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How Environmental Toxicants Affect Cognitive Development of Children Aged 5-12 Years Old

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ABSTRACT

Children's cognitive development is increasingly put at risk due to ubiquitous environmental toxicants, threatening their physiological and cognitive health. Moreover, such environmental toxicants have further reached food and water resources, causing developmental delays which are profoundly unavoidable. This literature review studies how environmental toxicants might negatively affect the cognitive development of children aged 5-12 years old. The purpose of this paper is to spread awareness of the dangers that children are facing due to the increasing level of environmental toxicants. Throughout the paper, negative associations were found between most of the environmental toxicants and developmental cognitive test scores. Furthermore, the paper highlights the environmental injustices that create disparities in children's cognitive health.

Introduction

According to the World Health Organization, the diagnosis of cognitive illness among children is vastly increasing along with industrial rapid growth (2018). While concerns about children's physiological health increased due to increasing environmental toxicants, the fact that they also pose a threat to children's cognitive health is neglected due to their invisible and obtrusive manifestation.

Studying such a topic will allow us to learn more about risk factors to children's cognitive growth and provide a path for a new policy to protect child development. Maintaining healthy cognition is a crucial component as it allows them to think, learn and remember which is an important feature to perform daily activities and learning (NIH National Institute on Aging (NIA), 2020). With compromised cognitive functioning, a child may encounter difficulties while following instructions or learning at school which leads to poorer educational, health, and economic outcomes at the population level. Ultimately, this review will provide evidence for the presence of an invisible threat to children's cognitive development.

Literature Limitations

Literature proposes toxicants have a direct relationship with declined cognitive development, however, it doesn't highlight the disparity that such toxicants are distributed among different populations such as those with lower vs higher Socio-Economic Status (SES). It's imperative that we consider how low SES populations are more influenced by toxicants as industrialization typically localizes in low-income areas. Closely, low-income neighborhoods and low-income countries are more likely to have fewer laws protecting their residents from environmental toxicants (*What is environmental racism and how can we fight it?,* 2020). This also has wide implications on WEIRD vs. Non-WEIRD countries and systemic racism (Henrich et al., 2010).

Particular kinds of toxicants and their effects on children's cognitive abilities are analyzed in this paper which are arsenic, air pollution, fluoride, and lead. The core objective of the paper is to determine the effect of toxicants on

children's cognitive abilities and spotlight the unnoticed catastrophe we are currently situated in. Further, this study will discover new pieces of information and suggest further research to address the issue.

Defining Toxicant

Environmental toxicants are man-made, artificial toxicants introduced to nature during human activities (National Cancer Institute). According to the New York Health Foundation, there are 80,000 chemicals which an average person can be exposed to regularly within their daily activities in the United States (2018). Toxicants are exposed to humans in multiple ways: inhalation, digestion, and direct contact (New York State Department of Health, 2013). They are contained in daily used products such as household cleaners, cosmetic products, and more. Importantly, these figures are in the United States alone, a leading developed country with some of the strictest environmental laws on a global scale. This does not represent the inequity an underdeveloped country might face when measuring toxins experienced every day by individuals.

While an environmental toxicant is man-made as stated above, a toxin is a natural product that might be harmful to our bodies in the same or similar way (National Cancer Institute). Here, we focus on toxicants because those are more likely to be controlled and limited by our own actions.

Defining Cognitive Ability

According to the APA Dictionary of Psychology, cognitive ability indicates the skill involved in performing the tasks associated with perception, learning, memory, understanding, awareness, reasoning, judgment, intuition, and language (2022).

We can divide the process of cognitive development into two stages: childhood, 6-12 years old, and adolescents, 12-18 years old (Stanford Medicine, 2022). Particularly, children ages 6-12, start to develop a way of thinking called concrete operations. Concrete operational skill includes knowing how to do simple math: add, subtract, divide, sort, or transform objects and actions. Cognitive abilities are composed of variable mechanisms which allow thinking, taking in information, remembering, processing, planning, goal direction, and action, there are a wide variety of tests. Today, most literature examines the development of cognitive abilities on more specialized and transferable mechanisms such as Executive Functions (EF) (inhibition, working memory, and cognitive flexibility) to closely examine the foundations upon which they are built (Miyake et al., 2002). Less commonly, some literature still relies on a holistic IQ measure focused on reasoning, cultural knowledge, and abstract thinking (Blair, 2017). While EFs are more representative of math abilities and future success, they are largely influenced by development, in contrast to IQ measures which are less variable throughout development, yet they still provide some insight into negative environmental influence. The literature referenced in this paper uses IQ to examine cognitive abilities affected by toxicants, however, we recommend EF to be used for future direction as it provides a clearer lens on external influence on various foundational developmental cognitive stages. Throughout the paper, cognitive abilities are measured by standardized tests on intellectual, verbal, motor, visual-spatial, vocabulary, memory, and speech abilities.

Methodology

First, search terms were distinctly identified by making inclusion and exclusion criteria to define the study population. The main keywords included in the inclusion criteria were environmental toxins, children aged 5-12, and cognitive development, extended keywords can be found in appendix A. Exclusion criteria included the following: anyone outside the age of 5-12 years and clinical populations which didn't include a control group. The study extraction process was administered with a digital database, jstor, using the advanced search function. Keywords from the inclusion

criteria were put into the advanced search and studies with related titles were filtered out. Then, only studies with relevant abstracts were selected. See appendix B for further details on extracted papers.

Results

Air pollution

Multiple studies have revealed the association between children exposed to air pollution (Nitrogen Dioxide; NO2) and impairments in cognitive abilities. National Air Toxics Assessment (NATA) child-level pollution values used in the study by Clark-Reyna et al. include air toxicants that cause cancer, respiratory, and neurological diseases (Environmental Protection Agency, 2013). A study by NATA revealed a significant ($p<.01$) negative correlation ($r=-.08$ to $-.21$) with lower Grade Point Average (GPA) among fourth and fifth-grade school children in El Paso, Texas, U.S. Moreover, the mother's education exhibited the second strongest positive correlation ($r=.31$, $p<.01$) with children's GPA (Clark-Reyna et al., 2015).

A study done in Rome revealed that the major factors that determined full-scale IQ (tested by the Wechsler Intelligence Scale for Children-III, a.k.a WISC-III) were maternal and paternal educational level, maternal age at birth, and number of siblings (2016). Regardless, nitrogen dioxide resulted in the decrease of two subtest scores: the information subtest and the arithmetic reasoning subtest. The results of other subtest scores showed a weak association with NO2 exposure (Daniela Porta et. al, 2016).

Research done in Spain also examined the effect of NO2 using the Spanish version of the McCarthy Scale of Children's Abilities (MSCA) which gives standardized test scores for cognitive abilities including quantitative, verbal, memory, perceptual performance, and motor skills. Their analysis showed that NO2 exposure greater than 24.75$\mu g/m^3$ significantly affected the general cognitive ($p=0.05$) and perceptual performance ($p=0.04$) scores. Children exposed to NO2 higher than 24.75$\mu g/m^3$ had 4.19, 6.71, 7.37, and 8.61 points decrease in general cognitive score, quantitative, working memory and gross motor areas, respectively (Carmen Freire, 2010). After the model was fully adjusted for multiple variables, NO2 exposure showed weak negative associations with all the MSCA areas except for motor skills (Carmen Freire, 2010). The study area had little industrial activity and the source of pollution was vehicles, which begs the question of what consequences are left for larger industrial environments.

Arsenic

Another study examined Mexican school children near a metallurgic smelter complex discovered that Arsenic exposure harms children's cognitive development. It revealed an inverse association between the level of Arsenic in urine (UA) and complex cognitive processes like memory, problem-solving, and attention (Rosado et. al, 2007). Children with higher urine arsenic presented with lower scores on 7 out of 11 standardized tests that tested cognitive ability. This relation even appeared at a lower level than the declared safe amount of Arsenic exposure which was 50$\mu g/L$. Additionally, SES exhibited an inverse association with Arsenic exposure (Rosado et. al, 2007).

Gail A. Wasserman and coauthors examined intellectual function through WISC-III in Bangladesh to examine the cognitive effects of arsenic exposure through water (Wasserman, 2004). After the covariate adjustments for paternal occupation, the negative association remained solid by explaining 4.33, 0.89, and 3.88% of the variance in performance, verbal, and full-scale raw scores respectively. Children with exposures more than 50µg/L received distinctively lower performance and full-scale scores compared to children with exposures lower than 5. 5µg/L.

Fluoride

Barberio et al. found no association between fluoride exposure and parental or self-reported survey on the diagnosis of learning disability after adjustment for key confounders (2017). However, each urinary fluoride, creatinine-adjusted urinary fluoride, specific gravity-adjusted urinary fluoride, or fluoride concentration of tap water in unadjusted models showed an association with a learning disability. Association between creatine-adjusted urinary fluoride and diagnosis of Attention Deficit Disorder (ADD) appeared in the unadjusted model (p=0.003) but soon reduced to non-significant (p=0.107) after creatine adjustment (creatine adjust differences in urinary concentration). Of note, they found that children with and without learning disabilities did not differ in urinary fluoride measures (Barberio et al., 2017).

Lead

Studies on how lead exposure may have a negative influence on children's health have been consistently debated. Nevertheless, recent data indicated that even children with relatively low blood lead concentration are at risk of reduced cognitive ability such as IQ deficits and poor academic performance.

In the past, low-dose of lead exposure was considered non-lethal until a significant amount of observation discovered that higher levels of lead in teeth resulted in cognitive impairments such as difficulty following classroom instruction, unruly behavior, greater distractibility, and reduced auditory and verbal processing, attention, and IQ scores particularly on verbal components. Surprisingly, these patterns were seen within the acceptable standards of lead exposure.

It is also found that blood lead levels and IQ have a significant inverse relationship. There was a 0.46-point decrease in IQ for each microgram per deciliter in an increase in lifetime average blood lead concentration.

Koller et al. warned that even a "safe" amount of lead exposure may lead to neuron damage (2004). Using hair tissues to demonstrate lead-arsenic exposures, they accounted for 5% of the variance in reading achievements, 7% of spelling achievements, and 8% of visual-motor achievements. Conversely, improvements were shown in children with a learning disability who were nutritionally counseled to reduce lead and calcium levels (Koller et al., 2004).

Environmental Injustices

Throughout the review, SES also appeared to influence the differences in the cognitive abilities of children. SES and cognitive ability always had a positive relationship, noting that research supports environmental more than biological factors are responsible for this relationship. Communities in poverty tended to have 35% higher matter emissions than the overall population (Wilis, 2018). Also, people of color made up half the population of the area near dangerous chemical plants. Chemical facilities were found twice as often in communities of color compared to white neighborhoods and people living there were suffering from negative health impacts of the emissions (Center for Effective Government).

Closely, it's reported that even though child lead exposure in the U.S. is decreasing, children of color and low-income families are still disproportionately suffering from lead poisoning (Known to be toxic for a century, lead still poisons thousands of Midwestern kids, 2022). Children from low-income families who live in houses that were built before 1978 are particularly in danger since lead-based paints and housing components were banned after 1978 (Populations at Higher Risk, 2021). Thus they have a greater chance to be exposed to leads.

Regrettably, children of immigrants or refugees from less-developed countries were found to be at higher risk of lead exposure due to looser rules and policies regarding lead exposure and usage (Populations at Higher Risk, 2021).

This environmental racism disproportionately burdens people of color and low-income communities, and puts them at significant health risk from hazardous pollution and thus future disadvantages which they themselves cannot control. In order to solve this matter, it's important to prioritize basic human rights for healthy living conditions before any economic or technical benefits, as those supersede one's ability to prosper and innovate. Constant actions of raising voice and awareness of the problem prove to be critical.

Discussion

The purpose of this paper was to investigate how environmental toxicants affect the cognitive development of children aged 5-12 years old. Throughout the paper, we discovered that 3 out of the 4 environmental toxicants explain the lower cognitive abilities responsible for outcomes in standardized tests.

Children of color, and children from low-income families in wealthy countries and low-income countries were at higher risk of toxicant exposures due to industrialization within specific communities and looser regulations negatively impacting the environment surrounding them. It's our moral obligation to fight against environmental injustices for a more equal society. Every child has the right to grow up in a safe environment and develop positive chances in life. A healthy environment plays a big role in developing physical and mental health which is a critical component in raising a child as a healthy member of society (Environmental Child Rights). Further, it's for the benefit of every country's progress and economic growth to improve the development of their population to ensure the next generations are well-equipped to innovate and lead the future. More research and improvements are needed on such topics for equal opportunities for every child. It's every child's right to be protected from any harm and to have a healthy start in life. Because cognitive health is inconspicuous, more attention and caution are needed.

Conclusion

Among the four environmental toxicants examined, this paper revealed that three of the environmental toxicants (air pollutants, arsenic, and lead) are associated with lower cognitive abilities in children. Additionally, research pinpoints the stronger effects such toxicants have on lower SES and underrepresented groups.

Such a finding advances understanding of a child's development of cognitive abilities and the effects of daily used or exposed environmental toxicants. In the science field, it gives insights into the problematic situation the human race is in currently.

Limitations

Executive Functions

In this paper, we synthesized research that used standardized tests to measure cognitive abilities rather than components of EF. However, in the future, we hope that more research will use components of EF rather than standardized cognitive scales as EF provides a detailed understanding of each cognitive developmental stage throughout childhood (Miyake et al., 2002; Ardilla, 2018). EF skills include mental processes that help children control their behavior and attention, delay gratification, resist impulses, remember new information and engage in goal-directed behaviors which allows us to better understand an individual's capacity in cognitive abilities (Miyake et al., 2002; Ackerman, 2017).

WEIRD and Non-WEIRD countries

WEIRD is an acronym for Western, Educated, Industrialized, Rich, and Democratic, a term first used and created by Professor Joseph Henrich at Harvard University (Henrich, 2020). He has stated the term to measure psychological characteristics from different cultures and found that individuals from such cultures tend to have specific combined psychological characteristics (How the West became WEIRD, 2020). Non-WEIRD countries indicate countries that are the opposite of WEIRD countries, Not Western, Educated, Industrialized, Rich, and Democratic.

The initial intent of this paper was to divide the studies by WEIRD and Non-WEIRD countries to prevent pooling completely different countries together, allowing more fair observations of each country. However, there weren't enough studies found in order to divide the countries into those two categories. Because environmental and economic differences result in diverse cognitive processes, pooling the studies separately into WEIRD and Non-WEIRD countries will lead to more accurate results and deeper analyses in the future. We hope to find more research conducted on Non-WEIRD countries to better understand their vulnerabilities and suggest ways of assisting them.

Appendix A

Toxin-related keywords	'Phthalates'; 'Mercury'; 'CO2'; 'methane'; 'Toxi*' ; 'chemical*'; 'Pollut*' ; 'environment*' ; 'contamin*' ; 'polluted'; 'envrionment*'; 'Traffic' ; 'cars' ; 'Industri*' ; 'industrial develop*' ; 'Industrial product*' ; 'industrial toxi*'; 'Air qualit*' ; 'air pollution'; 'Arsenic' ; 'Lead'
Cognitive development-related keywords	'IQ' ; 'Mental dis;der*' ; cognitive dis;der*' ; 'emotion* dis;der' ; 'development*' ; 'disorder*' ; 'Learning abilit*' ; 'learning disabilit*' ; 'learing delay' ; 'academic delay' ; 'Cognitive flexibilit*' ; 'cognitive abilit*'; 'ASD' ; 'Autism' ; 'Autism Spectrum' ; 'Autism spectrum dis;der'; 'ADHD' ; 'Attention deficit hyperactivity dis;der' ; 'Social delay' ; 'social abilit*' ; 'social develop*'; 'Speech delay*' ; 'speech dis;der*'; 'Emotion* delay*' ; 'emotion* disorder*' ; 'emotion* intelligen*' ; 'emotion* defici*' ; 'emotinoal develop*'
Age-related keywords	'Aged 5-12' ; 'Preschooler*' ; 'Elementary' ; 'elemantary school student*' ; 'Toddler*' ; 'Child*' ; 'Kid*' ; 'Pre-adolescen*' ; 'First grade*' ; '1st grade*' ; 'Second grade*' ; '2nd grade*' ; 'Third grade*' ; '3rd grade*' ; 'Fetus*' ; 'fet*stage'

	'Pregnancy' ; 'Developing' ; 'early childhood' ; 'young child*'

Appendix B

Name (Year)	Author(s)	Age	Toxicants examined	Cognitive function examined	Test used	Outcomes
Fluoride exposure and reported learning disability diagnosis among Canadian children (2017)	Amanda M. Barberio, Carlos Quiñonez, F. Shaun Hosein and Lindsay McLaren	3-12	Fluoride	Learning disability, ADD diagnosis, ADHD diagnosis	Survey (parental or self-report)	No association found between fluoride exposure and learning disabilities. A significant association was found between ADD diagnosis and the unadjusted regression model but soon disappeared in the adjusted model.
Residential exposure to air toxics is linked to lower grade point averages among school children in El Paso, Texas, USA (2016)	Stephanie E. Clark-Reyna, Sara E. Grineski and Timothy W. Collins	8-13	Air toxics	Academic performance	Grade Point Average(GPA) gathered by a survey from primary and secondary caretakers	A significant negative correlation was found between all 8 of the air toxic variables and lower GPA.
Arsenic Exposure and Cognitive Performance in Mexican Schoolchildren (2007)	Jorge L. Rosado et al.	6-8	Arsenic	Memory, attention, problem-solvin g, vocabulary processes	Wechsler Intelligence Scale for Children Revised Mexican Version (WISC-RM), ...	Association of urinary Arsenic(UA) and several cognitive tests, independent from socio-demographic variables.
Recent Developments in Low-Level Lead Exposure and Intellectual Impairment in Children (2004)	Karin Koller, Terry Brown, Anne Spurgeon and Len Levy	6-16	Lead	Intellectual	Abbreviated Stanford-Binet Intelligence Scale	Blood lead levels and IQ have a significant inverse relationship. There's a 0.46-point decrease in IQ for each microgram per deciliter, increasing lifetime average blood lead concentration.
Air Pollution and Cognitive Development at Age 7 in a Prospective Italian Birth Cohort (2016)	Daniela Porta et al.	7	Air pollutants	Intellectual	Wechsler Intelligence Scale for Children-III	Association was found between constant pollution of NO2 during childhood and verbal area of cognitive development.

The consequences of exposure to developmental, neurological, and respiratory toxicants for school performance: a closer look at environmental ascription in East Baton Rouge, Louisiana (2013)	Helen Scharber, Cristina Lucier, Bruce London, Anna Rosofsky and John Shandra	Elementary, middle, and high-school students	Air pollutants	School Performance	School Performance Score (SPS) including	Found negative and significant between the measure of pollutant and school performance scores.
Main and interaction effects of metallic toxicants on classroom behavior (1985)	Mike Marlowe et al.	Elementary school students	Lead, arsenic, mercury, cadmium, and aluminum	Class behavior	Walker Problem Behavior Identification Checklist (WPBIC) done by teachers	egression analysis showed a positive association between the metal concentration and WPBIC scores (acting our, disturbed peer relation, immaturity).

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