Children’s Environmental Chemical Exposures in the US, NHANES 2003-2012

Michael Hendryx, PhD 1

Juhua Luo, PhD 2

1. Corresponding author. Professor, Department of Applied Health Science, School of Public Health, Indiana University, 1025 E. 7th St., Bloomington, IN 47405. 812-856-8875; hendryx@indiana.edu

2. Associate Professor, Department of Epidemiology and Biostatistics, School of Public Health, Indiana University, 1025 E. 7th St., Bloomington, IN 47405. 812-856-2858; juhluo@indiana.edu

Abstract

Children are vulnerable to environmental chemical exposures, but little is known about the extent of multiple chemical exposures among children. We analyzed biomonitoring data from five cycles (2003-2012) of the National Health and Nutrition Examination Survey (NHANES) to describe multiple chemical exposures in US children, examine levels of chemical concentrations present over time, and examine differences in chemical exposures by selected demographic groups. We analyzed data for 36 chemical analytes across five chemical classes in a sample of 4,299 children aged 6-18. Classes included metals, pesticides, phthalates, phenols, and polycyclic aromatic hydrocarbons. We calculated the number and percent of chemicals detected, and tested for secular trends over time in chemical concentrations. We compared log concentrations among groups defined by age, sex, race/ethnicity, and poverty using multiple linear regression models, and report adjusted geometric means. Among a smaller subgroup of 733 children with data across chemical classes, we calculated the linear correlations within and between classes, and conducted a principal components analysis. The percentage of children with detectable concentrations of an individual chemical ranged from 26% to 100%; the average was 93% and 29 of 36 were detected in more than 90% of children. Concentrations of most tested chemicals were either unchanged or declined from earlier to more recent years. Many differences in concentrations were present by age, sex, poverty, and race/ethnicity categories. Within and between class correlations were all significant and positive, and the principal components analysis suggested a one factor solution, indicating that children exposed to higher levels of one chemical were exposed to higher levels of other chemicals. In conclusion, children in the US are exposed to multiple simultaneous chemicals at uneven risk across socioeconomic and demographic groups. Further efforts to understand the effects of multiple exposures on child health and development are warranted.

Childhood is a period of rapid growth and development, and during this period human beings are particularly vulnerable to toxic chemical exposures (ATSDR 2013; Perera 2017). Poor outcomes experienced by children resulting from environmental pollutants include neurodevelopmental and cognitive impairments (Grandjean and Landrigan 2014), impaired physical growth and development (Xu et al. 2015), reproductive problems, respiratory impairments, and possibly cancer (Perera 2017).

Exposure to multiple environmental pollutants is ubiquitous in general populations (CDC 2009). There is increasing awareness and concern about the possible adverse effects of multiple chemical exposures, but still much remains to learn about the presence and patterns of multiple exposures, particularly in children. Documentation of multiple exposures among children have been undertaken but are often limited to exposures to two chemicals at a time (Claus Henn et al. 2014; Xu et al. 2015; Zota et al. 2015). However, there are some studies that have examined children's exposures to multiple chemical groups (Frederiksen et al. 2013; Larsson et al. 2014; Lewis et al. 2013). There have also been studies of the effects of mothers' prenatal exposures to multiple chemicals on subsequent child development (Lee et al. 2017; Smit et al. 2015).

Despite these efforts, there is still limited evidence on simultaneous levels of chemical exposures across multiple chemical classes in children. Woodruff et al. (2011) analyzed one cycle of NHANES data and reported that pregnant women had detectable levels of many chemicals across chemical classes. In the current study we address a similar question for children. Studies of children's exposures to environmental chemicals in NHANES have been undertaken, but these have generally focused on testing associations between a chemical, or members of a single chemical class, and a health outcome. For example, NHANES data have been used to identify associations between phthalate exposure and attention deficit disorder and learning disabilities (Chopra et al. 2014). Childhood obesity is related to polycyclic aromatic hydrocarbon (PAH) (Scinicariello and Buser 2014) and phthalate exposures (Buser et al. 2014). Increased asthma risk has been found in association with PAHs (Liu et al. 2016). Children with higher urinary cadmium concentrations may have increased risk of learning disabilities and special education (Ciesielski et al. 2012).

Studies of multiple chemical classes, or trends in exposures over time, using NHANES are less common. Zota et al. (2014) examined NHANES trends over time in phthalates, including both children and adults. Calafat et al. (2017) conducted a pilot study of 122 children ages 3-5 (NHANES includes children's urine samples beginning at age 6), and showed that the younger children could reliably provide adequate samples, and that young children had evidence for exposure to multiple chemicals across several chemical classes.

In this study we provide an assessment of the presence of multiple environmental chemicals across several chemical classes in over 4000 NHANES children aged 6-18 over a ten year period. We examine secular trends in exposure levels, test for statistical differences according to sex, age, race/ethnicity, and poverty status, and examine within class and between class correlations among exposures. Our intent is to identify the extent of exposures to multiple chemicals to begin to understand patterns of exposures in children, as a foundation for informing future work on specific health consequences of multiple exposures.

Methods

Design. The study design is non-experimental, consisting of five two-year cross sectional cycles of National Health and Nutrition Examination Survey (NHANES) data covering the 10 year period 2003-2012. The NHANES is a biennial, nationally representative sample of non-institutionalized US residents conducted by the Centers for Disease Control and Prevention (CDC). It is designed to allow combining datasets across multiple cycles for increased sample size and estimate precision (Johnson et al. 2013). Additional detail regarding sampling procedures and analytic methods may be found from the CDC NHANES site (CDC 2016).

Sample. We included 4299 children ages 6-18 for analysis. The chemicals of interest were not collected from children less than 6 years of age.

Measures. One of our intended purposes was to examine secular trends in levels of environmental chemicals in children over time. For that reason, we selected measures that were available consistently among children across multiple NHANES cycles. We included 36 such chemicals, all measured via urinary analytes or metabolites, representing five chemical classes: (11 metals, 2 pesticides, 3 phenols, 11 phthalates, and 9 polycyclic aromatic hydrocarbons (PAHs)). All chemicals were measured as µg/L except PAHs, measured as ng/L.

Seven additional chemicals were considered but not analyzed for this study. These included two metals, beryllium and platinum, which were usually present below detection levels and were not collected in NHANES in the 2011-2012 cycle. Three additional pesticides were also usually below detection and were dropped in the last cycle. Two phthalates, mono-n-octyl and mono-cyclohexyl were not collected in the last cycle and were usually below detection limit. Additional chemicals (e.g. VOCs, PCBs, organophosphate pesticides) were not collected in all cycles or were only collected for children beginning at age 12. The 36 chemicals that we included were all collected consistently in children aged 6-18 across all five NHANES cycles.

In addition to these measures, we included as descriptive variables and covariates: age in years (divided into younger (aged 6-12) and older (aged 13-18)), sex, race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic, and Other (including Asian, multiracial and other groups), poverty status (yes/no based on reported family income relative to federal poverty levels), and urinary creatinine (mg/dL). Poverty status was missing from 276 cases because family income data were not reported. To reduce loss of cases to missing data, we replaced missing creatinine levels (n=133) with median values.

Analysis. We calculated the number and percent of tested chemicals that were present at detectable levels among children in the sample. We examined the secular trends over the five NHANES cycles to identify whether or not creatinine-adjusted chemical concentrations have been increasing or decreasing over time. Distributions of all chemicals were skewed with a small number of high end outliers, so we used the log values for statistical analysis. Tables report adjusted geometric means. We used SAS software version 9.4 Proc Surveyreg to estimate multiple linear regression models to identify the independent effects of age, sex, race/ethnicity, and poverty on children’s concentrations of environmental chemicals, controlling in addition for log values of creatinine. We conducted a sensitivity analysis to examine whether differences in these models were influenced by adding serum cotinine as an additional covariate to control for smoking or second hand smoke. Statistical models were weighted using the NHANES weights specific to the chemical class, and using cluster and sampling variables provided by NHANES. We found the average linear correlations among chemicals at within-class and between-class levels. These correlations were restricted to a small number of children (N=733) who were measured across classes. Among this subgroup of children, we conducted a principal components analysis to explore how the scores across the 36 chemicals might be grouped into fewer variables. We used p<.01 for all tests as the significance standard.

Results

There were 4299 children ages 6-18 available for analysis. The mean age was 12.1 (standard error=.07, range 6-18). Distributions by sex, race, and poverty status are shown in Table 1.

Table 2 summarizes the number of children who were tested on each of the 36 chemicals of interest, along with the number and percent who had concentrations of tested chemicals above the detection limits. Most children had detectable levels of most chemicals, with a range from 26.8% to 100% of children; 93.1% of children on average had detectable levels of the 36 tested chemicals.

Table 3 shows the creatinine-adjusted geometric mean values across time. Based on a linear trend p<.01, we observed of the 36 tested chemicals, 16 showed significant declines over the five NHANES cycles, 16 were unchanged, and 4 increased. Declining chemicals included 5 of 11 metals, one pesticide, 1 of 3 phenols, 7 of 11 phthalates, and 2 of 9 PAHs. Of the four that increased over time, there were 3 PAHs and 1 phthalate. Significant increases or decreases in chemical concentrations over time may be identified by the two final columns of the table showing the p values and the positive or negative direction of the coefficients.

Table 4 shows the results of the multiple linear regression models that tested for differences in chemical concentrations by age, sex, race/ethnicity and poverty. Cell values in the table are least squares adjusted geometric means. Sex differences were found for 12 of 36 chemicals, and in 11 of these instances females had higher concentrations. Chemicals were often higher in older children (29 chemicals); a notable exception being mono-ethyl phthalate. There were 21 significant differences by race/ethnicity but no consistent pattern was observed. Pesticides were higher in Blacks and Hispanics compared to the White or Other race groups. Levels of total urinary arsenic were highest in the Other race group, perhaps reflecting dietary intake in Asian populations. Benzophenone-3 was higher among White children. Two phthalates (mono-ethyl and mono-isobutyl) were highest among Black children, but another phthalate (mono-(3-carboxypropyl)) was lowest in Black children. Five PAHs showed significant race/ethnicity differences; one of these (2-napthol) was higher among minorities, but the others were not. Poverty differences included two phenols that were lower in the poverty group; both pesticides were higher, one metal (Pb) was higher, as were seven PAHs. The results of the sensitivity analysis (not shown) indicated that adding serum cotinine as an additional covariate made few differences on the estimates by age, sex or race; however, poverty differences became less common among the PAH tests, indicating that smoking or second hand smoke is influencing PAH findings among the poverty group. Because serum cotinine was missing in 643 cases we report results without cotinine to increase the sample size.

Table 5 shows the average within-class and between-class correlations among chemicals. All within-class correlations were significant, and were higher than between class correlations with the exception of phenols. However, all between-class correlations were significant (p<.01) and positive. The principal components analysis (results not shown) suggested a six factor solution based on factors with eigenvalues >1. However, the first factor alone accounted for 46% of the variance, and this fell to 6% to 3% in factors two through six. A visual scree plot also suggested a one factor solution, as eigenvalues fell from 16.5 for the first factor, to 2.2 for the second, leveling off thereafter. Finally, our interpretation of the factor loadings suggested a one factor solution; all factor loadings on the first factor were positive and 31 of the 36 measures had the highest loadings on the first factor, while two phenols loaded onto factor five, the two pesticides loaded onto factor four, and the remaining factors seemed largely uninterpretable.

Discussion

We examined 36 environmental chemicals tested among children aged 6-18 years across five NHANES cycles (2003-2012). We observed that detectable concentrations of these chemicals were present in most children. On average, the chemicals were detected in 93% of tested children. Five classes of chemicals were represented including metals, phenols, pesticides, phthalates, and PAHs.

It was encouraging to observe that the levels of many of the tested chemicals declined from earlier years to later years. This may be a reflection of safer consumer products, greater public awareness of the need to avoid exposures in children, and policies to reduce pollutant emissions into the environment. Note that of the four chemicals that increased over time, three were PAHs and one was a phthalate. PAHs were the only class where increasing chemical levels over time outnumbered decreasing chemicals; perhaps this reflects greater exposures over time to fossil fuel combustion products, although exact sources are unknown. Reductions in lead have been previously documented and reflect less use of lead paint, lead-containing plumbing materials, and elimination of leaded gasoline (Brown and Margolis 2012). Phthalate use has been reduced in the manufacture of some children’s toys.

Results of models examining differences by age, sex, poverty status, and race/ethnicity identified many differences in exposure levels among population groups. Poverty differences included the finding that two of the phenols were lower in the poverty group, perhaps reflecting differential access to consumer products. Levels of lead were higher in the poverty group, as were both pesticides, two phthalates, and seven of the PAHs. When we added serum cotinine as an additional covariate, the sample size was reduced but six of the seven PAH differences became non-significant, indicating that differences in smoking exposures in the poverty group may be influencing PAH findings. Higher concentrations among older children may reflect differences in activity patterns or time spent outside the home, or consequences of longer exposure. Higher concentrations among female children may reflect their average smaller size, or differential exposure to certain consumer products.

There were many differences across race/ethnicity groups. Higher pesticide exposures in Black and Hispanic children is concerning to see. NHANES classifies these two chemicals as pesticides, but they are also present as a product of chlorinated tap water. These dichlorophenols may influence pubertal timing (Wolff et al. 2016), and contribute to thyroid dysfunction (Wei and Zhu 2016a), metabolic syndrome (Wei and Zhu 2016b), obesity (Twum and Wei 2011) and food allergies (Jerschow et al. 2012). Black and Hispanic children also had higher concentrations of mono-ethyl phthalate, a plasticizer often used as a fragrance ingredient in personal care products (EWG 2016); exposure to this and other phthalates has been linked to reproductive problems. Phthalates are used in the manufacture of children's toys but are present as well in many other consumer products.

In addition to observing that most chemicals were present above detection limits, we also observed significant correlations within and between chemical classes. A principal components analysis also pointed to a one factor solution indicating that values across chemicals were positively associated. That is, children with higher concentrations in one chemical were at risk for higher concentrations in other chemicals. We don't know how the simultaneous presence of dozens of chemicals in children may act in additive, synergistic, or redundant fashion to influence child's health and development. Some studies have examined chemical mixtures in children but they tend to be limited to few, often only two, chemicals at one time (Xu et al. 2015; Zota et al. 2015). The current study did not attempt to examine health outcomes of multiple exposures, but serves only to document the simultaneous occurrence of multiple chemicals among US children, examine their changes over time, and examine their associations with demographic variables. It will be important for future research to understand how multiple exposures may operate to impact children's health and development.

Further study into the use of toxicologically-related classes of chemicals could offer one approach to understanding the interactive health effects of multiple chemicals (ATSDR 2014). Also important will be to identify through empirical evidence which co-exposures are truly synergistic in promoting adverse health consequences (interactions), which may confer only additive effects of individual exposures (main effects), and which may confer no extra risk after the effects of a related chemical are accounted for (null or redundant effects). Studies to examine the effects of multiple co-exposures, 36 in the case of the present study, will also benefit from the development of statistical models that allow for the estimation and interpretation of higher order interactions. Conventional statistical approaches have limited ability to model complex interactions, but spatial modeling techniques (Shmool et al. 2014), structural equation models (Peters et al. 2016), or person-centered models (Lanza and Rhoades 2013) are possibilities for further applications to co-occurring environmental exposures.

Limitations of the study include incomplete knowledge about safe or unsafe levels of the tested chemicals. Wigle and Lanphear (2005) argue that there may often be no safe level of exposure to harmful chemicals. Children are more vulnerable to environmental toxicants than adults and may experience greater vulnerability at lower levels of exposure (ATSDR 2013; NRC 1993). We also don't know if all of the tested chemicals necessarily have negative impacts on child health and development, although as chemical classes we know that adverse effects have been identified for all. A third limitation is that the correlations within and between chemical classes were based on a small sample of children. Finally, several chemicals that were infrequently detected were dropped from NHANES, so the fact that most tested chemicals were detected in most children provides a somewhat biased view, as undetected chemicals are not included in measurement over time. However, levels of detection varied from about 27% to 100%, while averaging 93%, and only a small number of chemicals with very low detection rates were eliminated.

In conclusion, the study indicates that most children have detectable concentrations of multiple environmental chemicals across chemical classes. Levels of some of these chemicals have been in decline from earlier to later years. The need for further investigations into the effects of exposures to multiple simultaneous environmental chemicals, including multiple low dose exposures, on the health and development of children are indicated by these findings, as current understanding of the effects of multiple chemical exposures in children is still insufficiently developed.

References

ATSDR. (2013). Principles of pediatric environmental health: Why are children often especially susceptible to the adverse effects of environmental toxicants? Available: https://www.atsdr.cdc.gov/csem/csem.asp?csem=27&po=3 [accessed 01-18-17.]

ATSDR. 2014. Interaction profiles for toxic substances. Available: https://www.atsdr.cdc.gov/interactionprofiles/index.asp [accessed 10-10-17].

Brown, M. J., & Margolis, S. (2012). Lead in drinking water and human blood lead levels in the United States. MMWR Suppl, 61(4), 1-9.

Buser, M. C., Murray, H. E., & Scinicariello, F. (2014). Age and sex differences in childhood and adulthood obesity association with phthalates: analyses of NHANES 2007-2010. Int J Hyg Environ Health, 217(6), 687-694. doi:10.1016/j.ijheh.2014.02.005

Calafat, A. M., Ye, X., Valentin-Blasini, L., Li, Z., Mortensen, M. E., & Wong, L. Y. (2016). Co-exposure to non-persistent organic chemicals among American pre-school aged children: A pilot study. Int J Hyg Environ Health, S1438-4639(16)30254-1. doi:10.1016/j.ijheh.2016.10.008

CDC. (2009). Fourth National Report on Human Exposure to Environmental Chemicals. Atlanta, GA: Centers for Disease Control and Prevention National Center for Environmental Health.

CDC. (2016). National Health and Nutrition Examination Survey. Available: https://www.cdc.gov/Nchs/Nhanes/index.htm [accessed 10-12-17].

Chopra, V., Harley, K., Lahiff, M., & Eskenazi, B. (2014). Association between phthalates and attention deficit disorder and learning disability in U.S. children, 6-15 years. Environ Res, 128, 64-69. doi:10.1016/j.envres.2013.10.004

Ciesielski, T., Weuve, J., Bellinger, D. C., Schwartz, J., Lanphear, B., & Wright, R. O. (2012). Cadmium exposure and neurodevelopmental outcomes in U.S. children. Environ Health Perspect, 120(5), 758-763. doi:10.1289/ehp.1104152

Claus Henn, B., Coull, B.A., Wright, R.O. (2014). Chemical mixtures and children's health. Curr Opin Pediatr 26:223-229.

EWG. (2016). Human toxome project: monoethyl phthalate. Available: http://www.ewg.org/sites/humantoxome/chemicals/chemical.php?chemid=100364 [accessed 10-12-17.]

Frederiksen, H., Nielsen, J.K., Morck, T.A., Hansen, P.W., Jensen, J.F., Nielsen, O., et al. (2013). Urinary excretion of phthalate metabolites, phenols and parabens in rural and urban Danish mother-child pairs. Int J Hyg Environ Health 216:772-783.

Grandjean, P., & Landrigan, P. J. (2014). Neurobehavioural effects of developmental toxicity. Lancet Neurol, 13(3), 330-338. doi:10.1016/S1474-4422(13)70278-3

Jerschow, E., McGinn, A. P., de Vos, G., Vernon, N., Jariwala, S., Hudes, G., & Rosenstreich, D. (2012). Dichlorophenol-containing pesticides and allergies: results from the US National Health and Nutrition Examination Survey 2005-2006. Ann Allergy Asthma Immunol, 109(6), 420-425. doi:10.1016/j.anai.2012.09.005

Johnson, C. L., Paulose-Ram, R., Ogden, C. L., Carroll, M. D., Kruszon-Moran, D., Dohrmann, S. M., & Curtin, L. R. (2013). National Health and Nutrition Examination Survey: analytic guidelines, 1999-2010. Washington DC: National Center for Health Statistics.

Lanza, S.T., Rhoades, B.L. (2013). Latent class analysis: An alternative perspective on subgroup analysis in prevention and treatment. Prev Sci 14:157-168.

Larsson, K., Ljung Bjorklund, K., Palm, B., Wennberg, M., Kaj, L., Lindh, C.H., et al. (2014). Exposure determinants of phthalates, parabens, bisphenol a and triclosan in swedish mothers and their children. Environ Int 73:323-333.

Lee, W.C., Fisher, M., Davi, K., Arbuckle, T.E., Sinha, S.K. (2017). Identification of chemical mixtures to which canadian pregnant women are exposed: The MIREC study. Environ Int 99:321-330.

Lewis, R.C., Meeke,r J.D., Peterson, K.E., Lee, J.M., Pace, G.G., Cantoral, A., et al. (2013). Predictors of urinary bisphenol a and phthalate metabolite concentrations in mexican children. Chemosphere 93:2390-2398.

Liu, H., Xu, C., Jiang, Z. Y., & Gu, A. (2016). Association of polycyclic aromatic hydrocarbons and asthma among children 6-19 years: NHANES 2001-2008 and NHANES 2011-2012. Respir Med, 110, 20-27. doi:10.1016/j.rmed.2015.11.003

NRC. (1993). Pesticides in the diets of infants and children. Washington, DC: National Resource Council.

Perera, F. P. (2017). Multiple Threats to Child Health from Fossil Fuel Combustion: Impacts of Air Pollution and Climate Change. Environ Health Perspect, 125(2), 141-148. doi:10.1289/EHP299

Peters, K.O., Williams, A.L., Abubake, S., Curtin-Brosnan, J., McCormack, M.C., Peng, R., et al. (2017). Predictors of polycyclic aromaric hydrocarbon exposure and internal dose in inner city Baltimore children. J Exp Science Environ Epidem, 27, 290-298.

Scinicariello, F., & Buser, M. C. (2014). Urinary polycyclic aromatic hydrocarbons and childhood obesity: NHANES (2001-2006). Environ Health Perspect, 122(3), 299-303. doi:10.1289/ehp.1307234

Shmool, J.L., Kubzansky, L.D., Newman, O.D., Spengler, J., Shepard, P., Clougherty, J.E. (2014). Social stressors and air pollution across New York City communities: A spatial approach for assessing correlations among multiple exposures. Environ Health 13, 91.

Smit, L.A., Lenters, V., Hoyer, B.B., Lindh, C.H., Pedersen, H.S., Liermontova, I., et al. (2015). Prenatal exposure to environmental chemical contaminants and asthma and eczema in school-age children. Allergy 70, 653-660.

Twum, C., & Wei, Y. (2011). The association between urinary concentrations of dichlorophenol pesticides and obesity in children. Rev Environ Health, 26(3), 215-219.

Wei, Y., & Zhu, J. (2016a). Associations between urinary concentrations of 2,5-dichlorophenol and metabolic syndrome among non-diabetic adults. Environ Sci Pollut Res Int, 23(1), 581-588. doi:10.1007/s11356-015-5291-z

Wei, Y., & Zhu, J. (2016b). Para-dichlorobenzene exposure is associated with thyroid dysfunction in US adolescents. J Pediatr, 177, 238-243. doi:10.1016/j.jpeds.2016.06.085

Wigle, D. T., & Lanphear, B. P. (2005). Human health risks from low-level environmental exposures: no apparent safety thresholds. PLoS Med, 2(12), e350. doi:10.1371/journal.pmed.0020350

Wolff, M. S., Pajak, A., Pinney, S. M., Windham, G. C., Galvez, M., Rybak, M., et al. (2016). Associations of urinary phthalate and phenol biomarkers with menarche in a multiethnic cohort of young girls. Reprod Toxicol, 67, 56-64. doi:10.1016/j.reprotox.2016.11.009

Woodruff, T. J., Zota, A. R., & Schwartz, J. M. (2011). Environmental chemicals in pregnant women in the United States: NHANES 2003-2004. Environ Health Perspect, 119(6), 878-885. doi:10.1289/ehp.1002727

Xu, X., Liu, J., Huang, C., Lu, F., Chiung, Y. M., & Huo, X. (2015). Association of polycyclic aromatic hydrocarbons (PAHs) and lead co-exposure with child physical growth and development in an e-waste recycling town. Chemosphere, 139, 295-302. doi:10.1016/j.chemosphere.2015.05.080

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. Environ Health Perspect, 122(3), 235-241. doi:10.1289/ehp.1306681

Zota, A. R., Needham, B. L., Blackburn, E. H., Lin, J., Park, S. K., Rehkopf, D. H., & Epel, E. S. (2015). Associations of cadmium and lead exposure with leukocyte telomere length: findings from National Health and Nutrition Examination Survey, 1999-2002. Am J Epidemiol, 181(2), 127-136. doi:10.1093/aje/kwu293

Table 1. Demographic characteristics of sample.

Variable	**Unweighted Frequency**	**Weighted Percent**
Sex		
Male	2175	50.5
Female	2124	49.5
Race/ethnicity		
Non-Hispanic White	1189	58.4
Non-Hispanic Black	1276	15.0
Hispanic	1503	18.9
Other	331	7.7
Poverty [a]		
No	2693	76.7
Yes	1330	23.3

[a] Poverty based on reported family size and income relative to federal poverty levels; missing in 276 cases.

Table 2. Chemicals measured and detected in NHANES children ages 6 – 18, 2003-2012.

Chemical	**Number tested**	**Number Above Detection Limit**	**Percent above detection limit**
Metals			
Arsenic	4123	4071	98.7
Barium	4126	4060	98.4
Cadmium	4122	3047	73.9
Cobalt	4126	4096	99.3
Cesium	4126	4126	100
Molybdenum	4126	4126	100
Lead	4126	3904	94.6
Antimony	4126	3360	81.4
Thallium	4126	4113	99.7
Tungsten	4123	3948	95.8
Uranium	4125	3665	88.8
Pesticides			
2,5-dichlorophenol	4184	4128	98.7
2,4-dichlorophenol	4184	3811	91.1
Phenols			
Triclosan	4192	3280	78.2
Benzophenone-3	4177	4139	99.1
Bisphenol A	4177	3976	95.2
Phthalates			
Mono-n-butyl	4214	4182	99.2
Mono-ethyl	4214	4213	99.98
Mono-(2-ethyl)-hexyl	4214	3216	76.6
Mono-isononyl	4214	1128	26.8
Mono-benzyl	4214	4200	99.7
Mono-n-methyl	4214	2536	60.2
Mono-(3-carboxypropyl)	4214	4166	98.9
Mono-(2-ethyl-5-hydroxyhexyl)	4214	4209	99.9
Mono-(2-ethyl-5-oxohexyl)	4214	4197	99.6
Mono-isobutyl	4214	4191	99.5
Mono-2-ethyl-5-carboxypentyl	4214	4213	99.98
Polycyclic aromatic hydrocarbons			
1-napthol	4122	4117	99.9
2-napthol	4150	4149	99.98
3-fluorene	4126	4111	99.6
2-fluorene	4142	4141	99.98
3-phenanthrene	4120	4080	99.0
1-phenenthrene	4138	4137	99.98
2-phenanthrene	4132	4064	98.4
1-pyrene	4136	4129	99.8
9-fluorene	4137	4134	99.9

Table 3. Trends in creatinine adjusted chemical geometric means over time, 2003-2012, NHANES children 6-18.[a]

Chemical	**2003-4**	**2005-6**	**2007-8**	**2009-10**	**2011-12**	**p**	**b**
Metals (μg/L)							
Arsenic	2.00	2.05	1.96	1.96	1.93	.34	-.02
Barium	2.29	2.10	1.98	1.68	1.52	.0007	-.05
Cadmium	0.10	0.09	0.08	0.07	0.07	.0001	-.06
Cobalt	0.49	0.51	0.49	0.45	0.43	.02	.03
Cesium	5.46	5.19	4.57	3.89	3.89	.0003	-.04
Molybdenum	60.47	68.55	67.11	57.19	54.17	.02	.02
Lead	0.72	0.53	0.43	0.36	0.31	.0001	-.15
Antimony	0.11	0.09	0.07	0.06	0.07	.0001	-.08
Thallium	0.21	0.19	0.17	0.15	0.16	.20	-.01
Tungsten	0.12	0.15	0.16	0.11	0.12	.02	.04
Uranium	0.009	0.007	0.008	0.007	0.007	.78	.006
Pesticides (μg/L)							
2,5-dichlorophenol	16.10	12.03	9.94	7.66	4.18	.0001	-.24
2,4-dichlorophenol	1.22	1.16	1.10	0.96	0.74	.03	-.06
Phenols (μg/L)							
Triclosan	11.47	16.41	15.20	11.12	9.25	.22	-.04
Benzophenone-3	23.50	22.43	23.54	22.40	23.06	.46	.04
Bisphenol A	3.84	2.71	2.39	1.93	1.71	.0001	-.15
Phthalates (μg/L)							
Mono-n-butyl	34.59	31.31	26.70	19.91	11.21	.0001	-.18
Mono-ethyl	108.92	92.71	71.02	46.97	32.08	.0001	-.23
Mono-(2-ethyl)-hexyl	2.92	3.58	2.67	1.70	1.56	.0001	-.14
Mono-isononyl	1.23	1.07	1.06	1.18	1.16	.18	.03
Mono-benzyl	21.57	18.52	13.23	1.00	8.05	.0001	-.17
Mono-n-methyl	2.22	1.87	1.60	1.75	1.87	.87	.004
Mono-(3-carboxypropyl)	5.41	3.93	4.70	3.94	3.47	.31	-.02
Mono-(2-ethyl-5-hydroxyhexyl)	34.39	37.37	29.38	15.01	10.07	.0001	-.26
Mono-(2-ethyl-5-oxohexyl)	23.54	24.68	17.04	9.82	6.73	.0001	-.26
Mono-isobutyl	5.95	8.56	10.40	10.30	8.48	.0001	.17
Mono-2-ethyl-5-carboxypentyl	53.86	58.75	45.29	26.71	17.20	.0001	-.24
Polycyclic aromatic hydrocarbons (ng/L)							
1-napthol	1855.45	1539.99	1586.12	1344.13	1086.49	.002	-.05
2-napthol	2822.56	3030.07	3319.20	3062.56	3905.57	.0001	.15
3-fluorene	110.31	107.16	99.60	82.27	82.04	.34	-.01
2-fluorene	263.40	260.77	248.62	195.48	202.07	.66	-.006
3-phenanthrene	127.56	103.63	98.43	70.60	61.64	.0001	-.11
1-phenenthrene	158.62	136.36	125.75	116.55	113.23	.29	-.01
2-phenanthrene	48.88	49.09	55.30	56.01	57.57	.0004	.05
1-pyrene	124.85	118.75	142.68	146.53	133.73	.0001	.10
9-fluorene	252.83	242.24	267.44	194.32	185.98	.55	-.01

[a] P values based on SAS proc surveyreg model, specifying the sample time period as a continuous independent variable, and using the log of the chemical value as the dependent variable. Models included

log of creatinine level, the strata and sampling cluster variables provided by NHANES, and were weighted using NHANES weights specific to the chemical class. The last column shows the beta (b) coefficient for the linear trend estimate; negative coefficients indicate declines in levels over time.

Table 4. Multivariate adjusted geometric mean chemical concentrations by sex, age, race/ethnicity and poverty status, children aged 6-18, NHANES 2003-2012.[a]

Chemical	**Sex**		**Age**		**Race**				**Poverty**	
	Male	**Female**	**6-12**	**13-18**	**White**	**Black**	**Hispanic**	**Other**	**No**	**Yes**
Metals (μg/L)										
Arsenic	8.29	7.81	**7.10**	**9.14****	**6.42**	**6.89**	**7.85**	**12.06****	8.28	7.84
Barium	1.72	1.78	**1.61**	**1.90****	**2.27**	**1.19**	**1.65**	**2.11****	1.72	1.78
Cadmium	**0.083**	**0.091****	**0.091**	**0.083***	**0.074**	**0.088**	**0.086**	**0.102****	0.087	0.087
Cobalt	**0.43**	**0.51****	**0.41**	**0.51****	**0.50**	**0.39**	**0.48**	**0.48****	0.46	0.46
Cesium	4.72	4.60	**3.88**	**5.58****	**4.63**	**3.79**	**4.82**	**5.56****	4.66	4.66
Molybdenum	**64.26**	**59.32***	**48.42**	**78.73****	**61.62**	**52.96**	**64.97**	**68.51****	62.18	61.13
Lead	0.51	0.49	**0.39**	**0.64****	**0.45**	**0.54**	**0.52**	**.48****	**0.44**	**.56****
Antimony	0.08	0.8	**0.07**	**0.09****	0.08	0.07	0.08	0.08	0.08	0.08
Thallium	0.18	0.18	**0.15**	**0.21****	**0.18**	**0.16**	**0.18**	**0.20****	0.18	0.18
Tungsten	0.14	0.13	**0.11**	**0.17****	0.13	0.13	0.15	0.14	0.14	0.14
Uranium	0.008	0.008	0.008	0.008	**0.008**	**0.007**	**0.010**	**0.008****	0.008	0.008
Pesticides (μg/L)										
2,5-dichlorophenol	13.68	13.07	**11.75**	**15.17***	**6.41**	**28.79**	**19.89**	**8.65****	**11.63**	**15.32***
2,4-dichlorophenol	1.19	1.23	**1.06**	**1.39****	**0.87**	**1.66**	**1.53**	**0.98****	**1.14**	**1.30***
Phenols (μg/L)										
Triclosan	11.22	13.13	12.63	11.67	11.48	10.19	11.87	15.64	**14.21**	**10.37****
Benzophenone-3	**11.61**	**22.74****	**14.30**	**18.43***	**28.22**	**9.68**	**14.59**	**17.36****	**20.21**	**13.05****
Bisphenol A	2.41	2.48	**2.06**	**2.89****	**2.54**	**2.64**	**2.16**	**2.44****	2.36	2.53
Phthalates (μg/L)										
Mono-n-butyl	**20.37**	**27.28****	**17.64**	**31.50****	24.29	23.57	24.85	21.76	22.36	23.57
Mono-ethyl	**64.07**	**86.92****	**87.36**	**63.68****	**57.40**	**109.95**	**92.76**	**52.98****	**68.92**	**80.56****
Mono-(2-ethyl)-hexyl	**2.33**	**2.68***	**2.26**	**2.75****	2.30	2.64	2.38	2.70	2.51	2.49
Mono-isononyl	1.09	1.17	1.11	1.14	1.11	1.15	1.08	1.16	1.17	1.08
Mono-benzyl	12.81	14.30	**9.28**	**19.61****	15.33	13.74	13.07	12.06	12.55	14.59
Mono-n-methyl	1.80	2.03	**1.58**	**2.31****	1.83	1.84	2.07	1.90	1.86	1.96
Mono-(3-carboxypropyl)	3.92	3.96	**2.78**	**5.60****	**4.81**	**3.29**	**3.78**	**4.06****	3.90	3.98
Mono-(2-ethyl-5-hydroxyhexyl)	21.39	23.81	**17.89**	**28.39****	24.48	21.86	21.63	22.20	21.76	23.29

Mono-(2-ethyl-5-oxohexyl)	**13.57**	**15.55***	**11.45**	**18.43****	15.96	13.89	14.06	14.30	14.01	15.04
Mono-isobutyl	**8.37**	**10.54****	**7.22**	**12.22****	**8.25**	**10.14**	**9.53**	**9.78****	**8.83**	**9.99***
Mono-2-ethyl-5-carboxypentyl	35.73	38.95	**29.22**	**47.62****	39.64	33.45	37.51	39.13	35.87	38.86
Polycyclic aromatic hydrocarbons (ng/L)										
1-napthol	1479.12	1544.57	1450.99	1574.35	1564.78	1563.37	1341.17	1590.81	1436.55	1595.59
2-napthol	**3209.92**	**3835.29****	3576.00	3426.18	**3208.31**	**3334.24**	**4253.94**	**3394.80****	**3219.56**	**3823.80****
3-fluorene	99.13	97.01	**92.12**	**104.38****	**103.51**	**108.46**	**87.17**	**94.48****	**90.83**	**105.95****
2-fluorene	231.83	241.99	**224.75**	**249.63****	252.40	243.96	226.78	225.65	**218.98**	**256.21****
3-phenanthrene	89.55	90.31	**75.87**	**106.59****	**94.19**	**100.58**	**76.83**	**96.40****	87.97	95.22
1-phenenthrene	**120.77**	**133.75****	**116.40**	**138.80****	**139.21**	**114.43**	**123.84**	**126.60****	**121.39**	**133.09***
2-phenanthrene	52.68	54.98	51.94	55.76	55.64	53.20	50.50	56.12	**51.72**	**56.0***
1-pyrene	**128.00**	**150.81****	**118.39**	**163.06****	141.54	136.46	131.50	146.79	**129.15**	**149.46****
9-fluorene	224.19	242.23	222.07	244.64	**254.93**	**261.13**	**204.79**	**216.16****	**208.30**	**260.76***

[a] Cell values are least squares adjusted geometric means. Results from Proc surveyreg models specifying sex, race (non-Hispanic white, non-Hispanic black, Hispanic, other), age (ages 6-12 vs 13-18), poverty status (yes/no), and log of urinary creatinine as independent variables, and using the log of the chemical value as the dependent variable. Models included the strata and sampling cluster variables provided by NHANES, and were weighted using NHANES weights specific to the chemical class.

*p<.01; **p<.001

Table 5. Mean in-class and between class correlations.

	Within	**Between**				
		Metals	**Pesticides**	**Phenols**	**Phthalates**	**PAHs**
Metals	.45	--				
Pesticides	.85	.24	--			
Phenols	.15	.26	.16	--		
Phthalates	.49	.39	.27	.23	--	
PAHs	.71	.43	.30	.38	.25	--