust.[28] Household dust is an important exposure route for toxic chemicals, especially for infants and children who spend considerable time on or near the floor where they may ingest or inhale the dust.[29] Plastic based building products containing phthalates such as vinyl flooring and wall coverings have a large surface area from which phthalates can migrate into the indoor air and household dust exposing residents.[30]

Plastics that contain chlorine or bromine, such as polyvinyl chloride (PVC), when incinerated for "waste-to-energy" conversion can result in harmful exposures to neurotoxic chemicals such as dioxins and furans, some of the most highly toxic chemicals, exposing workers and residents of surrounding communities. They also contribute to environmental disasters such as the East Palestine, Ohio, train derailment that involved the burning of vinyl chloride, used to make PVC.

Plastic Particles *In Utero*, in Infants, and Children

Babies today enter the world with their brains and bodies already contaminated with plastics. Micro- and nano-plastic particles have been found in the placenta[31] [32] and newborns' first stool,[33] with exposures continuing through breastmilk and infant formula.[34] [35] Brains are targets as microplastics can be transported across the blood-brain-barrier and induce inflammation as observed in rodent experiments.[36] Even short-term exposures to microplastics induce behavioral changes in mice and alter immune responses in the brain.[37]

Micro- and nano-plastics penetrate cell walls and are toxic because they impair mitochondrial function in cells.[38] Mitochondria are responsible for the cell's energy production and play an important role in placental function. A 2024 review paper in the Lancet summarized how exposure to nano- and microplastics can lead to adverse effects in multiple organ systems in animals and humans through inflammation, immune impairment, oxidative stress, alterations in biochemical and energy metabolic processes, disruption to organ development, and carcinogenicity.[39]

Recently, a Hawaiian study of banked placenta samples reported that 60% of placentas contained plastic particles in 2006, 90% in 2013, and 100% in 2021.[40] The presence of plastic particles in placental tissues both on the maternal and fetal sides[41] [42] is concerning as the placenta exchanges nutrients, antibodies, gases, and waste products between the mother and fetus. The growth and development of the fetus is supported by the placenta. Chemical additives to plastics and the plastic particles themselves can disrupt placental endocrine and immune function as well as its lipid and energy metabolism,[43] [44] [45] [46] affecting not only overall fetal growth[47], but brain growth and development, and behavior including motor function, learning, and memory.[48] [49] [50]

Some babies are at especially high risk of harm from exposure to plastic particles - especially those born too small or prematurely who are at higher risk for developmental disabilities already. A recent study detected microplastics in the placentas from all babies who were small for gestational age but in only 3 of 30 placentas in normal weight babies, and microplastics exposure was inversely related to birthweight, length, head circumference, and 1-minute Apgar score.[51] [52]

Plastics Impacts on Neurodevelopment

For some classes of chemicals comprising or added to plastics, there is overwhelming evidence that prenatal and early childhood exposures are contributing to problems with child brain development and neurodevelopmental disorders. Here we provide brief summaries of the scientific evidence of neurological harm from some of the problematic classes of chemicals used in plastics, including bisphenols, phthalates, and organohalogen and organophosphate flame retardants.

These chemical classes and their substitutes leach from plastics into food and dust[53], and are widely found in pregnant women, infants, and children, passing to the fetus via the placenta, and to the infant via breastmilk and formula.[54]

Ortho-Phthalates (Phthalates) are a group of chemicals incorporated into plastics to make them more durable and flexible. They are widely used in food and drink packaging, personal care products, and cosmetics, building materials such as vinyl flooring and wall coverings, medical tubing and devices, printing inks, pesticides, and synthetic clothing.[55] Phthalates are not chemically bound to the products that contain them, and readily migrate into dust, food, and the environment.[56]

The class of ortho-phthalates has been clearly established as neurotoxic, including di-2ethylhexyl phthalate (DEHP), di-butyl phthalate (DBP), and butylbenzyl phthalate (BBzP).[57] A substantial and growing body of evidence documents the impacts of prenatal exposure to phthalates on brain development, including cognitive and motor function being affected in the preschool period[58] [59] [60] [61], or later childhood/early adolescence[62] [63], impacts on behavior, including poor executive function, attention and working memory[64] [65] [66], delayed language development[67] [68], reduced IQ[69], and preschool and childhood ADHD.[70] [71]

Phthalate exposure in pregnancy has been linked to sex-specific changes in brain structural development, including changes in gray and white matter volumes, assessed by MRI, that may reduce IQ.[72]

There has been a reduction in use of DEHP, but there is emerging evidence that the typical replacement, DiNP, can also harm child brain development.[73] [74] Phthalates are also antiandrogenic and impair development of the male reproductive tract.[75]

Organohalogen (Brominated or Chlorinated) Flame Retardants (OFRs) are a large group of industrial chemicals that are added to furniture, electronics, and other materials to suppress fires. OFRs are not chemically bound to plastics and can escape into indoor environments, accumulating in dust and leading to exposure via ingestion and other pathways.[76] [77]

Polybrominated diphenyl ethers (PBDEs) are extensively researched OFRs; many studies find PBDEs are associated with learning, behavioral, or intellectual impairment.[78] [79] [80] [81] Children with autism may be more susceptible to the effects of PBDEs through suppression of their immune response.[82] The combination of PBDEs' adverse effects on children's brain development and widespread exposure is indicative of a significant public health problem with large costs to society. A study of costs associated with lost IQ points in Europe from PBDEs and organophosphate pesticides estimated annual costs of greater than 150 billion euros.[83]

The international Stockholm Convention on Persistent Organic Pollutants ("POPs Treaty") has banned certain brominated flame retardants including PBDEs (the penta- and octa- BDE commercial mixtures and deca-BDE), hexabromocyclododecane (HBCD), and hexabromobiphenyl (HBB).[84] The U.S. EPA has restricted certain uses of PBDEs, including for deca-BDE in 2021,[85] however these restrictions have not gone into effect for some uses.[86] PBDEs are persistent, ubiquitous in the environment, and found in many consumer products made from plastics.[87]

For example, pentaBDE is still in high concentrations in older furniture foams in current use and may contribute to exposure disparities among people with lower incomes.[88] In addition, plastics that contain PBDEs are allowed to be recycled into new products such as toys, food handling utensils, and food containers.[89] High levels of polybrominated dibenzo-p-dioxins and dibenzofurans (PBDD/Fs) have also been found in toys and other consumer products manufactured from black plastics containing PBDEs and other brominated flame retardants.[90]

Due to national and international restrictions, PBDEs have been largely replaced by non-PBDE organohalogen flame retardants as well as organophosphate flame retardants. Emerging evidence on non-PBDE organohalogen flame retardants demonstrates concerns with child brain development. For example, exposure to hexabromocyclododecane (HBCD) has been associated with reduced cognitive function in adolescents,[91] while tetrabromobisphenol A (TBPPA) has been shown to have neuroendocrine and neurobehavior toxicity in animal studies.[92]

Organophosphate Flame Retardants - Recent studies evaluating the neurodevelopmental effects of organophosphate ester flame retardants (OPEs), note concerns for a range of adverse outcomes associated with exposures during pregnancy.[93] Over the last 6 years, studies of OPEs in children have found associations with reduced fine motor skills, behavior problems, reduced language abilities, lower working memory, and higher risks of attention disorders.[94] [95] [96]

Bisphenols - Bisphenol A (BPA) is a high production volume chemical with an estimated 5-6 billion pounds being produced annually, mostly used in polycarbonate plastics.[97] The neurotoxicity of BPA and its primary replacement chemicals, bisphenol S, bisphenol F, and bisphenol AF (BPS, BPF,BPAF) have been studied extensively in animal and cell models.[98] [99] [100] A systematic review of BPA rodent exposure during pregnancy, infancy, or adolescence reported deficits in memory or cognitive function.[101]

Human studies of bisphenols showed that BPA exposures contribute to ADHD, autism, depression, emotional problems, anxiety, and cognitive disorders in children.[102] Additionally, early BPA exposure has been associated with hyperactivity in boys and girls.[103]

Less is known about the more recently introduced BPA substitutes, although prenatal BPF exposure has been associated with lower IQ scores in 7-year-olds[104] [105] and neurodevelopmental delays in infants,[106] while BPAF exposure may have neurodevelopmental impacts in infants.[107] Human studies that examined the impact of multiple bisphenols showed greater contribution to neurodevelopmental impacts from the substitutes than from BPA.[108] [109] Likewise, comparison animal studies suggest that BPA replacement chemicals are as or more neurotoxic than BPA itself.[110]

Issues of Regrettable Substitutions

It is critical that we prevent harm to children's brain health by eliminating non-essential uses of plastics and harmful classes of chemicals, rather than trying to eliminate toxic compounds one by one.[111]

Numerous compounds can be used for the same purpose in plastics, and generally when one is eliminated, another is selected. As described above for phthalates, bisphenols, and flame retardants, the replacement chemicals often prove to be equally or more neurotoxic than the initial chemical additives, referred to as regrettable substitution.

For example, consider U.S. population exposure to the neurotoxic classes of plastics additives described above:

- Exposures to di-n-butyl phthalate (DnBP), BBzP, and DEHP have declined, while exposures to replacement phthalates such as DiNP, diisobutyl phthalate (DiBP), and DEHTP have increased.[112]

- Similarly, as BPA was phased out, levels of BPS and BPF in people have risen, and all compounds have very similar structures and thus similar modes of toxicity.[113]
- As PBDEs are phased out, OPE flame retardants have become ubiquitous in people and are now found at even higher levels in people than during peak exposure levels to PBDEs.[114]

Recommendations for Strengthening the Global Treaty on Plastics Pollution

We call for a strong plastics treaty that protects the health of children's developing brains by reducing the production and use of plastics and subsequent generation of plastic particles, and by preventing the harmful effects of plastics throughout their life cycle. An effective treaty will include legally binding provisions to:

1. **Substantially reduce and cap plastics production** toward elimination of single-use plastics and other non-essential uses of plastics;

2. **Phase out use of the most toxic plastic polymers**, including polyvinyl chloride, and polystyrene;

3. **Phase out use of neurotoxic chemical classes as additives in plastic**, including at a minimum, brominated and chlorinated flame retardants, organophosphate ester flame retardants, phthalates, chlorinated paraffins, UV stabilizers, and bisphenols.

    a. Governments should start by immediately **banning these chemical classes** from use in plastic food contact materials.
        i. A recent review of different types of interventions intended to reduce people's exposures to bisphenols and phthalates found that policies that restrict the use of phthalates and BPA in goods and packaging resulted in widespread, long-term decreases in exposures, while interventions aimed at dietary changes were much less effective in reducing exposures.[115]

    b. It is imperative to **ban classes of toxic additives in plastics** to avoid regrettable substitution.
        i. In some cases, there are alternative solutions to using chemicals at all, as with changes to California state regulations that enabled furniture manufacturers to meet flammability standards without use of flame retardant chemicals.[116]

4. **Ban intentionally added nanoplastics and microplastics** in products such as cosmetics, cleaning products, and toys;

5. **Require full transparency and public disclosure** of information in accessible forms that include identification and reporting of all chemicals used in the production of plastics as well as plastics additives;

6. **Ensure that disposal and recycling of plastics does not result in releases of toxic substances** into the environment, and that toxic substances are not present in products made from recycled plastic;

7. **Prevent incineration (which by definition includes pyrolysis and gasification) of plastics**—including "chemical recycling," "advanced recycling," and "waste-to-energy" schemes, which are not true recycling and merely perpetuate the toxicity of plastic.

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Project TENDR is a program of The Arc, a national non-profit organization advocating for and with people with intellectual and developmental disabilities and serving them and their families.

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