Title
Socio-Demographic Patterning of Phthalate Burden in the U.S. (2001-2016)

Author
Benoit, Gabrielle Eva

Publication Date
2023

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA

Santa Barbara

Socio-Demographic Patterning of Phthalate Burden in the U.S. (2001-2016)

A thesis submitted in partial satisfaction of the requirements for the degree Master of Arts in Geography

by

Gabrielle Eva Benoit

Committee in charge:

Professor Susan Cassels, Chair

Professor Elizabeth Ackert

Professor Stuart Sweeney

June 2023

The master's thesis of Gabrielle Eva Benoit is approved.

Elizabeth Ackert

Stuart Sweeney

Susan Cassels, Committee Chair

June 2023

ABSTRACT

Socio-Demographic Patterning of Phthalate Burden in the U.S. (2001-2016)

by

Gabrielle Eva Benoit

For most humans, environmental exposure to toxicants begins as early as the moment of conception and accrues differently based on where a person lives, the nature of their work, and a variety of other socio-economically linked behaviors. A toxicant of particular interest are phthalates – the chemicals used to make plastics flexible and durable. They are found in clothes, furniture varnishes, toys, pharmaceuticals, food containers, and personal care products - to name just a few sources of exposure. Phthalates can make their way into bodies through ingestion, inhalation, and dermal absorption, and the breakdown of them within bodies can be measured as phthalate metabolites in urine. The specific physiological mechanisms linking phthalate exposure to health outcomes are still being deciphered, although it is abundantly clear that they pervade all aspects of the environment and our bodies, resulting in negative health outcomes. We study the level of the metabolite, mono-ethyl phthalate (MEP), in urine samples of children and adult participants in the National Health and Nutrition Examination Survey (NHANES), years 2001-2016. We have chosen mono-ethyl phthalate as our biomarker indicating exposure to phthalates because it is one of the most abundant phthalate metabolites present in human urine; it is the primary metabolite of diethyl phthalates (DEP). We ask which socio-demographic characteristics are associated with higher phthalate levels in urine within children and adults. Socio-demographic characteristics we examine include: age, gender, education, race/ethnicity, family income to poverty level, citizenship status. We expect that socio-demographically disadvantaged groups will have the highest levels of phthalate exposure. Factors such as education, SES, and gender influence where people live, (and their built environment exposures), their time-use patterns, their occupation, their

treatment at healthcare facilities, and their purchasing patterns. Those factors (where people live, time-use patterns, occupation, etc.) shape phthalate exposure. Consequently, we expect some of these groups to have more phthalates in their bodies than other groups. This research contributes to understanding health experiences outside of clinical definitions, drawing attention to structural vulnerabilities and the way that environmental toxicants are embodied in individuals and populations.

I. Introduction

Plastics were created in the 1940s, and the time period from then to the present has been labeled by some researchers as "the plasticene" because of the ubiquitous and enduring nature of plastics in modern society (Campanale et al., 2020). There is a brewing public health crisis related to microplastics, yet due to a lack of immediately conclusive science that links the wide variety of plastics (and their accompanying chemicals) to precise health impacts, scholars fear a delay in public health and policy action similar to the delays in tackling the crisis of smoking during the 1920s-1950s (Parker, 2022). Experts in the field of microplastics, endocrinology, and epidemiology encourage a more proactive approach to intervening in the growing problem of plastics.

Microplastics are plastics that are less than 5mm, about the size of a pencil eraser tip. As they break down into their chemical components, whether that is due to time, heat exposure, or a contact interaction, they pose greater threat to the health of humans. Phthalates are primarily used in the creation of plastics and solvents, and they are colorless, odorless, oily liquids. They do not chemically bind to the material they are added to, which leads to them being readily absorbed into the human body (NIH PEPH, 2021, Meeker et al., 2009). They can make their way into bodies through leaching into food or water that has been stored in container made with phthalates, exposure to airborne phthalate particles when working with materials such as plastic piping or synthetic furniture, and our skin can absorb phthalates from certain lotion and cosmetics (Zarus et al., 2021).

Phthalates are chemically disruptive through their ability to mimic and alter the synthesis and function of natural hormones (Fackelmann and Sommer, 2019). The extent of exposure that one has to phthalates – even before they are born, as phthalates do cross the placenta – creates the urgency to better identify populations most at risk of greater exposure to phthalates. Research has shown that within the range of what is normally found in indoor environments, phthalates are associated with allergic symptoms in children (Bornehag et al., 2004). Furthermore, research has suggested that exposure to phthalates leads to differential brain development and poor outcomes that can persist throughout the lifecourse. Li et al., conducted a longitudinal study of mothers and children, and assessed phthalate level in urine samples of the women prenatally (16 weeks gestational age), and the women-children pairs from birth to 8 years old (2019). They found that there was a correlation between phthalate metabolites and children's full scale IQ. Primarily leaning on animal studies, the mechanism thought to be at play are related to phthalates' endocrine disruptive nature; they impact the development of the thyroid, which creates hormones that are essential for the proper development of the hippocampus (Akaike et al., 1991; Breous et al., 2005; Huang et al., 2007; Meeker et al., 2007; Miodovnik et al., 2014; Moog et al., 2017). The lipid signal transduction pathway is hypothesized to influence brain development as well (Xu et al., 2007). An additional pathway that could be a mechanism through which the neurodevelopmental process is interrupted is via the anti-androgenic properties of phthalates (Andrade et al., 2006; Howdeshell et al., 2008b). Li et al., found that the cumulative urinary concentration of the phthalates di- ethylhexyl phthalate (DEHP), monobenzyl phthalate (MBzP), mono-ethyl phthalate (MEP), and mono-(3-carboxypropyl) phthalate (MCPP) in the 2 to 3 year olds were inversely associated with their IQ (2019).

The inverse relationship between increased phthalate levels prenatally and in early childhood and IQ persists in school age children (Factor-Litvak et al., 2014). Similarly, a longitudinal pregnancy and birth cohort (HOME) that enrolled pregnant women from Cincinnati, Ohio, reported that the greater the childhood phthalate index level was associated with more problem behaviors (Li et al., 2020). The problem behaviors were documented using the behavioral assessment system for children, second edition (BASC2), which assesses hyperactivity, anxiety, depression, leadership. They highlighted that the phthalates monobenzyl phthalate (MBzP), mono-carboxy-isononly (MCNP), and mono-ethyl phthalate (MEP) largely contributed to these associations.

The first national research to measure phthalate levels within population health data was conducted by the Centers for Disease Control in the NHANES 1999-2000. Testing for phthalates in urine samples has remained in the survey continuously since then. Even though evidence is mounting about negative effects of phthalates on health, we don't have population-level estimates of actual phthalate levels according to socio-demographic characteristics (social determinants of health). This paper seeks to determine which socio-demographic characteristics are associated with higher levels of phthalate in urine, observed in NHANES, years 2001-2016. The final sample size is 19,113. We are exploring our sample stratified by age – 7,727 children and 14,622 adults. NHANES has been used to investigate the increase/decrease of urinary phthalate levels in the U.S. population over time, however, none have focused on the socio-demographic variation of urinary phthalates among NHANES participants, who are a representative sample of the U.S. population. We examine various socio-demographic characteristics – including education (of both the participants and household head), age, gender, race/ethnicity, family income to poverty level, and citizenship status. We expect urinary phthalate levels to differ by education, race/ethnicity, gender, citizenship status, and income level because these factors shape exposure to phthalates through area of residence, built environment, time-use trends, healthcare interactions, and purchasing patterns. We hypothesize that historically disadvantaged groups will have higher levels of phthalates. We expect that lower levels of education will be associated with higher levels of mono-ethyl phthalate, even when holding other covariates constant; minority racial groups and females will be associated with higher levels of mono-ethyl phthalate; non-U.S. citizenship status and those earning lower incomes will be associated with higher levels of mono-ethyl phthalate.

II. Conceptual Framework

Social determinants of health frameworks can inform expectations for how phthalate levels may differ by socio-demographic factors. Social determinants of health refers to the upstream factors - those that are occurring prior to health care interventions - that contribute to health outcomes (CDC, 2022). An overarching concept is that social determinants of health are influential across the life course. There are vast differences among where people are born, grow, live, work, and age (Marmot, 2015). Frequently, there are wide disparities and inequities across these environments. While some aspects of the environment are determined by nature, many are impacted by historical, economic, and sociopolitical factors subjecting some populations to greater harm, and protecting other populations (Healthy People 2030).

A. Life Course Factors

Throughout the lifecycle, exposures influence health in differing ways. "Life course effects" captures the phenomenon of how both current and previous living circumstances (such as in utero effects) influences health status at every age, for each given birth cohort (Kawachi et al., 2002). Kawachi et al. (2002) outlines the leading hypotheses that connect lifecourse effects to the origins of health inequalities; *latent, pathway,* and *cumulative effects. Latent effects* identify how early life environments have far reaching effects during adulthood later in life. *Pathway effects* are the way in which early life environments influence the trajectory one embarks on, and consequently, health status over time. *Cumulative effects ensue* as a result of the dose-response relationship between the extent of exposure to detrimental environments across many years. These are independent and potentially additive effects; they are not mutually exclusive. Life course theory suggests that there are potentially critical time periods for development, during which, phthalate exposure could be more detrimental. Additionally, it can be inferred from life course theory that phthalate levels and/or the lagged effect of phthalates (such as fertility challenges) could vary among age groups.

i. Age

Age is potentially a critical predictor leading to phthalate burden. The timing of exposure to environmental hazards, particularly during sensitive developmental windows, can have exaggerated effects. Exposure to phthalates can begin prior to birth. Maternal exposure to phthalates are able to impact the developing fetus, due to their ability to cross the placenta (Qian et al., 2020). Once born, children's physiology causes them to be more vulnerable to exposure to toxicants. They are not in control of where, with what, and how they play, and naturally, young children explore with their mouths, causing them to be more exposed to ingestion of phthalates. They have developing organs and faster metabolisms, leading to greater potential harm of phthalates. Cumulative effects of susceptibility factors, such as age, heat, pollution, and poverty results in greater risk of health complications and less ability to make adaptations in behavior and the surrounding environment (Balbus and Malina, 2009, Pacheco, 2020). Within our sample of children, we will explore the relationship between the variable continuous age and phthalate level, in order to get a more fine gradient effect of age. Among the adults in our sample, we will explore the relationship between age and phthalate level using a categorical age variable, seeking to identify differences in phthalate level among young adults, middle aged adults, and older adults.

ii. Environment

All three of the life course arguments involve one's "environment." This leads to the question of what constitutes "environment?" A definition of environment is offered by the work of Karlsson et al. (2021), describing the "human exposome," which refers to the lifetime sum of environmental exposures. Through this lens, Karlsson et al. emphasizes the non-genetic factors that make up our physical and chemical "environment." "Environment" captures those that are social in nature, such as stress, behavior, education, policy, and those that are physical hazards, such as air pollution, drugs, radiation, microbiota, and psychosocial stress (2021). The physical and chemical environment that we are exposed to changes throughout our life course, and a way that our exposures get under our skin is through these environmental exposures modifying the expression of our DNA. Essentially all people, particularly those living in industrialized societies, have countless exposures to phthalates in their daily lives. To identify a few sources of phthalates in our environment consider the components of typical food packaging, water bottles, body products, and furniture. Even before birth, the environment is shaping human development, and more research is needed to understand, given the ubiquitous exposure to phthalates within our environment, how some populations within the same given city, for example, have differing levels of phthalates. Do environmental factors such as pollution and stress contribute to greater/less absorption of phthalates and more/less excretion? This paper is laying the foundation for future research, by first identifying the populations that have greater levels of urinary phthalates.

iii. Upstream and downstream factors

The distribution of people, and consequently, their unequal exposure to environmental hazards, is a function of their socio-demographics. Residential mobility and neighborhood choice are shaped by socio-demographic factors (Foster, 2017). Furthermore, neighborhood resources and processes are shaped by the socio-demographic composition of neighborhoods and communities, resulting in "unequal neighborhood environments by racial and economic status" (Candipan & Sampson, 2023). This is seen through decisions such as where to locate new schools, healthy grocery stores, and companies that pollute. For example, even amidst nationwide declines in pollution levels, on average, Blacks and Latinos are exposed to greater amounts of nitrogen dioxide (NO2) and particulate matter (PM2.5 and PM10) (Kravitz-Wirtz et al., 2016). There is a relationship between socio-demographic factors and social determinants of health, and both influence exposure and elimination of phthalates (see Figure 1).

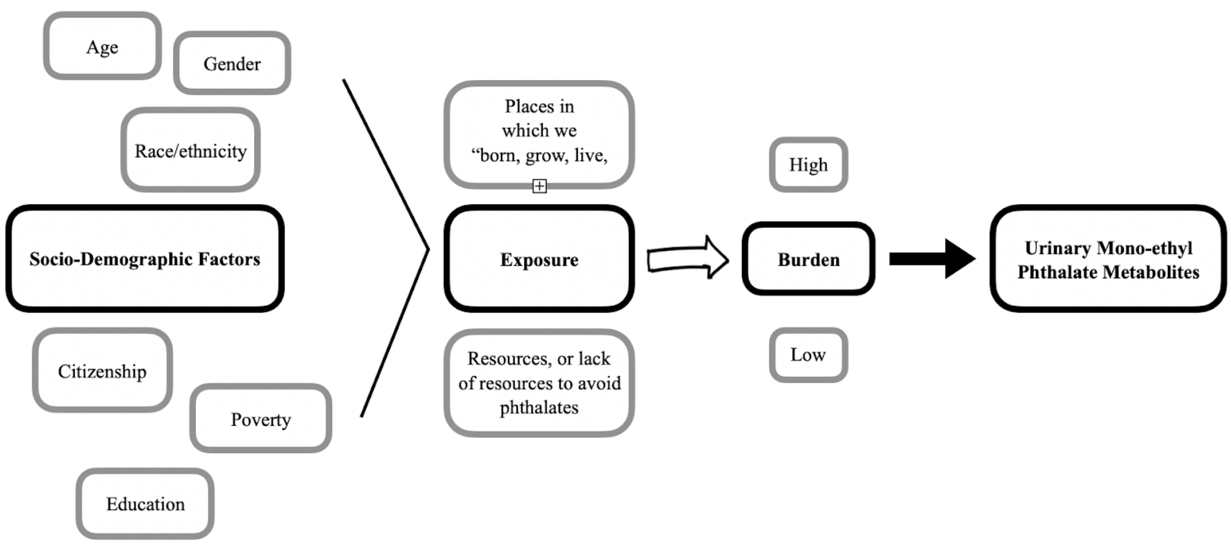

Figure 1. Conceptual framework linking socio-demographic factors to phthalate burden.

Broadly, health inequalities impact morbidity and mortality, resulting in patterns arising by a variety of factors including income, education, location of residence, occupation, sex, race/ethnicity. The mechanisms that underpin these patterns are complex and interrelated. "Upstream factors" refers to the social and structural contexts which shape the manifestation of health outcomes, whereas "downstream factors" refers to the immediate response and direct intervention to a health crisis (McKinlay, 1975). In order to demonstrate potential pathways that elucidate how health inequalities arise within individuals and populations at large, we will explore the role of education, race/ethnicity, and age as associated with phthalate levels.

iv. Education

Education is one of the most significant socio-demographic variables that correlates positively and consistently with healthy behaviors (Ross and Mirowsky, 2010). Education is a component of human capital, given that it allows for individuals to have greater knowledge, skills, and personal characteristics that position them to be more productive, typically in terms of economic attainment and economic mobility (OECD, 2020). Education cultivates the diligence to solve problems, to apply analytical skills to challenges, and provides opportunities to gain a sense of self assurance amidst adversity (Ross and Mirowsky, 2010). Through this understanding, the effects of education are far-reaching, beyond simply knowledge acquisition and preparation for employment. Lack of access to quality education, an upstream effect, may put people at greater risk of certain behaviors and exposures that lead to poorer health outcomes (Link and Phelan, 1995). For example, among middle aged Americans, higher education leads to more healthy behaviors, such as refraining from smoking and engaging in physical activity, in addition to more beneficial life adjustments following a new diagnosis, all of which point to socio-economic status offering opportunity to manage health more effectively (Margolis, 2013). Research has demonstrated that educational attainment is a critical predictor for risky alcohol consumption (Kaplan et al., 2015). This informs our work that tests whether education serves as a proxy for access to resources and therefore, an indicator of socioeconomic status influencing phthalate burden among certain NHANES participants. We expect that even when holding other covariates constant, lower levels of education will be associated with higher levels of mono-ethyl phthalate.

A downstream example of socio-demographics influencing phthalate burden is through access to lifestyle factors that can enable the body to work as an efficient detox system. Four common ways that phthalates are eliminated from the body are through the skin, liver, kidneys, and gastrointestinal tract (Anderson et al., 2001). Engaging in behaviors that allow these systems to function effectively, such as adequate exercise, hydration, minimal alcohol intake, and eating plenty of fiber could allow for the body to more quickly and completely eliminate phthalates in the body. It has been established that phthalates are associated with metabolic disruptions, including obesity, insulin resistance, and diabetes (Radke et al., 2019, Gaston and Tulve, 2019). Possibly, some phthalates get taken up by fat cells in the body and then gradually excreted via the urine over time, in addition to those phthalates that take the direct route. The process of *urinary* metabolites accumulating though is contrary to the knowledge that the relatively short half life – some sources report 5 hours, other 12hr. We expect that those with higher educational attainment will have less exposure to phthalates, and consequently, a lower level of mono-ethyl phthalate.

v. Citizenship

There are 40 million immigrants in the U.S., which represents nearly a fifth of immigrants worldwide (Budiman, 2020). Mexico is the largest source of immigrants, composing 25% of all immigrants living in the U.S. (Gonzalez-Barrera and Krogstad, 2019). In research regarding diversions within immigrant health frameworks, it is revealed that the medicalization of inequalities allows policy makers to hide behind an equity agenda without truly addressing the fundamental causes of health (Garcia et al., 2021). Garcia's research reinforces the importance of assessing the demographic variable, citizenship status, within our models. Social structures, institutional behavior, privilege, and power varies widely for those of immigrant descent. They potentially have fewer flexible resources such as knowledge, money, prestige, and beneficial social connections. This has led to us exploring the relationship between citizenship status and phthalate levels. We anticipate that non-U.S. citizens will have higher phthalate levels.

vi. Race/Ethnicity

Another socio-demographic variable that we expect to be correlated with phthalate burden is race/ethnicity. This expectation is not because of a biological mechanism, but rather because of the social and structural systems that provide unequal access to resources and knowledge to non-white populations. Race is not a biological category, it is a social and cultural category. The Human Genome Project found that the amount of genetic diversity that we observe within races is actually larger than what we observe across races (Duello et al., 2021). However, differential treatment within medical facilities persists. There is evidence that quality of medical care is inferior for racial minorities, and the disparity in the effectiveness of access to medical care varies across SES gradients (Ross and Mirowsky, 2010).

A case study that demonstrates this phenomenon is found among women with uterine fibroids. Uterine fibroids are benign (noncancerous) growths within the uterus that can be entirely asymptomatic or cause a variety of symptoms including heavy menstrual bleeding, pelvic pain, urinary disruption, and backaches (Louie, 2022). Some risk factors identified with increased incidence of uterine fibroids include diet and lifestyle behaviors such as a diet high in red meat, a diet low in green vegetables and fresh fruit, alcohol, and vitamin D deficiency (Louie, 2022). These downstream "choices" could be rooted in neighborhood deprivation constraining the choices available to individuals. Neighborhoods that are primarily Non-Hispanic Black are spatially disadvantaged; regardless of their socioeconomic composition, they are consistently associated with overwhelmingly disadvantaged surroundings (Sharky, 2014). While there is still a lack of research regarding what definitively causes fibroids, a known risk factor is race/ethnicity. Black women are more likely to have fibroids, and more severe symptoms, than any other racial group (Louie, 2022). Emerging research has shown that phthalates are positively correlated with uterine volume, and likely associated with fibroid outcomes (Zota et al., 2019). Black women with uterine fibroids are twice as likely to undergo hysterectomies as opposed to minimally invasive options compared to white women with uterine fibroids (Mostafavi, 2020). Racial/ethnic disadvantage is embedded in interactions with healthcare providers and can result in: 1) lack of access to regular visits, 2) fewer resources to manage symptoms, or 3) reduced sets of treatment options.

A similar pattern of lack of timely, effective, and sufficient health care could be seen in the treatment of other symptoms that can arise from exposure to phthalates, such as allergies, attention disorders, and infertility, furthering the detrimental effect of phthalate burden. This supports our choice to examine race/ethnicity as a variable of importance determining phthalate burden, and can motivate awareness of disparities, in addition to initiating more targeted interventions to help alleviate underserved communities.

B. Motivation

Through an approach that is informed by social determinants of health and life course theory, with an understanding of "environment" in the most all-encompassing sense of the word, we find an abundance of motivation demonstrating the need for our work. We are running two fully stratified models by age to identify key characteristics of populations with the highest levels of urinary mono-ethyl phthalates, since it appears that the processes of exposure differ significantly by age. This work will serve as a proof of concept for identifying populations that elicit further inquiry into the social and structural systems that are resulting in their disproportionate phthalate burden, and consequently, inform policies that remedy the situation.

III. Data and Sample

We use the publicly available National Health and Nutrition Examination Survey (NHANES), years 2001 to 2016 to investigate the relationship between socio-demographic characteristics and the urinary metabolite, mono-ethyl phthalate. NHANES was the first program in the United States to begin collecting phthalate samples within a nationally representative sample. The CDC surveys about 5,000 people in 15 different counties across the U.S that results in a nationally representative sample of the civilian, non-institutionalized U.S. population. One person in the study represents about 65,000 other individuals like themselves across the country. We use data from 2001-2002, 2003-2004, 2005-2006, 2007-2008, 2009-2010, 2011-2012, 2013-2014, 2015-2016 cycles of NHANES. Of the 40,000 participants in the sample across our years of study, there were 22,439 participants during these years that had phthalate metabolite measurements. There were participants with missing demographic data (n = 3,326), which resulted in a final sample size of 19,113 study participants. Descriptive statistics for the demographic variables in our sample of children are provided in Table 1A. Descriptive statistics for the demographic variables in our sample of adults are provided in Table 2A. We run bivariate models, then multiple regression models - one for children and one for adults. All estimates are weighted, with the sample weights accounting for the unequal selection probability of the complex NHANES sampling and the oversampling of selected population subgroups. Both the summary statistics and model results use the sampling weights.

Our variables of interest are: education, age, gender, race/ethnicity, ratio of family income to poverty level, and citizenship status. The outcome variable is mono-ethyl phthalate. Appendix 1 outlines the variables chosen for this analysis, the way they were originally coded, and the way we have re-coded them into logical categories. The phthalate metabolites were measured via spot urine samples collected in the Mobile Examination Center for a subsample within NHANES. The samples were stored at –20°C and shipped to the CDC's National Center for Environmental Health in Atlanta, Georgia for analysis. We restricted our sample to participants with phthalate metabolites measured and we also eliminated missing data from our sample. There is 1.4% missing data in the sample of children and 1.4% missing in the sample of adults.

Characteristic		N = 7,727
Age		
	Mean (SD)	11.4 (4.1)
Gender		
	Female	50%
	Male	50%
Race/Ethnicity		
	Mexican American	14%
	Non-Hispanic Black	14%
	Non-Hispanic White	57%
	Other Hispanic	7%
	Other or Multi	8%
Ratio of Family Income to Poverty Level		
	At poverty threshold	23%
	2x above	23%
	3x above	17%
	4x above	13%
	5x above	9%
	More than 5x above	16%
Citizenship Status		
	US citizen by birth or naturalization	96%
	Not US citizen	4%
Educational Achievement of Household Reference Person		
	College and beyond	26%
	Partial college and below	74%
Log(Mono-ethyl Phthalate)		
	Mean (SD)	3.92 (1.42)

Table 1 A. Descriptive statistics (weighted) of the 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

Characteristic		**N = 14,622**
Age		
	Young Adult ≥ 19, ≤ 25	14%
	Middle-aged >25, <64	69%
	Older Adult ≥ 65	17%
	Mean (SD)	46 (17)
Gender		
	Female	52%
	Male	48%
Race/Ethnicity		
	Mexican American	8%
	Non-Hispanic Black	12%
	Non-Hispanic White	68%
	Other Hispanic	5%
	Other or Multi	7%
Ratio of Family Income to Poverty Level		
	At poverty threshold	15%
	2x above	21%
	3x above	15%
	4x above	13%
	5x above	11%
	More than 5x above	25%
Citizenship Status		
	US citizen by birth or naturalization	91%
	Not US citizen	9%
Educational Achievement of Adult Participant		
	Less than HS/GED	17%
	High school grad/GED	23%
	Some college or AA	32%
	College grad or above	28%
Log(Mono-ethyl Phthalate)		
	Mean (SD)	4.25 (1.6)

Table 2A. Descriptive statistics (weighted) of the 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

A. Measures

The metabolite, mono-ethyl phthalate, is quantitatively measured in urine samples by harnessing two techniques: high performance liquid chromatography and electrospray ionization-tandem mass spectrometry (HPLC-ESI-MS-MS). The detailed protocol is described in the Laboratory Manual for NHANES (NCHS, 2015). Previous research has demonstrated that using urinary metabolites rather than air samples reduces exposure misclassification, which further strengthens our use of urinary phthalates for our analyses (Adibi et al., 2008, Hoppin et al., 2002). Urinary mono-ethyl phthalate values in the sample are heavily right-skewed. All of the regression results use the log-transformed phthalate values so that model errors are approximately normal and hypothesis tests are valid. Summary measures for the untransformed and transformed mono-ethyl phthalate among the children in the sample are in Table 1B, and the graphical representation is in Figure 2. Summary measures for the untransformed and transformed mono-ethyl phthalate among the adults in the sample are in Table 2B, and the graphical representation is in Figure 3.

(Untransformed) Mono-ethyl Phthalate

	Quantile	CI: 2.5	CI 97.5	SE
0.1	9.40	8.51	10.23	0.43
0.5	43.90	41.50	46.81	1.34
0.9	340.45	306.83	369.93	15.94

(Log) Mono-ethyl Phthalate

	Quantile	CI: 2.5	CI 97.5	SE
0.1	2.24	2.14	2.33	0.05
0.5	3.78	3.73	3.85	0.03
0.9	5.83	5.73	5.91	0.05

Table 1B. Summary measures for the untransformed and log transformed mono-ethyl phthalate among the children in the sample. 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

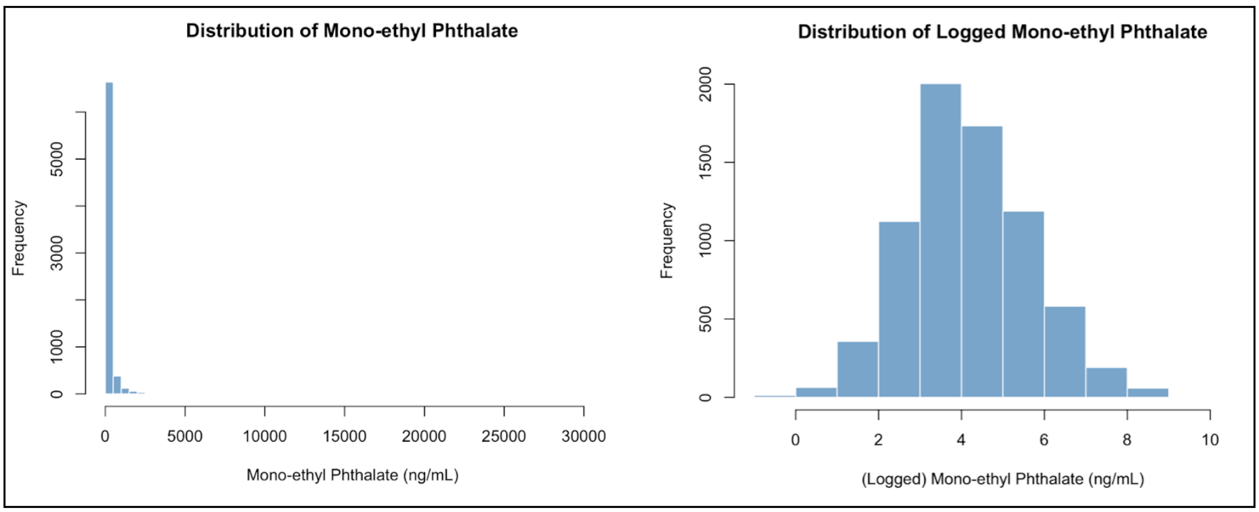

Figure 2 Distribution and of the untransformed mono-ethyl phthalate urinary metabolite and the transformed mono-ethyl phthalate among the children in the sample. 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

(Untransformed) Mono-ethyl Phthalate	Quantile	CI: 2.5	CI 97.5	SE
0.1	9.64	9.20	10.36	0.29
0.5	63.40	59.86	67.80	2.01
0.9	597.00	558.90	639.28	20.30

(Log) Mono-ethyl Phthalate	Quantile	CI: 2.5	CI 97.5	SE
0.1	2.27	2.22	2.34	0.03
0.5	4.15	4.09	4.22	0.03
0.9	6.39	6.33	6.46	0.03

Table 2B. Summary measures for the untransformed and log transformed mono-ethyl phthalate among the adults in the sample. 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

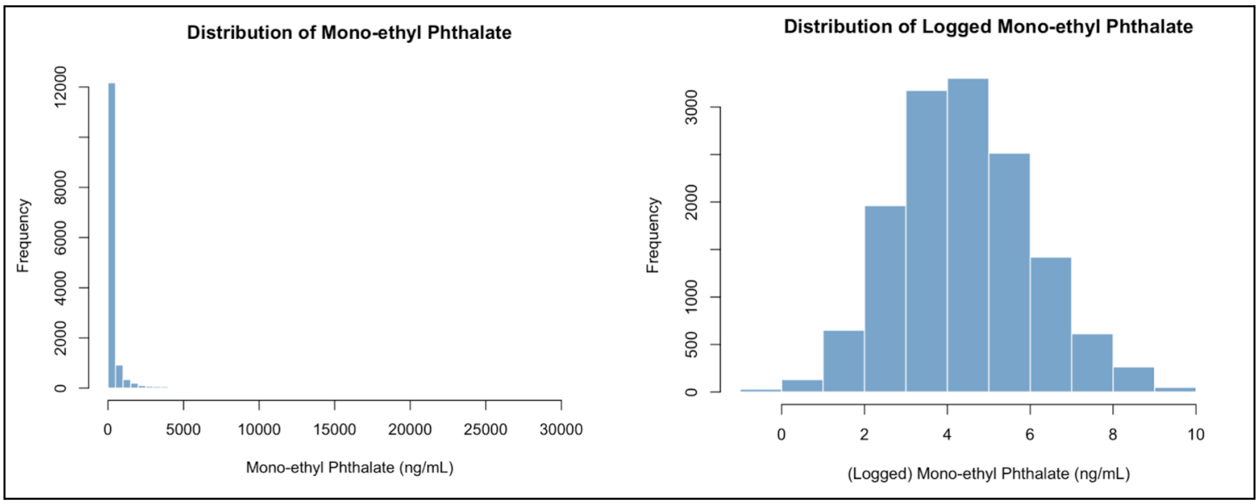

Figure 3 Distribution and of the untransformed mono-ethyl phthalate urinary metabolite and the transformed mono-ethyl phthalate among the adults in the sample. 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

Two variables that require background information are *household reference person,* and *ratio of family income to poverty level.* The household reference person is defined by NHANES as the first household member 18 years of age or older, who is listed on the household member roster and the member of the household that owns or rents the location where members of the household live. It is common for analysts to focus on the household reference person when they are characterizing the socioeconomic status of survey participants in that household (NCHS, 2015). We have chosen to use the education level of the household reference person in our analyses for the children model due to that variable consistently carrying over throughout the duration of our survey years, few missing data points (whereas the child participant's education level has far more education data missing), and due to theory reinforcing the idea that a household reference person's educational attainment potentially exerts power and control over the household's lifestyle factors, such as location and quality of residence, food security and nutrition, healthcare coverage and usage (NCHS, 2015).

The ratio of family income to poverty level reports a household's income in relation to whether it is at the poverty level, 2, 3, 4, or 5+ times the poverty threshold. Within our analyses, we organize family income to poverty level into the following categories: "at poverty threshold": $fpl \leq 1$, "family income 2x poverty threshold": $1 \leq fpl < 2$, "family income 3x poverty threshold": $2 \leq fpl < 3$, "family income 4x poverty threshold": $3 \leq fpl < 4$, "family income 5x poverty threshold: $4 \leq fpl < 5$, "family income more than 5x poverty threshold": $fpl = 5$. We chose to use family income to poverty ratio due to the availability of the data – we do not have access to income or occupation data. NHANES utilizes the Department of Health and Human Services poverty guidelines to calculate the ratio (National Center for Health Statistics, 2023). These calculations are used to determine eligibility for national programs such as Head Start, Supplemental Nutrition Assistance Program (SNAP), Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), and the National School Lunch Program. The poverty guidelines vary in relation to family size and geographic location. There are different guidelines for the 48 contiguous states, the District of Columbia, Alaska, and Hawaii, however, these state thresholds don't take local cost of living into account.

B. Analytic Strategy

We were informed by theory as to which variables would make most sense to include in our models. While gender was not a significant explanatory variable when exploring the bivariate relationships among the adult NHANES sample (however, it was for children), theory informs us that there are gender differences that would influence phthalate exposure, such as personal care routines, occupational exposure, and metabolism. Additionally, AIC model fit tests guided us in our model selection. We expect that phthalate levels are likely to differ by geographic location, however, the NHANES restricts geographic location below the national level (CDC/NCHS, 2018). In our future work, we plan to analyze the geographic variation using the restricted data. All statistical analyses were performed using R Studio, Version 2022.12.0+353, and $P<0.05$ was regarded as statistical significance.

Children: (population subset to children, age < 19)

$$\log(\text{mono-ethyl}_i) = \beta_0 + \beta_1 refED + \beta_2 age + \beta_3 gender + \beta_4 race/ethnicity + \beta_5 fpl + \beta_6 citizenship + \beta_7 year + \varepsilon_i$$

Where,

log(mono-ethyl) = logged mono-ethyl phthalate level (ng/mL)
$refED$ = household reference person education attainment (ref = college and beyond)
age = age of the participant (continuous)
$gender$ = gender of the participant (ref = female)
$race/ethnicity$ = race/ethnicity of the participant (ref = Non-Hispanic white)
fpl = ratio of family income to poverty level (ref = at poverty threshold)
$citizenship$ = U.S. citizenship status of the participant (ref = US citizen by birth or naturalization)
$year$ = year of participant survey (ref = 2001)
$\beta_{0,\ldots,}\beta_7$ are regression coefficients
ε_i = error term

Adults: (population subset to adults, age ≥ 19)

log(mono-ethyl) = $\beta_0 + \beta_1\, adultED + \beta_2\, age + \beta_3\, gender + \beta_4\, race/ethnicity + \beta_5\, fpl + \beta_6\, citizenship + \beta_7\, year + \varepsilon_i$

Where,

log(mono-ethyl) = logged mono-ethyl phthalate level (ng/mL)
$adultED$ = educational attainment of participants 20+ y.o. (ref = college graduate or above)
age = age of the participant (categorical, ref = middle-aged)
$gender$ = male or female listed gender of the participant (ref = female)
$race/ethnicity$ = race/ethnicity of the participant (ref = Non-Hispanic white)
fpl = ratio of family income to poverty level (ref = at poverty threshold)
$citizenship$ = U.S. citizenship status of the participant (ref = U.S. citizen by birth or naturalization)
$year$ = year of participant survey (ref = 2001)
$\beta_{0,\ldots,}\beta_7$ are regression coefficients
ε_i = error term

IV. Results

We estimated bivariate analyses for all socio-demographic characteristics that we hypothesized to be associated with phthalates. Table 3 and Table 4 show the model coefficients when not controlling for any other variables; simply examining the mean differences. Figures 3A and 3B show the visual depiction of the bivariate analyses among children in the sample, and figures 4A and 4B show the visual depiction of bivariate analyses among adults in the sample.

Variable	Coefficients	95% CI	P Value
Age			
continuous	0.10	0.09, 0.11	0.00
Gender			
Male	-0.14	-0.23, -0.06	0.00
Female (ref)			
Race/Ethnicity			
Non-Hispanic Black	0.88	0.75, 1.01	0.00
Mexican American	0.23	0.07, 0.40	0.01
Other Hispanic	0.47	0.30, 0.64	0.00
Other or Multi	-0.07	-0.23, 0.09	0.41
Non-Hispanic White (ref)			
Ratio of Family Income to Poverty Level			
2x above	-0.15	-0.26, -0.04	0.01
3x above	-0.18	-0.33, -0.03	0.02
4x above	-0.19	-0.36, -0.03	0.02
5x above	-0.23	-0.44, -0.03	0.02
More than 5x above	-0.48	-0.65, -0.32	0.00
At poverty threshold (ref)			
Citizenship Status			
Not U.S. citizen	0.18	-0.00, 0.36	0.06
US citizen by birth or naturalization (ref)			
Educational Achievement of Household Reference Person			
Partial college and below	0.47	0.34, 0.59	0.00
College and beyond (ref)			
Year			
2003	0.11	-0.10, 0.31	0.30
2005	-0.04	-0.23, 0.15	0.70
2007	-0.14	-0.35, 0.07	0.19
2009	-0.63	-0.82, -0.45	0.00
2011	-1.09	-1.37, -0.82	0.00
2013	-1.11	-1.29, -0.92	0.00
2015	-1.22	-1.43, -1.01	0.00
2001 (ref)			

Table 3 Bivariate associations between log-phthalate levels and socio-demographic characteristics. 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

Variable	Coefficients	95% CI	P Value
Age			
Young Adult ≥ 19, ≤ 25	0.13	0.01, 0.24	0.03
Older Adult ≥ 65	-0.09	-0.20, 0.01	0.08
Middle-aged >25, <64 (ref)			
Gender			
Male	0.02	-0.04, 0.09	0.50
Female (ref)			
Race/Ethnicity			
Mexican American	0.49	0.37, 0.61	0.00
Non-Hispanic Black	0.9	0.80, 1.00	0.00
Other Hispanic	0.54	0.38, 0.70	0.00
Other or Multi	-0.31	-0.46, -0.17	0.00
Non-Hispanic White (ref)			
Ratio of Family Income to Poverty Level			
2x above	-0.04	-0.15, 0.07	0.48
3x above	-0.11	-0.24, 0.03	0.13
4x above	-0.11	-0.24, 0.01	0.08
5x above	-0.17	-0.33, -0.02	0.03
More than 5x above	-0.28	-0.42, -0.14	0.00
At poverty threshold (ref)			
Citizenship Status			
Not US citizen	0.27	0.15, 0.38	0.00
US citizen by birth or naturalization (ref)			
Educational Achievement of Adult Participant			
Less than HS/GED	0.55	0.43, 0.68	0.00
High school grad/GED	0.48	0.37, 0.59	0.00
Some college or AA	0.36	0.25, 0.46	0.00
College grad or above (ref)			
Year			
2003	0.08	-0.10, 0.25	0.38
2005	-0.10	-0.27, 0.06	0.22
2007	-0.29	-0.44, -0.15	0.00
2009	-0.61	-0.75,-0.47	0.00
2011	-1.18	-1.35, -1.02	0.00
2013	-1.22	-1.37, -1.07	0.00
2015	-1.27	-1.43,-1.11	0.00
2001 (ref)			

Table 4 Bivariate associations between log-phthalate levels and socio-demographic characteristics. 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

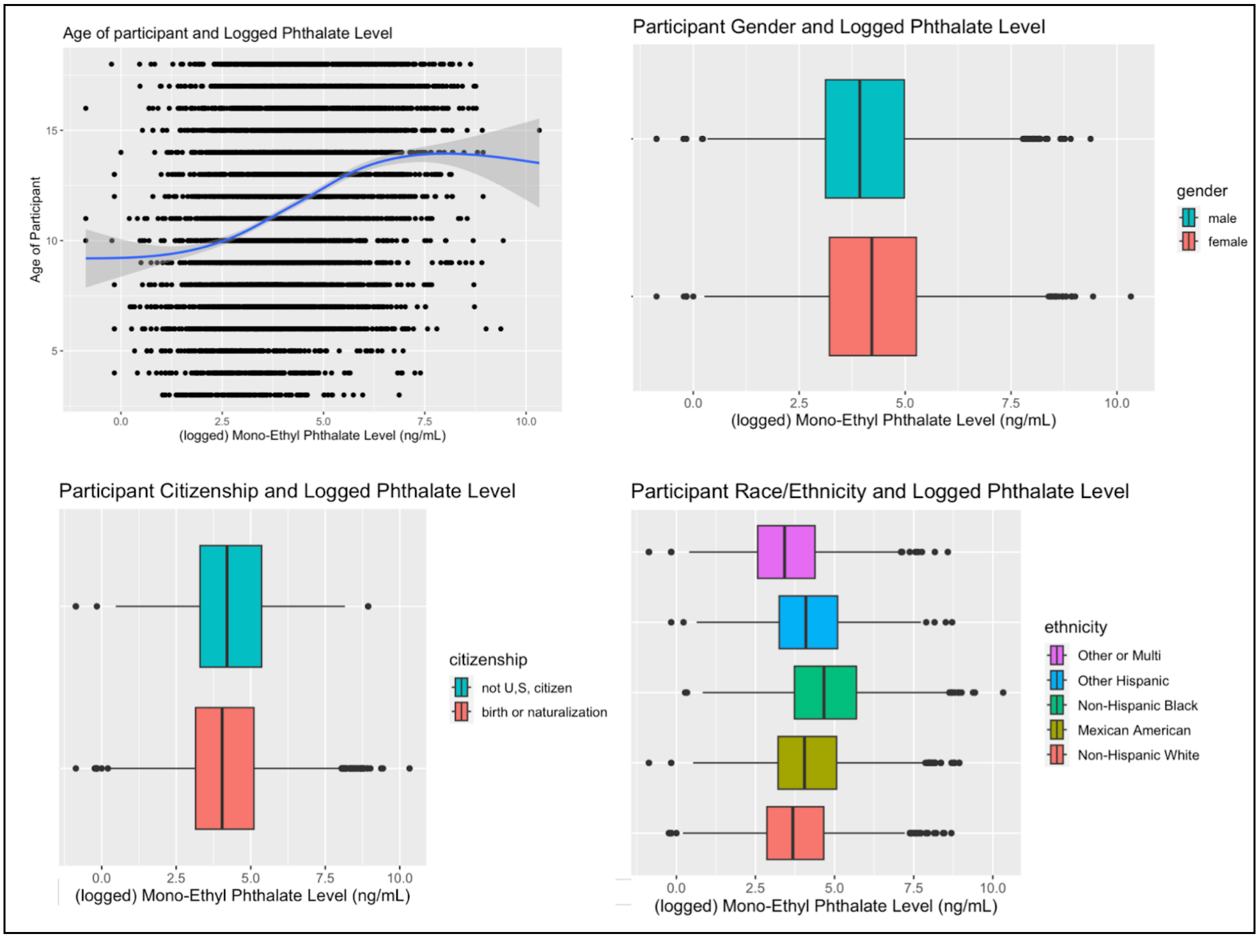

Figure 3 A Graphical representation of bivariate analyses of the variable of interest to be used in the multiple regression among the children in the sample. 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

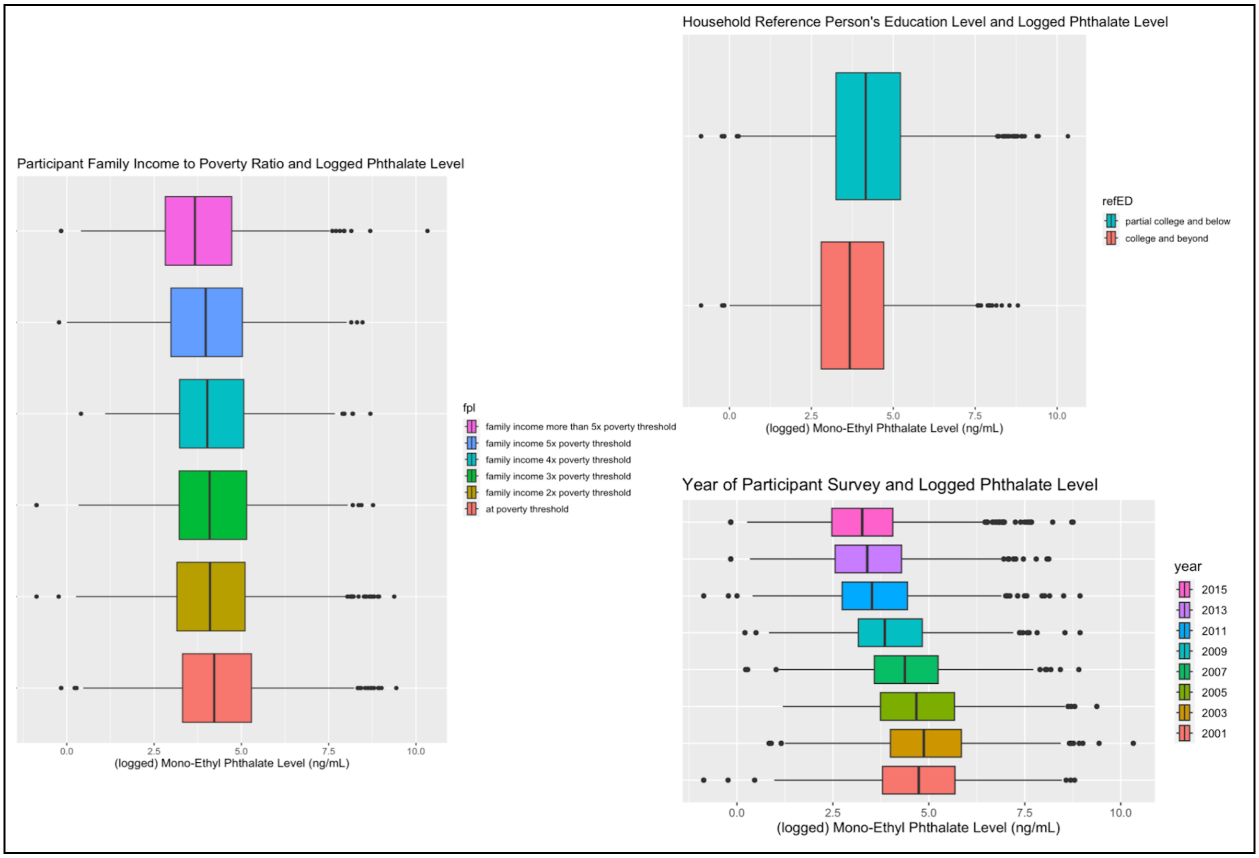

Figure 3 B Graphical representation (continued) of bivariate analyses of the variable of interest to be used in the multiple regression among the children in the sample. 2001-2016 NHANES: children (n = 6,632), age 3 - 18, and sampled for phthalates.

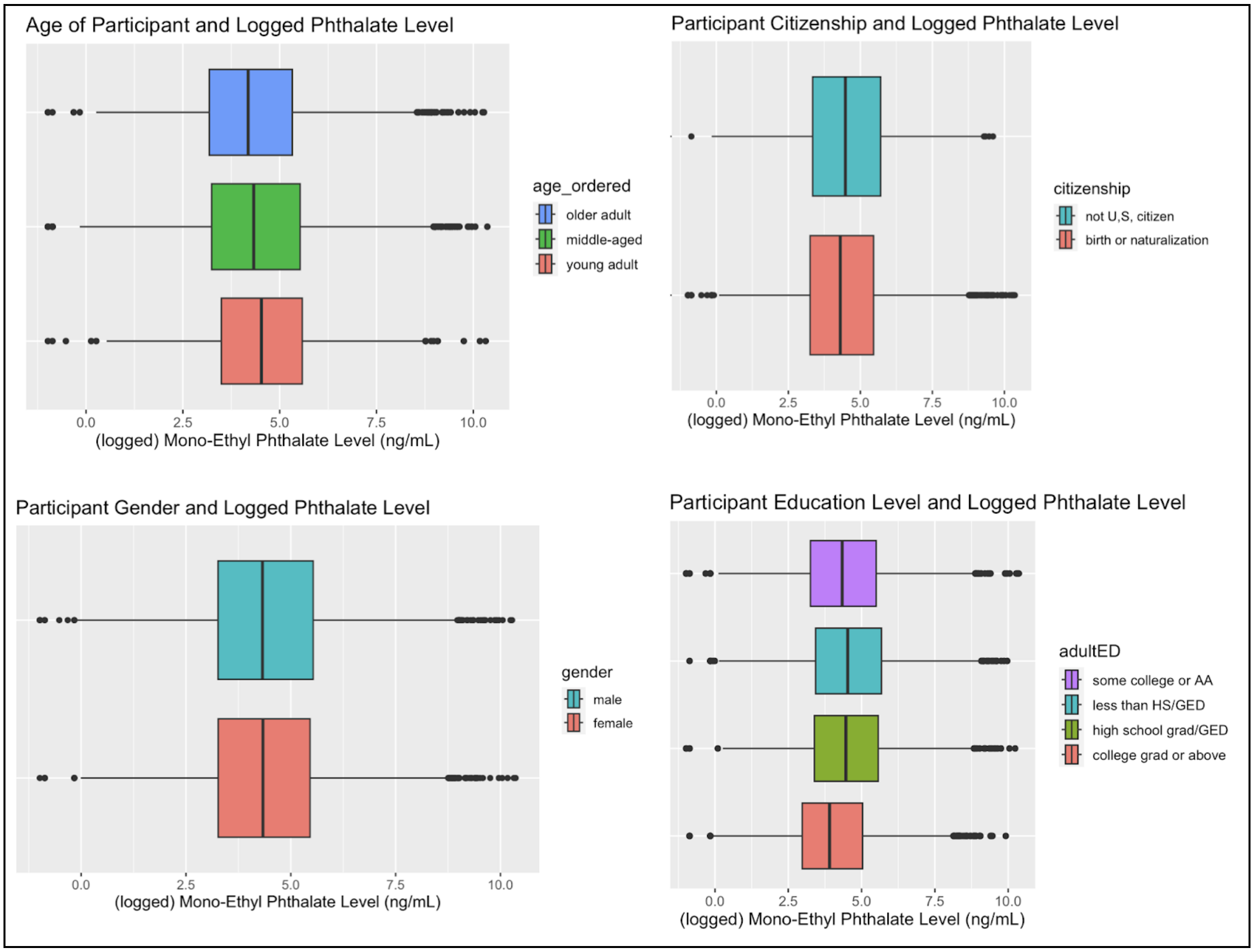

Figure 4 A Graphical representation of bivariate analyses of the variable of interest to be used in the multiple regression among the adults in the sample. 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

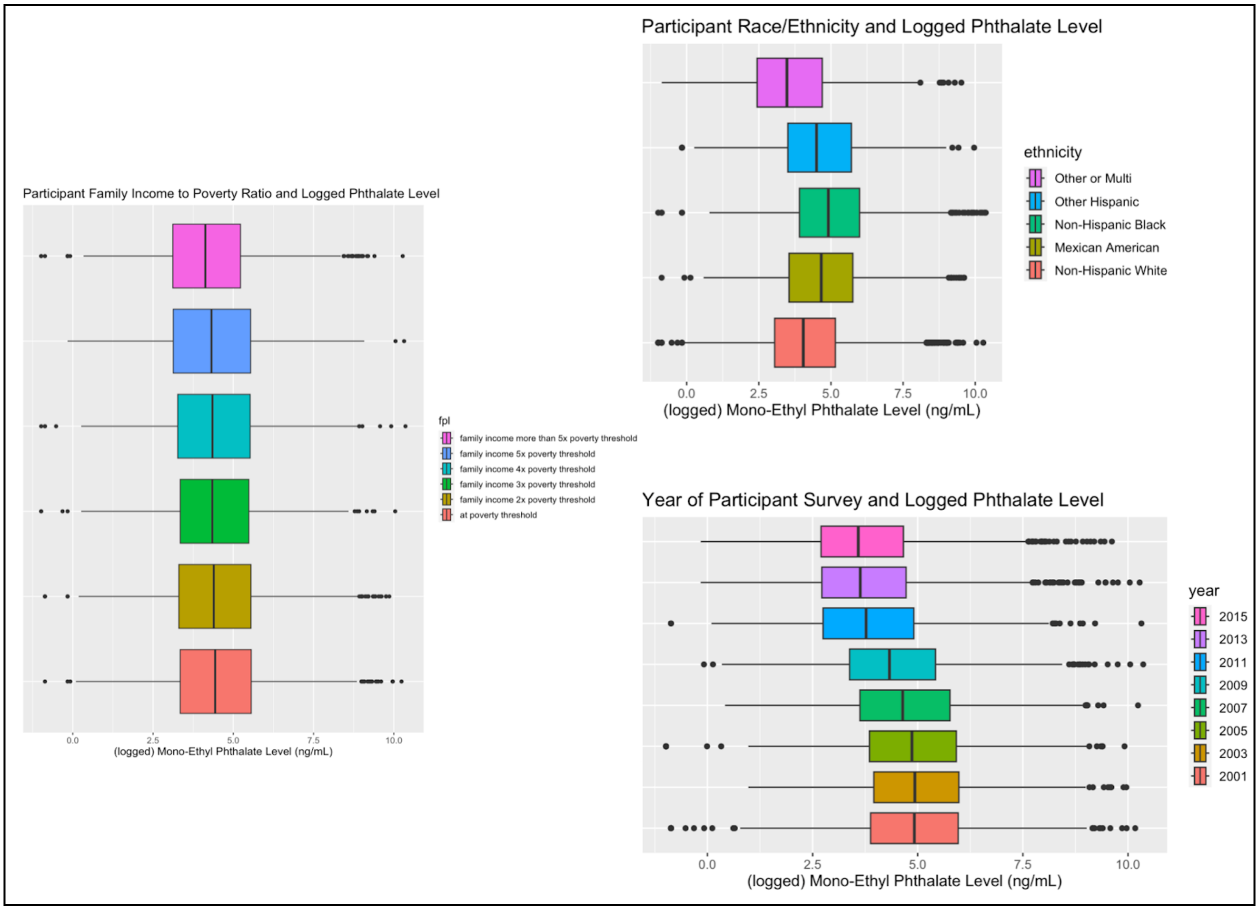

Figure 4 B Graphical representation of bivariate analyses of the variable of interest to be used in the multiple regression among the adults in the sample. 2001-2016 NHANES: Adults (n = 12,481), age 19 - 85, and sampled for phthalates.

Looking at those distributions, we see some patterns of differences in phthalates by socio-demographics. The bivariate analyses demonstrate that education level of the household reference person, participant's age, race/ethnicity, ratio of family income to poverty level, and citizenship status are significantly associated with levels of mono-ethyl phthalate in the urine of participants. We find that among children in the sample, lower household reference person educational attainment, older age, female gender, non-Hispanic white race/ethnicity, and earlier year of the survey is associated with increased phthalates. Among adults in the sample, we find that minority race/ethnicity, lower educational attainment of the participant, and earlier year of the survey is associated with increased phthalates. From these results, we created two regression models and reported on the estimated coefficients.

As previously mentioned, we run separate models for children and adults given differences in their physiology. The processes by which phthalates enter, harm, and leave the body differ for adults and children. See Figure 4 and Figure 5 for multiple regression models.

A. Phthalate patterns among children in NHANES

Results from the regression analysis are displayed in Figure 5. We find that many socio-demographic characteristics are associated with phthalate levels in children, independent of other control variables. First, as hypothesized, education of the household reference person was significantly associated with phthalate levels in children, with lower education associated with higher phthalate level. Participants less than nineteen years old, in a home with a household reference person that has attained partial college and below, have a predicted higher phthalate level: 0.24(SE 0.06) compared to participants that have attained college education or more schooling, holding other variables constant. Age of the child was also significantly associated with phthalate levels: each standard deviation increase in age predicted higher phthalate level of: 0.09 log mono-ethyl phthalate (SE 0.00). Gender and ethnicity were also significantly associated with phthalate levels in the urine of children. Holding other variables constant, children identifying as male, compared to females, had a predicted lower phthalate level of: -0.16(SE 0.04). Compared to Non-Hispanic white children, Mexican American children and other Hispanics had a predicted higher phthalates level of: 0.30(SE 0.06) and 0.50(SE 0.08), respectively. Non-Hispanic Blacks had a predicted higher phthalate level: 0.83(SE 0.05). Other or Multi-ethnic participants had a statistically insignificant predicted higher phthalate level: 0.08(SE 0.08). Results suggest that family income to poverty level and citizenship status are not significantly associated with phthalate level among children in our sample. However, the year the participant completed the survey is significantly associated with the expected phthalate level for the more recent years (2009-2015) as compared to the survey year of 2001-2002, which suggests that the year the participant took the survey significantly impacted their urinary phthalate level, holding all other variables constant.

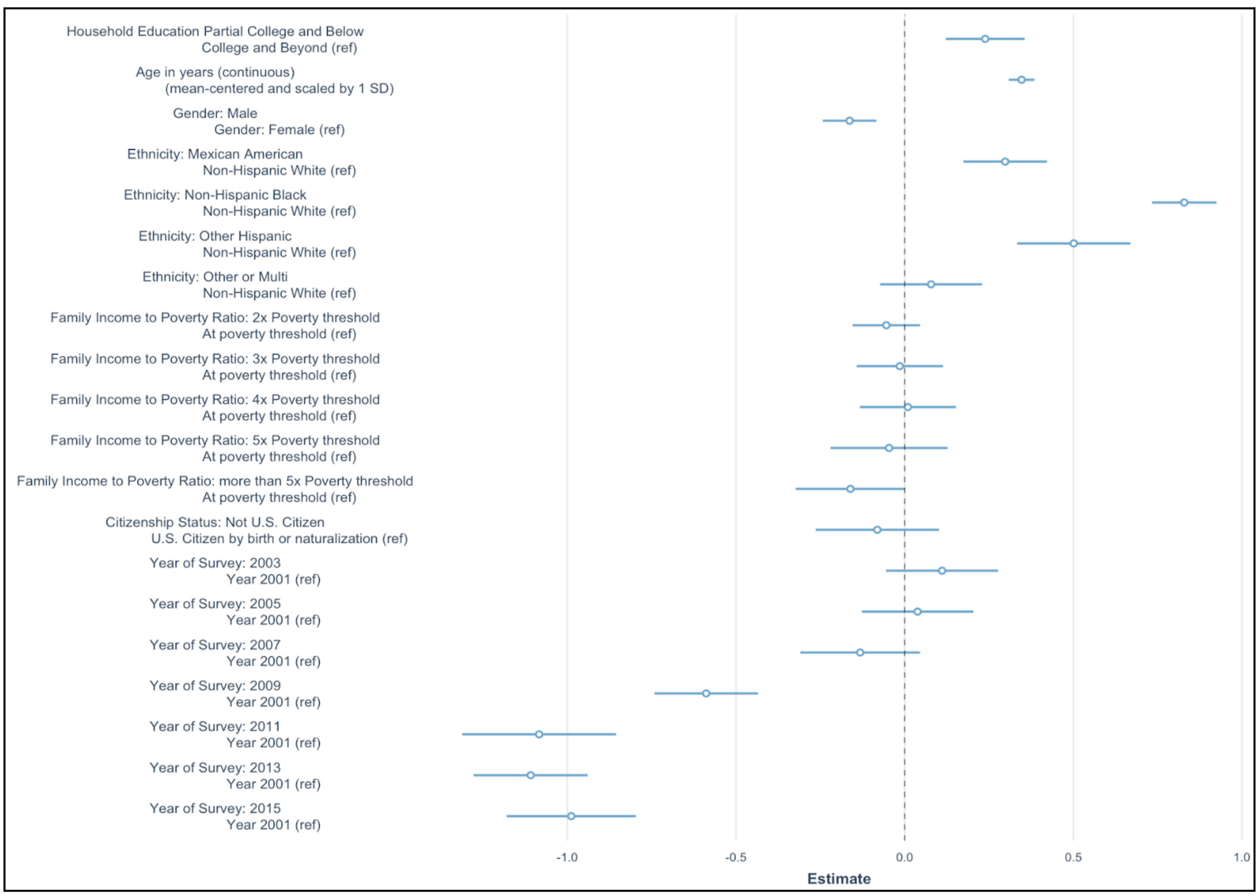

Figure 5. Forest plot showing multiple regression analysis of socio-demographic variables and phthalates among child participants. Coefficients with CI = 0.95. N = 6,632.

B. Phthalate patterns among adults in NHANES

Results from the regression analysis for adults are displayed in Figure 6. Gender and age among participants nineteen years and older did not result in statistically significant difference in phthalate level. There is a significant association between race/ethnicity and the level of phthalate in urine. Compared to Non-Hispanic whites, Mexican American and other Hispanic participants nineteen years and older have a predicted higher phthalate level: 0.43(0.05) and 0.58(0.08), respectively. Non-Hispanic Black adult participants have a predicted higher phthalate level: 0.91(SE 0.04), as compared to Non-Hispanic whites. Other or Multi-ethnic identifying adult participants have a predicted lower phthalate level compared to Non-Hispanic whites, holding other variables constant: -0.20(SE 0.07). Education is significantly associated with the level of phthalate in urine. Holding other variables constant, participants nineteen years and older that have an educational attainment of high school completion or GED have a predicted higher phthalate level compared to college completion and above: 0.32(SE 0.05). Those with an education attainment of less than high school completion or GED have a predicted higher phthalate level compared to college completion and above: 0.26(SE 0.06). Those with an education attainment of some college or associated degree have a predicted higher phthalate level compared to college completion and above: 0.28(SE 0.05). Family income to poverty level and citizenship status did not result in a statistically significant impact on predicted phthalate levels. However, the year the participant completed the survey is significantly associated with the expected phthalate level for the more recent years (2007-2015) as compared to the survey year of 2001-2002, which suggests that the year the participant took the survey significantly impacted their urinary phthalate level, holding all other variables constant.

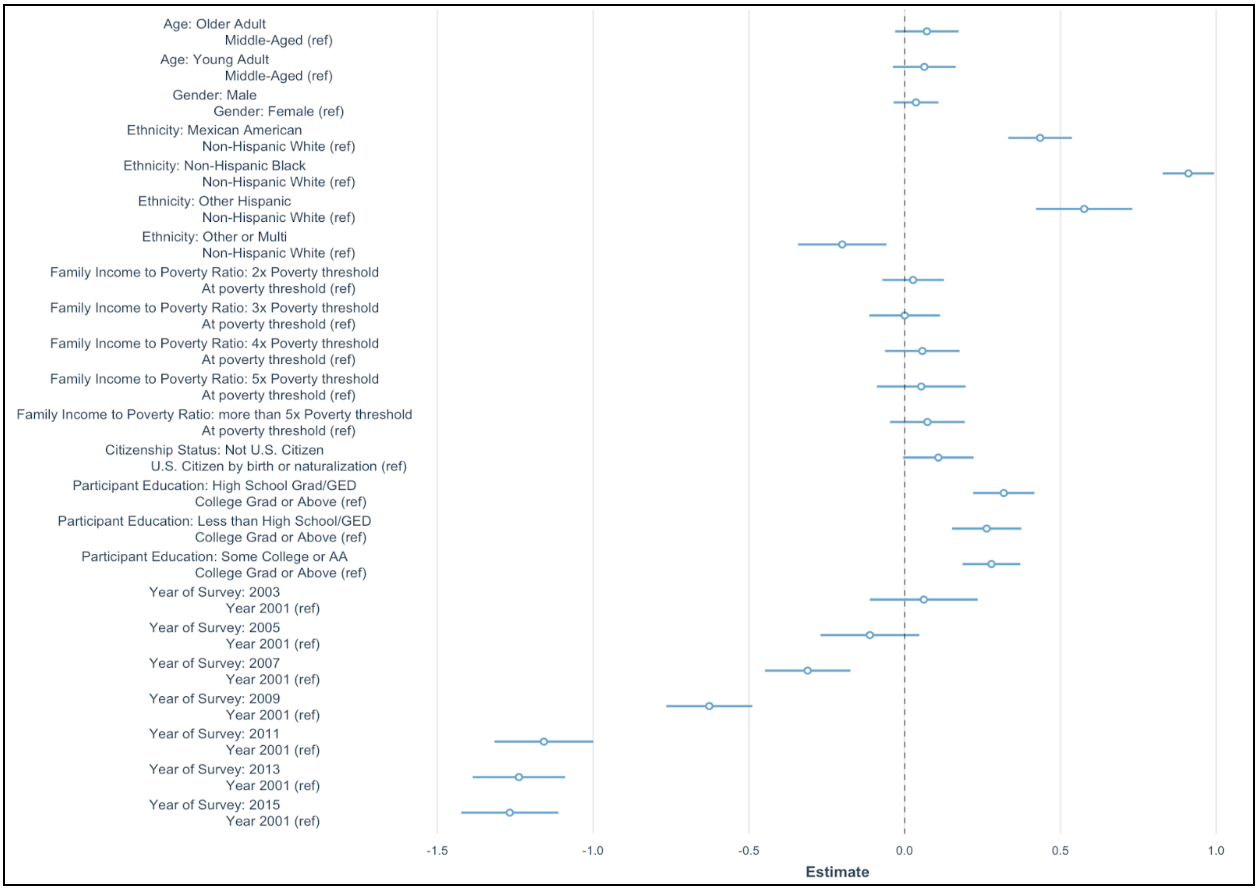

Figure 6. Forest plot showing multiple regression analysis of socio-demographic variables and phthalates among adult participants. Coefficients with CI = 0.95. N = 12,481.

V. Discussion

Our results suggest that several of the socio-demographic characteristics are associated with statistically significant differences in urinary phthalate levels, with a primarily finding that historically disadvantaged groups tend to have higher phthalate levels. We found similar results among the children in the sample and among the adults in the sample. Age, education, race/ethnicity, and year of survey all lead to statistically significant differences among levels of the variable. Generally, higher household head educational attainment is associated with lower phthalate levels among children living in the household. Similarly, among adults, higher levels of education were also associated with lower levels. Non-Hispanic white and those identifying as Other or Multi-ethnic have lower predicted phthalate levels compared to Mexican Americans. Non-Hispanic Blacks have higher predicted phthalate levels compared to Mexican Americans. Of note, however, is that in children, those identifying as Other Hispanic had higher predicted levels of phthalate, whereas this was not a finding in adults. Among adults, age and gender were not significant predictors of mono-ethyl phthalates, however they were among children. Within the children model, male gender was associated with lower predicted phthalate levels among children, as was younger age. Family income to poverty level was not found to be significant predictors of mono-ethyl phthalate, nor was citizenship status, among both models.

A. Education

Among children, higher household education levels predicted lower phthalate levels. In the adults model, compared to those who have an educational attainment of college completion and beyond, those that have an educational attainment of less than high school completion/GED, completed high school/GED, and those that have completed some college or an AA have a higher predicted phthalate level. This may be a result of lack of educational attainment and absence of associated knowledge, awareness, and lifestyle benefits. It is important to note that while education has a significant effect on predicted phthalate levels, family income does not, which was contrary to our expectations – we thought both education and family income to poverty level would be statistically significant. Possibly this is due to the benefits of education above and beyond the higher earning potential it offers. Ultimately, more research is needed to untangle the role of income, wealth, and relative poverty on urinary phthalate metabolites.

The findings in our work could be explaining the role education has, serving as a proxy for greater access to resources and higher socioeconomic status. Socioeconomic status is a composite measure that typically incorporates economic, social, and work status (income, education, occupation). There is a gradient in health that parallels socioeconomic status; it's not just lowest and highest, it's every step along the way (Marmot, 2017). However, recent research counters this theory, pointing out that there is a "glitch" in the trajectory of 'more education, more health' among those with "some college" rather than college completion (Zajacova et al., 2012). This informed our grouping of educational attainment among household heads as "partial college and below" and "college completion and above." Building upon the theory expressed in the life course approach, we chose to explore the relationship between a variety of socio-demographic characteristics and urinary phthalate level due to the understanding that engagement with healthy behaviors that position the body and mind to perform at its best is often rooted in structural barriers and facilitators that enhance or limit accessibility of knowledge, resources, and time. People of different class, race, and gender have dramatically different environments that lead to both immediate and delayed impacts to their health and well-being. The role of socio-demographic variables can be viewed through a spatial lens, seen as the clustering of populations based on race, educational attainment, and occupation, and as a result, patterns of neighborhood wealth and deprivation. Social organization has a far reaching influence on health.

Our data are showing a clear relationship between greater educational attainment and decreased phthalate burden. Whether this is a result of greater awareness of the dangers of phthalates, and therefore greater avoidance of phthalate-containing products, it is unclear and unable to be answered with our current data. Education could also be serving as an avenue to greater access to resources, resulting in subconsciously less exposure to phthalates, and a lifestyle through which the baseline health is superior and harm from phthalates is less detrimental, such as the work by Dolinoy et al., demonstrating that supplementing with folic acid muted the effect of BPA (2007). This suggests that there is a connection between the way that nutrition interacts with harm from phthalates, such as BPA, and this could be a nexus of intervention. Maternal behavior, such as dietary supplements, can mitigate the epigenetic impact of exposure to phthalates. There are many upstream factors that shape diet. Accessibility, cost, and knowledge of nutritious food are impacted by social policies that influence the quantity and location of stores in a neighborhood and the marketing practices that target certain vulnerable populations. Possibly there are other such nutrients that serve as protection against the endocrine disrupting effects of phthalates, and these might be more commonly eaten among those with higher socioeconomic status.

The role of education in health cannot be understated. In the coming years, those with greater educational attainment might also be those that will be exposed to more media and knowledge related to the harms of phthalates, and they may have the motivation, resources, and strategies to better avoid phthalates, resulting in less phthalate burden for themselves, but increasing the gap between those with knowledge, skills, and resources, and those without.

B. Age

We found that younger age among children is associated with lower predicted phthalate levels, however, among adults, age is not significantly associated with predicted phthalate levels. Among children, there appears to be a pattern of increasing phthalates in those of greater age, which signifies a cumulative effect occurring throughout childhood, but then we see a plateau once adulthood is reached, through the fact that age is not a significant predictor of expected phthalate level among adults.

C. Race/Ethnicity

Our work identified that across the board, those identifying as non-Hispanic Black had higher levels of predicted phthalate burden compared to Non-Hispanic whites. Those identifying as Mexican American and Other Hispanic also had higher predicted levels of phthalates compared to Non-Hispanic whites as well. Among children, identifying as other or multi-ethnic did not result in a statistically significant difference in phthalate level compared to Non-Hispanic whites, however, among adults, those identifying as other or multi-ethnic resulted in a statistically significant expectation to have the lowest level of expected urinary phthalates. According to the U.S. Census, the largest multiracial combinations in 2020 were “white and some other race.” When comparing the 2020 census to the 2010 census, the “white alone” category decreased and there was a marked rise in the “two or more races” category, leading us to consider the role of question design and and coding procedures in the results that we observe among Non-Hispanic Whites and other or multi-ethnic groups (Jones, 2022).

Environmental racism may explain these patterns we see among non-Hispanic Blacks, Mexican Americans, and Other Hispanics. A first step to alleviating these disparities is to gather the data and report who is unequally burdened in society, and how the ease of plastics and all the products they make possible, are simultaneously causing insidious harm when left unchecked and unregulated. The next steps of the research – adding in geocoded data for the participants – has the potential to elucidate underserved populations, paint a picture of the community within the context of their surroundings, and elevate the voices of populations bearing the brunt of the burden, receiving the least support, and enjoying few benefits, which, across our two models, are identified as people of color.

D. Citizenship Status

Within our findings, among children, there was no significant impact of citizenship status on the predicted level of urinary phthalates. However, among adults, those that are not U.S. citizens have a predicted higher phthalate level compared to U.S. citizens by birth or naturalization. It is likely that non-citizen children may have spent fewer cumulative years in another country compared to non-citizen adults, who likely spent large portions of their lives in a country other than the U.S. This leads us to believe that there needs to be greater attention focused on the upstream social determinants of health, such as education, socioeconomic equality, adequate housing, access to healthy food and health care, all of which come before the direct health outcome of phthalate exposure and the resulting higher urinary phthalates.

E. Year

We have included the variable "year" within our model due to the role that time of survey (i.e.: a survey taking place in 2007, or a survey taking place in 2014) has on the prevalence of phthalates and phthalate alternatives in society. Over the years, information has become increasingly accessible and digestible. Citizens are able to explore their own questions about their environment, health, and various phenomena, and then alter their decisions and behaviors according to their new knowledge. For example, vinyl shower curtains are a common source of phthalate exposure in the home, and the added aspect of hot temperatures leading to greater phthalate leaching compounds the exposure. However, in recent years, there is more awareness about this, and alternatives are available and marketed, such as curtains made of cotton, hemp, and sail cloth. With this in mind, we expected to see a relationship between year and expected phthalate level. Our results for adults reinforce the broader literature on this topic – more recent year results in decreased phthalate level among participants in our sample. However, among children, we see that the lowest level was for the 2013 survey year, and then an increase in 2015. This raises concerns about the emergence of look-a-like phthalates replacing banned phthalates in children's toys, food packaging, and other items geared toward children (Huo et al., 2023). Yet this is a hypothesis; further work is needed in order to identify a causal link between year of survey and policies within society.

F. Limitations and Future Work

While NHANES is the most comprehensive data source for longitudinal panel data of urinary phthalates, NHANES does not adequately categorize a handful of their demographic variables. They conflate race and ethnicity and they heavily aggregate data having many individuals falling into the category of "Other or Multi," for example, persons that identify as a race/ethnicity from Asia. The NHANES data combines racial and ethnic groups in non-logical ways, and muddles the possibility of understanding the nuances between different racial and ethnic populations. Additionally, our work is correlational, not causal. However, this work serves as a jumping off point for further research that has the potential to identify the differences in experiences and behavior between those identifying as non-Hispanic Black, and those identifying as non-Hispanic white and Other or Multi-Ethnic. What about their environment and perspective is detrimental or protective in relation to phthalate burden?

i. Analysis of Gender

Another language limitation that the NHANES poses is for "gender." The data for gender is not posed as a question, rather it is just "entered" by the interviewer as "male," "female," or "missing" [Interviewer Procedure Manual, page 69]. " It would be best if it was either gathered as "sex assigned at birth" or, it could be more inclusive than its current binary options by incorporating an option that allows self-identification of gender. This is all the more important due to the vast difference in personal care product usage, and consequently phthalate exposure, between people identifying as male versus those identifying as female (Braun et al., 2014).

ii. Policy

Policy has played a role in reducing the burden of certain phthalates within the population. This is why the variable "year" within our model is a critical piece in the prediction of urinary phthalate levels. Zota et al., studied the trend in phthalate exposure and explored how the concentration of phthalates in urine samples of NHANES participants have changed over time (2014). An example of a policy action that led to a marked reduction in phthalate burden in the U.S. population is the Campaign for Safe Cosmetics. This is a national science-based advocacy organization that strives to prevent breast cancer by creating awareness and motivating industry changes in order to eliminate environmental exposures linked to breast cancer. Zota et al., found that there was a decline for phthalates that are the biomarkers for chemicals that have been banned in recent years (DEP, DnBP, BBzP, and DEHP), however, they also note a modest increase for unbanned chemicals (DiBP and DiNP), and they found phthalates in all participants sampled (2014). This raises concerns about companies replacing banned chemicals with minorly different chemicals (look-a-likes) that evade the ban but exert a comparable harm.

The Environmental Protection Agency (EPA) is another potential point where policy intervention could raise the bar in terms of what chemicals are allowed to be in the materials that humans interface with where we live, work, and play. The Toxic Substances Control Act (TSCA) dictates that the EPA Chemical Data Reporting (CDR) gathers information from manufacturers every four years regarding the types, amount, end uses, and possible exposure to chemicals in commerce. However, there are many points in this process where manufacturers and chemicals can fall through the cracks and not be accounted for. Points of concern include that reporting is generally required for manufacturers producing 25,000 lbs or more per year and only for chemical substances listed in TSCA. Information on chemical data reporting is available at: https://www.epa.gov/cdr, however, more discussion is beyond the scope of this paper.

Our work only examines a single phthalate, mono-ethyl phthalate, in depth. In future work, we can incorporate multiple phthalates and explore the intersectionality of the various phthalate urinary metabolites and the cumulative effects as well. Our work serves to guide focus to populations that are most at risk of a single phthalate, mono-ethyl phthalate, which is one of the most abundant phthalate metabolites present in human urine; it is the primary metabolite of diethyl phthalates (DEP). DEP is found in insecticides, cosmetics, pharmaceuticals, toothbrushes, automobile parts, toys, and food packaging (New Jersey Department of Health, 2012). We expect that our results would be accentuated if we were to add in multiple phthalates to our analyses.

In this work is that we do not know the mechanisms through which socio-demographics are associated with phthalate levels. This research is correlational, not causal, and as with the race/ethnicity and gender variables, the education variables have missing data, which for these analyses, the missing data was omitted (N=3,131). While we have the education and family income to poverty ratio data, and they are closely related to typical types of work, we do not have occupation data, and therefore cannot make conclusions about the way in which occupational exposure influences phthalate burden.

Next steps include incorporating the restricted GEO coded files for the NHANES data, which would allow us to analyze the locations of participants, their phthalate levels, and their sociodemographic characteristics. Possibly, we could add in outside data sources related to topics such as water quality, polluting industry locations, highways, in addition to exploring the intersectionality of the variables within our model.

Incorporating additional urinary phthalates and geo-coded participant data would allow us to dive deeper into our understanding of how life course theory impacts exposure to environmental hazards and ultimately both immediate and latent health outcomes. Kawachi et al., outlines the ways health responds to factors across time and space, identifying "pathway effects," "latent effects," and "cumulative effects" (2002). This language allows us to conceptualize the socio-demographic patterning of phthalate burden that we are observing in the NHANES data, and anticipate the reinforcing effects that incorporating additional urinary phthalates and adding geo-coded participant data will have on our understanding of the disparities in phthalate exposure and burden at large.

VI. Conclusion

This research explored the socio-demographic patterning of phthalate burden among NHANES children and adults, who represent the general U.S. population, throughout the years 2001-2016. We analyzed urinary mono-ethyl phthalate levels in relation to age, gender, education, race/ethnicity, family income to poverty level, citizenship status, and year of survey in order to construct a model that is informed by features of social determinants of health. Our results reveal that historically disadvantaged groups – women, Non-Hispanic Blacks, Mexican Americans, Other Hispanics, and those with lower levels of educational attainment – have higher predicted phthalate levels, even when holding all covariates constant. Our work motivates continued research into the socio-demographic patterning of phthalate burden in order to reduce these disparities, and contribute to policies to improve the social and structural systems to cultivate well-being and limit toxicant exposure across all socio-demographic populations.

In Nancy Kreiger's book, *Epidemiology and the People's Health*, she proposes points of intervention for improving modern-day public health efforts (2011). She warns of the prevailing trend toward "lifestyle" and the concept of choice when considering individual health. While there are healthy and unhealthy behaviors, of course, the book highlights how the presence of "lifestyle" within the literature of public health didn't appear in great number until the 1990s; it is essential to unveil the social and structural systems that unequally offer certain lifestyles to certain populations, and therefore, improved health outcomes (Krieger, 2011, p. 146). This research is a call to the socio-demographic patterning of mono-ethyl phthalate burden within the United States - it showcases the way in which populations are at greater risk, and that national policy is essential in reversing the trend toward greater phthalate exposure. Due to how entirely plastics have infiltrated our modern lifestyle, a multi-pronged approach is necessary to mitigate the risk of phthalates in society. There needs to be (1) more rigorous industrial regulations and policy on what food products can be packaged in and what ingredients can be in personal care products, (2) consistent public health surveillance of phthalate exposure, (3) active interventions to reduce exposure among those identified as having a higher phthalate burden (low household education, black persons, people identifying as females, older individuals, and non-US citizens), and (4) health literacy programs regarding where and how phthalate exposure occurs. These interventions could reduce socio-demographic differences in phthalate levels, such as those uncovered by this research.

References

1. Adibi, J. J., Whyatt, R. M., Williams, P. L., Calafat, A. M., Camann, D., Herrick, R., Nelson, H., Bhat, H. K., Perera, F. P., Silva, M. J., & Hauser, R. (2008). Characterization of Phthalate Exposure among Pregnant Women Assessed by Repeat Air and Urine Samples. *Environmental Health Perspectives*, *116*(4), 467–473. https://doi.org/10.1289/ehp.10749
2. Akaike, M., Kato, N., Ohno, H., Kobayashi, T., 1991. Hyperactivity and spatial maze learning impairment of adult rats with temporary neonatal hypothyroidism. Neurotoxicol. Teratol. 13, 317–322.
3. Anderson, W. A. C., Castle, L., Scotter, M. J., Massey, R. C., & Springall, C. (2001). A biomarker approach to measuring human dietary exposure to certain phthalate diesters. Food Additives and Contaminants, 18(12), 1068–1074. doi: 10.1080/02652030110050113
4. Andrade, A.J., Grande, S.W., Talsness, C.E., Gericke, C., Grote, K., Golombiewski, A., Sterner-Kock, A., Chahoud, I., 2006. A dose response study following in utero and lactational exposure to di-(2-ethylhexyl) phthalate (DEHP): reproductive effects on adult male offspring rats. Toxicology 228, 85–97.
5. Balbus, J. M., & Malina, C. (2009). Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational & Environmental Medicine, 51(1), 33–37. https://doi.org/10.1097/JOM.0b013e318193e12e
6. Blount, B. C., Silva, M. J., Caudill, S. P., Needham, L. L., Pirkle, J. L., Sampson, E. J., Lucier, G. W., Jackson, R. J., & Brock, J. W. (2000). Levels of seven urinary phthalate metabolites in a human reference population. Environmental health perspectives, 108(10), 979–982. https://doi.org/10.1289/ehp.00108979
7. Bornehag, C.-G., Sundell, J., Weschler, C. J., Sigsgaard, T., Lundgren, B., Hasselgren, M., & H, ägerhed-E. L. (2004). The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case–Control Study. Environmental Health Perspectives, 112(14), 1393–1397. https://doi.org/10.1289/ehp.7187
8. Budiman, A. (2022, December 1). Key findings about U.S. immigrants. Pew Research Center. Retrieved March 20, 2023, from https://www.pewresearch.org/fact-tank/2020/08/20/key-findings-about-u-s-immigrants/
9. Bullard, R. D. (1993). The Threat of Environmental Racism. Natural Resources & Environment, 7(3), 23–56. http://www.jstor.org/stable/40923229
10. Braun, J. M., Just, A. C., Williams, P. L., Smith, K. W., Calafat, A. M., & Hauser, R. (2014). Personal care product use and urinary phthalate metabolite and paraben concentrations during pregnancy among women from a fertility clinic. Journal of Exposure Science & Environmental Epidemiology, 24(5), Article 5. https://doi.org/10.1038/jes.2013.69
11. Breous, E., Wenzel, A., Loos, U., 2005. The promoter of the human sodium/iodide symporter responds to certain phthalate plasticisers. Mol. Cell Endocrinol. 244, 75–78.
12. Burnham, K. P., & Anderson, D. R. (2004). Multimodel Inference: Understanding AIC and BIC in Model Selection. Sociological Methods & Research, 33(2), 261–304. https://doi.org/10.1177/0049124104268644
13. Campanale, C., Massarelli, C., Savino, I., Locaputo, V., & Uricchio, V. F. (2020). A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. International Journal of Environmental Research and Public Health, 17(4), 1212. https://doi.org/10.3390/ijerph17041212

14. Candipan, J., & Sampson, R. J. (2023). Diverging trajectories of neighborhood disadvantage by race and birth cohort from childhood through young adulthood. PLOS ONE, 18(4), e0283641. https://doi.org/10.1371/journal.pone.0283641
15. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2001-2002][https://wwwn.cdc.gov/Nchs/Nhanes/2001-2002/PHPYPA_B.htm].
16. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2003-2004][https://wwwn.cdc.gov/Nchs/Nhanes/2003-2004/L24PH_C.htm].
17. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2005-2006][https://wwwn.cdc.gov/Nchs/Nhanes/2005-2006/PHTHTE_D.htm].
18. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2007-2008][https://wwwn.cdc.gov/Nchs/Nhanes/2007-2008/PHTHTE_E.htm].
19. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2009-2010][https://wwwn.cdc.gov/Nchs/Nhanes/2008-2009/PHTHTE_F.htm].
20. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2011-2012][https://wwwn.cdc.gov/Nchs/Nhanes/2011-2012/PHTHTE_G.htm].
21. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2013-2014][https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/PHTHTE_H.htm].
22. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2015-2016][https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/PHTHTE_I.htm].
23. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2001-2002][https://wwwn.cdc.gov/Nchs/Nhanes/2001-2002/DEMO_B.htm].
24. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2003-2004][https://wwwn.cdc.gov/Nchs/Nhanes/2003-2004/DEMO_C.htm].

25. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2005-2006][https://wwwn.cdc.gov/Nchs/Nhanes/2005-2006/DEMO_D.htm].
26. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2007-2008][https://wwwn.cdc.gov/Nchs/Nhanes/2007-2008/DEMO_E.htm].
27. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2009-2010][https://wwwn.cdc.gov/Nchs/Nhanes/2009-2010/DEMO_F.htm].
28. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2011-2012][https://wwwn.cdc.gov/Nchs/Nhanes/2011-2012/DEMO_G.htm].
29. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2013-2014][https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/DEMO_H.htm].
30. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, [2015-2016][https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/DEMO_I.htm].
31. Centers for Disease Control and Prevention. (2022). Social Determinants of Health at CDC. Centers for Disease Control and Prevention. Retrieved from https://www.cdc.gov/about/sdoh/index.html
32. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). (2018, May 18). RDC - geocodes - national health and nutrition examination survey. Centers for Disease Control and Prevention. https://www.cdc.gov/rdc/geocodes/geowt_nhanes.htm
33. Currie, J. and Moretti, E. (2003) Mother's Education and the Intergenerational Transmission of Human Capital: Evidence from College Openings, The Quarterly Journal of Economics, Volume 118, Issue 4, November 2003, Pages 1495–1532, https://doi.org/10.1162/003355303322552856
34. Dolinoy, D. C., Huang, D., & Jirtle, R. L. (2007). Maternal nutrient supplementation counteracts bisphenol A-induced DNA hypomethylation in early development. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(32), 13056–13061. https://doi.org/10.1073/pnas.0703739104
35. Duello TM, Rivedal S, Wickland C, Weller A. Race and genetics versus 'race' in genetics: A systematic review of the use of African ancestry in genetic studies. Evol Med Public Health. 2021 Jun 15;9(1):232-245. doi: 10.1093/emph/eoab018. Erratum in: Evol Med Public Health. 2021 Oct 27;9(1):289-291. PMID: 34815885; PMCID: PMC8604262.
36. Fackelmann, G., & Sommer, S. (2019). Microplastics and the gut microbiome: How chronically exposed species may suffer from gut dysbiosis. Marine Pollution Bulletin, 143, 193–203. https://doi.org/10.1016/j.marpolbul.2019.04.030

37. Factor-Litvak, P., Insel, B., Calafat, A. M., Liu, X., Perera, F., Rauh, V. A., & Whyatt, R. M. (2014). Persistent Associations between Maternal Prenatal Exposure to Phthalates on Child IQ at Age 7 Years. *PLOS ONE*, *9*(12), e114003. https://doi.org/10.1371/journal.pone.0114003
38. Foster, T. (2017). Decomposing American immobility: Compositional and rate components of interstate, intrastate, and intracounty migration and mobility decline. Demographic Research, 37, 1515–1548. https://doi.org/10.4054/DemRes.2017.37.47
39. García, S. J., Trummel, T., Cornejo, M., Maldonado, K., Ojeda, A., Flores, H., & Link, B. G. (2021). Immigrant Health Inequities: Exposing Diversions and White Supremacy. Social Sciences, 10(9), 341. MDPI AG. Retrieved from http://dx.doi.org/10.3390/socsci10090341
40. Gaston, S. A., & Tulve, N. S. (2019). Urinary phthalate metabolites and metabolic syndrome in U.S. adolescents: Cross-sectional results from the National Health and Nutrition Examination Survey (2003-2014) data. International journal of hygiene and environmental health, 222(2), 195–204. https://doi.org/10.1016/j.ijheh.2018.09.005
41. Gonzalez-Barrera, A., & Krogstad, J. M. (2020, May 31). What we know about illegal immigration from Mexico. Pew Research Center. Retrieved March 20, 2023, from https://www.pewresearch.org/fact-tank/2019/06/28/what-we-know-about-illegal-immigration-from-mexico/
42. Gottdiener, M., & Budd, L. (2005). Socio-spatial approach. In Key concepts in urban studies (pp. 140-145). SAGE Publications Ltd, https://dx.doi.org/10.4135/9781446279120.n32
43. Hoppin, J. A., Brock, J. W., Davis, B. J., & Baird, D. D. (2002). Reproducibility of urinary phthalate metabolites in first morning urine samples. Environmental health perspectives, 110(5), 515–518. https://doi.org/10.1289/ehp.02110515
44. Howdeshell, K.L., Wilson, V.S., Furr, J., Lambright, C.R., Rider, C.V., Blystone, C.R., Hotchkiss, A.K., Gray Jr., L.E., 2008b. A mixture of five phthalate esters inhibits fetal testicular testosterone production in the sprague-dawley rat in a cumulative, dose additive manner. Toxicol. Sci. 105, 153–165.
45. Huang, H.B., Chen, H.Y., Su, P.H., Huang, P.C., Sun, C.W., Wang, C.J., Hsiung, C.A., Wang, S.L., 2015. Fetal and childhood exposure to phthalate diesters and cognitive function in children up to 12 years of age: Taiwanese maternal and infant cohort study. PLoS One 10, e0131910.
46. Huo, W., Chen, X., Fang, H., Guan, H., Li, Q., & Huang, M. (2023). Research on the Chemical Hazard Risk of Toys Exported to EU from China Based on the Analysis of the EU “Safety Gate” Alerts Cases. Journal of Biomedical Science and Engineering, 16(4), Article 4. https://doi.org/10.4236/jbise.2023.164004
47. Jones, N. (2022, June 10). 2020 Census Illuminates Racial and Ethnic Composition of the Country. Improved Race and Ethnicity Measures Reveal U.S. Population Is Much More Multiracial. https://www.census.gov/library/stories/2021/08/improved-race-ethnicity-measures-reveal-united-states-population-much-more-multiracial.html
48. Kaplan R, Spittel M, David D (2015). Population Health: Behavioral and Social Science Insights. AHRQ Publication No. 15-0002. Rockville, MD: Agency for Healthcare Research and Quality and Office of Behavioral and Social Sciences Research, National Institutes of Health. https://archive.ahrq.gov/professionals/education/curriculum-tools/population-health/population-health.pdf

49. Karlsson, O., Rocklöv, J., Lehoux, A. P., Bergquist, J., Rutgersson, A., Blunt, M. J., & Birnbaum, L. S. (2021). The human exposome and health in the Anthropocene. International Journal of Epidemiology, 50(2), 378–389. https://doi.org/10.1093/ije/dyaa231
50. Kawachi, I., Subramanian, S., & Almeida-Filho, N. (2002). A glossary for health inequalities. Journal of Epidemiology and Community Health, 56(9), 647–652. https://doi.org/10.1136/jech.56.9.647
51. Kravitz-Wirtz, N., Crowder, K., Hajat, A., & Sass, V. (2016). THE LONG-TERM DYNAMICS OF RACIAL/ETHNIC INEQUALITY IN NEIGHBORHOOD AIR POLLUTION EXPOSURE, 1990–2009. Du Bois Review : Social Science Research on Race, 13(2), 237–259. https://doi.org/10.1017/S1742058X16000205
52. Krieger, N. (2011). Epidemiology and the people's health: Theory and context. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195383874.001.0001
53. Li, N., Papandonatos, G. D., Calafat, A. M., Yolton, K., Lanphear, B. P., Chen, A., & Braun, J. M. (2019). Identifying periods of susceptibility to the impact of phthalates on children's cognitive abilities. Environmental Research, 172, 604–614. https://doi.org/10.1016/j.envres.2019.03.009
54. Li, N., Papandonatos, G. D., Calafat, A. M., Yolton, K., Lanphear, B. P., Chen, A., & Braun, J. M. (2020). Gestational and childhood exposure to phthalates and child behavior. Environment International, 144, 106036. https://doi.org/10.1016/j.envint.2020.106036
55. Li, M., & Yuan, F. (2022). Historical Redlining and Resident Exposure to COVID-19: A Study of New York City. Race and social problems, 14(2), 85–100. https://doi.org/10.1007/s12552-021-09338-z
56. Link, B. G., & Phelan, J. (1995). Social Conditions As Fundamental Causes of Disease. Journal of Health and Social Behavior, 35, 80. https://doi.org/10.2307/2626958
57. Louie, M. (2022, September 21). What are uterine fibroids? A Mayo Clinic expert explains. Mayo Clinic: Diseases & Conditions. https://www.mayoclinic.org/diseases-conditions/uterine-fibroids/symptoms-causes/syc-20354288#:~:text=Uterine%20fibroids%20are%20noncancerous%20growths,almost%20never%20develop%20into%20cancer.
58. Margolis R. (2013). Educational differences in healthy behavior changes and adherence among middle-aged Americans. Journal of health and social behavior, 54(3), 353–368. https://doi.org/10.1177/0022146513489312
59. Marmot, M. (2017). The Health Gap: The Challenge of an Unequal World: the argument. International Journal of Epidemiology, 46(4), 1312–1318. https://doi.org/10.1093/ije/dyx163
60. McKinlay, J. B. (1975). A Case For Refocusing Upstream: The Political Economy Of Illness. IAPHS Occasional Classics.
61. Meeker, J.D., Calafat, A.M., Hauser, R., 2007. Di(2-ethylhexyl) phthalate metabolites may alter thyroid hormone levels in men. Environ. Health Perspect. 115, 1029–1034.
62. Meeker JD, Sathyanarayana S, Swan SH. Phthalates and other additives in plastics: human exposure and associated health outcomes. Philos Trans R Soc Lond B Biol Sci. 2009;364:2097–2113.
63. Miodovnik, A., Edwards, A., Bellinger, D.C., Hauser, R., 2014. Developmental neurotoxicity of ortho-phthalate diesters: review of human and experimental evidence. Neurotoxicology 41, 112–122.

64. Moog, N.K., Entringer, S., Heim, C., Wadhwa, P.D., Kathmann, N., Buss, C., 2017. Influence of maternal thyroid hormones during gestation on fetal brain development. Neuroscience 342, 68–100.
65. Mostafavi, B. (2020, April 12). Understanding racial disparities for women with uterine fibroids. University of Michigan Medicine. Retrieved February 17, 2023, from https://www.michiganmedicine.org/health-lab/understanding-racial-disparities-women-uterine-fibroids
66. National Institute of Health, Partnerships for Environmental Public Health (NIH PEPH). (2021). Phthalates: The Everywhere Chemical. https://www.niehs.nih.gov/research/supported/translational/peph/podcasts/2015/mar23_phthalates/index.cfm
67. Organisation for Economic Co-operation and Development. (2020). Productivity, human capital and educational policies. OECD. Retrieved March 12, 2023, from https://www.oecd.org/economy/human-capital/
68. Pacheco, S. E. (2020). Catastrophic effects of climate change on children's health start before birth. The Journal of Clinical Investigation, 130(2), 562–564. https://doi.org/10.1172/JCI135005
69. Parker, L. (2022, May 2). Microplastics are in our bodies. how much do they harm us? Environment. Retrieved September 29, 2022, from https://www.nationalgeographic.com/environment/article/microplastics-are-in-our-bodies-how-much-do-they-harm-us?loggedin=true
70. Qian, Y., Shao, H., Ying, X., Huang, W., & Hua, Y. (2020). The Endocrine Disruption of Prenatal Phthalate Exposure in Mother and Offspring. Frontiers in Public Health, 8, 366. https://doi.org/10.3389/fpubh.2020.00366
71. Radke, E. G., Galizia, A., Thayer, K. A., & Cooper, G. S. (2019). Phthalate exposure and metabolic effects: a systematic review of the human epidemiological evidence. Environment international, 132, 104768. https://doi.org/10.1016/j.envint.2019.04.040
72. Rappaport, S. M. (2011). Implications of the exposome for exposure science. *Journal of Exposure Science & Environmental Epidemiology*, *21*(1), Article 1. https://doi.org/10.1038/jes.2010.50
73. Ray, R., Perry, A. M., Harshbarger, D., Elizondo, S., & Gibbons, A. (2021, September 1). Homeownership, racial segregation, and policy solutions to racial wealth equity. Brookings. Retrieved February 20, 2023, from https://www.brookings.edu/essay/homeownership-racial-segregation-and-policies-for-racial-wealth-equity/
74. Rice, D., Barone, S., (2000). Critical periods of vulnerability for the developing nervous system: evidence from humans and animal models. Environ. Health Perspect. 108 (Suppl. 3), 511–533.
75. Ross, C. and Mirowsky J. (2010). Chapter 3: Why Education is Key to Socioeconomic Differentials in Health. *Handbook of Medical Sociology*.
76. Selleck, M. J., Senthil, M., & Wall, N. R. (2017). Making Meaningful Clinical Use of Biomarkers. Biomarker Insights, 12, 117727191771523. https://doi.org/10.1177/1177271917715236
77. Sharkey P. Spatial Segmentation and the Black Middle Class. 2014; 119(4).
78. Silva MJ, Samandar E, Preau JL Jr, Reidy JA, Needham LL,Calafat AM. Quantification of 22 phthalate metabolites in human urine. J Chromatogr B Analyt Technol Biomed Life Sci. 2007 Dec 1;860(1):106-12.

79. Smith KR, et al. 2014: Human health: impacts, adaptation, and co-benefits. In: Field CB, et al., eds. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Cambridge, United Kingdom, and New York, New York, USA: Cambridge University Press; 2015:709–754.
80. Survey Data Analysis with R. UCLA: Statistical Consulting Group. from https://stats.oarc.ucla.edu/r/seminars/survey-data-analysis-with-r/).
81. Tierney, A.L., Nelson, C.A., 2009. Brain development and the role of experience in the early years. Zero Three 30, 9–13.
82. Usman, S., Abdull Razis, A. F., Shaari, K., Amal, M. N. A., Saad, M. Z., Mat Isa, N., Nazarudin, M. F., Zulkifli, S. Z., Sutra, J., & Ibrahim, M. A. (2020). Microplastics Pollution as an Invisible Potential Threat to Food Safety and Security, Policy Challenges and the Way Forward. International Journal of Environmental Research and Public Health, 17(24), 9591. https://doi.org/10.3390/ijerph17249591
83. U.S. Census. (2021). "Quarterly Residential Vacancies and Homeownership, First Quarter 2021." U.S. Census Bureau, April 27, 2021. https://www.census.gov/housing/hvs/files/currenthvspress.pdf.
84. U.S. Department of Health and Human Services. (n.d.). Environmental conditions | Social Determinants of Health Literature Summaries. Healthy People 2030. Retrieved April 3, 2023, from https://health.gov/healthypeople/priority-areas/social-determinants-health/literature-summaries/environmental-conditions
85. Xu, Y., Agrawal, S., Cook, T.J., Knipp, G.T., 2008. Maternal di-(2-ethylhexyl)-phthalate exposure influences essential fatty acid homeostasis in rat placenta. Placenta 29, 962–969
86. Zajacova, A., Rogers, R. G., & Johnson-Lawrence, V. (2012). Glitch in the gradient: Additional education does not uniformly equal better health. Social Science & Medicine, 75(11), 2007–2012. https://doi.org/10.1016/j.socscimed.2012.07.036
87. Zarus, G., Muianga, C., Hunter, C. M., & Pappas, R. S. (2021). A review of data for quantifying human exposures to micro and nano-plastics and potential health risks. Science of The Total Environment, 756, 144010. https://doi.org/10.1016/j.scitotenv.2020.144010
88. Zota, A. R., Calafat, A. M., & Woodruff, T. J. (2014). Temporal Trends in Phthalate Exposures: Findings from the National Health and Nutrition Examination Survey, 2001–2010. Environmental Health Perspectives, 122(3), 235–241. https://doi.org/10.1289/ehp.1306681
89. Zota, A.R., Geller, R.J., Calafat, A.M., Marfori ,C.Q., Baccarelli, A.A., Moawad, G.N. (2019). Phthalates exposure and uterine fibroid burden among women undergoing surgical treatment for fibroids: a preliminary study. Fertil Steril. 2019 Jan;111(1):112-121. doi: 10.1016/j.fertnstert.2018.09.009.

Appendix

Appendix 1: NHANES variables used, renamed, recoded, NAs

Original	Re-named	Variable	Categorical Coding	NA values
WTINT2YR	persWeight	person-level weight	none	
SDMVPSU	psu	primary sampling unit	none	
SDMVSTRA	strata	strata-level sampling unit	none	
RIDAGEYR	age	age in years at screening	Child ≤ 18 Young Adult ≥ 19, ≤ 25 Middle-aged >25, <64 Older Adult ≥ 65,	220
RIAGENDR	gender	Gender (or rather sex) male, female	1 = male 2 =female	0
RIDRETH1	ethnicity	race/Hispanic origin	1 = Mexican American 2 = Other Hispanic 3 = Non-Hispanic White 4 = Non-Hispanic Black 5 = Other or Multi	0
INDFMPIR	fpl	ratio of family income to poverty level	At poverty threshold: <1 Family income 2x poverty threshold: ≥1, <2 Family income 3x poverty threshold: ≥2, <3 Family income 4x poverty threshold: ≥3, <4 Family income 5x poverty threshold: ≥4, <5 Family income more than 5x poverty threshold: = 5	1,750

DMDCITZN	citizenship	citizenship status	1 = birth or naturalization 2 = not a US citizen	42
DMDEDUC2	adultED	the highest grade/level of education completed by participants 20 years and older	Less than 9th grade = 1 9-11th grade = 2 High school grad/GED = 3 Some college or AA = 4 College grad or above = 5	8,723
DMDHREDU	refED	the household reference person's education level	Partial college and below = 1:4 College and beyond = 5	784
DMDHSEDU	refEDspouse	the household reference person's spouse's education level	Partial college and below = 1:4 College and beyond = 5	10,778
URXMEP	monoEthyl	mono-ethyl phthalate (ng/mL)	none	none
XXXX	year	year the observation took place *this was added when we merged the years of data		