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Co-exposure to non-persistent organic chemicals among American pre-school aged children: A pilot study

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Abstract

Background—General population human biomonitoring programs such as the National Health and Nutrition Examination Survey (NHANES) in the United States suggest that chemical exposures are common. Exposures during childhood may affect health later in life, but biomonitoring data in NHANES among pre-school aged children are limited.

Methods—A convenience group of 122 3–5 year old American boys and girls were recruited in 2013 for a pilot study to assess the feasibility of collecting urine from young children and analyzing it for select chemical exposure biomarkers for future NHANES. Children were primarily Hispanic (64.8%); the remainder was divided between non-Hispanic black, and non-Hispanic white and "other." We measured 52 urinary biomarkers: 13 phthalates and one non-phthalate plasticizer, five phenols and four parabens, 10 polycyclic aromatic hydrocarbons (PAHs), and 19 pesticides. For each biomarker, we calculated descriptive statistics. We also calculated the number of biomarkers detected within each child, and performed principal components analysis (PCA).

Results—NHANES staff obtained permission to attempt collection of 60 mL urine from 3 to 5 year olds who participated in the 2013 NHANES health examination; 83% of children successfully provided the target volume. We detected 24 individual biomarkers of pesticides, phenols and parabens, phthalates/non-phthalate plasticizers, and PAHs in 95–100% of children. The median number of biomarkers detected was 37: nine pesticides, five phenols and parabens, 13 phthalates and non-phthalate plasticizers, and 10 PAHs. Biomarkers concentrations appear to be similar to national estimates among 6–11 year old children from previous NHANES. PCA suggested high within-class correlations among biomarkers.

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Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the Research Data Center, the National Center for Health Statistics, or the Centers for Disease Control and Prevention.

Conflict of interest

The authors declare they have no competing financial interests.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijheh.2016.10. 008.

Conclusions—These young children successfully adhered to the collection protocol and produced enough urine for the quantification of environmental biomarkers currently being measured in NHANES participants 6 years of age and older. Using the same analytical methods employed for the analysis of samples collected from older NHANES participants, in this sample of pre-school aged children we detected multiple chemicals including plasticizers, combustion products, personal-care product chemicals, and pesticides. Starting with NHANES 2015–2016, the NHANES biomonitoring program will include urinary biomarkers for 3–5 year old children to provide exposure data to select chemicals at the national level among this age group.

Keywords

Biomonitoring; Coexposures; Exposure assessment; NHANES; PCA

1. Introduction

Interest exists in understanding the extent of chemical exposures during critical periods of human development, including childhood (US EPA, 2013). Children, because of their specific behaviors and physiology, experience different exposure situations than do adults (EPA, 2008). Therefore, identifying these differences as well as the exposure determinants is important for evaluating potential health hazards of these exposures.

Biomonitoring studies suggest that exposures to contemporary-use chemicals are common in modern societies (National Research Council, 2012). General population human biomonitoring programs are particularly useful for investigating such exposures (CDC 2015; Haines and Murray, 2012; Schulz et al., 2007). Interestingly, many contemporary chemicals are not persistent in people, and exposure biomarkers in urine are increasingly used to evaluate exposures to these compounds and to inform chemical risk assessments (Sobus et al., 2015). Compared to blood and other matrices, collecting urine is generally considered a non-invasive and relatively easy procedure, at least for adults. However, collecting urine from young children who cannot easily void in regular urine collection containers can pose logistic challenges (Lee and Arbuckle, 2009).

In the United States, the National Health and Nutrition Examination Survey (NHANES) collects data and biospecimens from persons aged one year and older to evaluate participants' general health and nutritional status (CDC, 2014). Blood and urine, collected during the participant's medical examination at the mobile examination center (MEC), are also used to assess exposure to environmental chemicals (Calafat, 2012). NHANES has collected urine specimens in its MEC since 1960, but, although urine has been successfully collected from young children for other studies by using various strategies including urine bags, diapers, and commode insert pans (Lee and Arbuckle, 2009), up to 2013–2014, only participants 6 years of age and older provide urine in the MEC. Therefore, information on Americans' exposure to environmental chemicals is more limited for children than for adults even though exposures during early childhood may be relevant to understand potential adverse effects on health later in life (US EPA, 2013).

To facilitate future efforts in the United States for closing this information gap, the National Center for Health Statistics (NCHS) in collaboration with the National Center for

Environmental Health (NCEH) designed a feasibility study to demonstrate that urine specimens from 3 to 5 year old children can be collected and analyzed for select chemical exposure biomarkers as part of NHANES. In this paper, to evaluate the feasibility of the urine collection, we describe the results of the analysis of the urine for metabolites of pesticides, plasticizers, combustion products, and personal-care product chemicals. To identify correlation patterns among these biomarkers, we also performed principal components analysis (PCA).

2. Materials and methods

2.1. Study population

A convenience sample of 3–5 year old American boys and girls who participated in the 2013 NHANES health examination were recruited for this feasibility study, conducted during four months in 2013 (Table 1). Although NHANES is a nationally-representative survey (CDC, 2014), this convenience sample of children was not. The 3–5 year old children, whose parent/guardian allowed them to provide a urine specimen, in addition to the examination component of NHANES (CDC, 2014), voided on a plastic commode insert pan placed on the toilet bowl at the MEC restroom by MEC staff, in the presence of their parent/guardian. As done for the urine collection materials used for older NHANES participants, the commode insert had been acid washed and individually packaged to eliminate metal contamination and ensure that the collected urine could also be analyzed for select metals (http://www.cdc.gov/nchs/features/nhanes_mec_collects_health_data.htm). Participating children had up to two attempts during their scheduled MEC exam to provide the urine; target volume was 60 mL. The urine collection protocol for 3–5 year old children included specific steps for the placement and use of the commode insert pan. MEC staff provided detailed instructions to the child's parent/guardian for the proper collection and handling of the commode insert to minimize external contamination. MEC staff also collected the urine container from the parent/guardian immediately after the child urinated and delivered to the MEC lab where the specimen was processed following NHANES approved procedures for the collection of urine from participants ≥6 years old (e.g., https://www.cdc.gov/nchs/data/nhanes/nhanes_15_16/2016_MEC_Laboratory_Procedures_Manual.pdf). The study protocol as well as the NHANES protocol were approved by the NCHS Research Ethics Review Board (ERB).

We accessed the demographic variables from NHANES and restricted biomarkers data from the present pilot study through the NCHS Research Data Center (RDC). Analysis of restricted data through the NCHS RDC was approved by the NCHS ERB.

2.2. Urinary biomarker concentrations

The urine samples were shipped on dry ice to CDC's NCEH laboratory and stored at or below −20 °C until analyzed. We used isotope-dilution coupled to mass spectrometry for the quantification of 52 urinary biomarkers (Table 2), already measured among NHANES participants ≥6 years of age, using previously described analytical chemistry methods (Davis et al., 2013; Kuklenyik et al., 2013; Li et al., 2014; Odetokun et al., 2010; Silva et al., 2013; Ye et al., 2005, 2006). Based on the volume of urine collected, the number of samples varied

slightly by method: phenols and parabens (N = 118); phthalates and plasticizers (N = 118); polycyclic aromatic hydrocarbons (PAHs, N = 119); and pesticides (N = 122). Calibration standards, quality control, and reagent blank samples were included in each analytical batch along with the study samples. The 52 urinary biomarkers and limits of detection (LOD), which, depending on the analyte, ranged from 0.01 μg/L to 1.0 μg/L are shown in Table 2.

2.3. Statistical analysis

We used SAS (version 9.3; SAS Institute Inc.; Cary, North Carolina) to perform statistical analyses. Of note, because of the convenience sampling nature of the population included in this pilot study, all analyses were unweighted (as opposed to weighted methods appropriate for the complex survey data typically used for NHANES biomarkers results). For concentrations below the LOD, we imputed a value equal to the LOD divided by the square root of 2 (Hornung and Reed, 1990).

On the basis of information reported by the child's parent or guardian, we categorized race/ethnicity as non-Hispanic black, non-Hispanic white and other, and All Hispanic. For each sex and race/ethnic group, we calculated the geometric mean (GM), if the frequency of detection was greater than 60%, and distribution percentiles for both volume-based (μg/L) and creatinine-corrected concentrations (μg/g creatinine). For the calculations of creatinine-corrected concentrations, we did not exclude any creatinine values, even those <30 mg/dL, an arbitrary cutoff concentration suggestive of excessive urine dilution in adults (Barr et al., 2005), because creatinine excretion depends on muscle mass which is much lower in young children compared to adults (Koch et al., 2011).

We determined the number of individual biomarkers detected in each child. We also performed principal components analysis (PCA) using SAS PROC FACTOR for analytes detected in at least 60% of samples (N = 38 biomarkers). As suggested before (Myridakis et al., 2015, 2016), to minimize potential bias because of the relatively low creatinine concentrations in young children, we conducted PCA on the volume-based log transformed urinary biomarkers concentrations (i.e., without correction for urinary dilution). PCA identified the maximum extent of mutual correlation between biomarkers by extracting latent factors or principal components from the detected biomarkers; the coefficients defining these linear combinations, called factor loadings, are the correlation coefficients of each biomarker with that component (Pang et al., 2016). The components are orthogonal (i.e., statistically independent) by using the varimax rotation method and, therefore, biomarkers loaded (i.e., grouped) within one component are considered to be uncorrelated with biomarkers included in other components. We retained all principal factors with eigenvalues ≥1.0 and considered factor loadings >0.5 to suggest high loadings. Because PCA omits individuals with any missing observations, the analysis was restricted to the 115 children with valid results for all target analytes.

3. Results

Ninety eight percent of parents of 3–5 year olds agreed to have their children participate in the pilot. Of those children, 83% provided 60 mL urine (63% on their first attempt and another 20% after a second attempt) to be analyzed for environmental chemicals. After the

two collection attempts, 84% of children provided 50 mL urine, 88% gave 40 mL and 94% only 30 mL. For this pilot, we analyzed the urine if the volume collected was at least 60 mL, the pre-established target volume. In this convenience sample of 122 children 3–5 years of age, most were Hispanic (64.8–66.1%), about one fifth were non-Hispanic white or of other race/ethnicities (20.2–21.3%), and about one seventh were non-Hispanic black (13.6–14.3%) (Table 1). The pilot included more boys (59.0–59.7%) than girls (40.3–41.0%).

Table 2 includes summary statistics for the volume-based concentrations of all 52 chemicals measured; we present the creatinine-corrected results in Table S1. We also present results by sex (Table S2) and race/ethnicity (Table S3). However, we did not compare the concentrations by sex or race/ethnicity because the sample size was relatively small particularly for certain demographic subgroups.

Creatinine concentration [median (interquartile range)] was 49 (30–76) mg/dL, similar to the creatinine concentrations reported among Canadian 3–5 year old children (61 (27–86) mg/dL) (Health Canada, 2013); thirty one of the samples had creatinine concentrations below 30 mg/dL. To minimize potential bias because of the relatively low creatinine concentrations in young children, previous studies recommended conducting PCA for the uncorrected concentrations (Myridakis et al., 2015, 2016). We also conducted PCA on the creatinine-corrected concentrations (Table S4), but results with corrected and uncorrected concentrations were similar. Therefore, we will only discuss the PCA on the uncorrected concentrations.

We detected at least one of 48 analytes in 10.7%–100% of the samples, including 23 individual pesticides, phenols, phthalates/plasticizers, and PAHs biomarkers in 95–100% of the children (Table 2). The interquartile ranges varied depending on the analyte and were broader for methyl and propyl paraben, triclosan, the sunscreen agent benzophenone-3 and 3-diethyl-carbamoyl benzoic acid (DCBA), a biomarker of exposure to the insect repellent N,N-diethyl-m-toluamide (DEET), than for the other compounds (Table 2). The highest GM was for methyl paraben (40.8 μg/L); benzophenone-3 displayed the highest GM (16.7 μg/L) among the phenols examined while monoethyl phthalate had the highest GM (19.3 μg/L) among the phthalates and alternative plasticizers measured. 2-Hydroxynaphthalene, a specific metabolite of naphthalene (CDC, 2009), was the PAH biomarker with the highest GM (3.74 μg/L). Among the various pesticides biomarkers measured, DCBA, a major metabolite of DEET (Selim et al., 1995), had the highest GM (2.3 μg/L).

The median number of biomarkers detected was 37 of a total of 52 measured (Fig. 1): nine of 19 (pesticides), five of nine (phenols and parabens), 13 of 14 (phthalates/plasticizers), and 10 of 10 (PAHs).

We conducted PCA and retained seven principal components with eigenvalues ≥1.0 which explained 72% of the total variance (Table 3). All of the PAH metabolites except for 1-hydroxynaphthalene comprised component 1 (loading factors: 0.51–0.77) which explained most of the variance (44.4%). Monoethyl phthalate, a metabolite of diethyl phthalate (CDC, 2009) was also included in component 1 (loading factor: 0.43). Eight phthalate metabolites and cyclohexane-1,2-dicarboxylic acid monohydroxyisononyl ester, a biomarker of exposure

to the non-phthalate plasticizer di(isononyl) cyclohexane-1,2-dicarboxylate (DINCH) grouped in component 2 (loading factors: 0.51–0.90). The organophosphate insecticide metabolites dimethyl phosphate, dimethyl thiophosphate, diethyl phosphate, 3,5,6-trichloro-2-pyridinol, and p-nitrophenol, the herbicide 2,4 dichlorophenoxyacetic acid, 1-hydroxynaphthalene, and the two phthalate metabolites monocarboxy-isononyl phthalate and monomethyl phthalate comprised component 3 (loading factors: 0.41–0.76). Monobenzyl phthalate, the non-specific pyrethroid metabolite 3-phenoxybenzoic acid, the DEET metabolite DCBA, bisphenol A (BPA), and benzophenone-3 grouped in component 4 (loading factors: 0.36–0.62). 2,4-Dichlorophenol and 2,4 dichlorophenol were included in component 5 (loading factors: 0.72–0.84). Methyl and propyl parabens exclusively clustered in component 6 (loading factor ~ 0.90) while triclosan comprised component 7 (Table 3).

4. Discussion

The results of the present feasibility study demonstrate that urine specimens from 3 to 5 year old children can be successfully collected from NHANES participants and that the collected urine can be analyzed for select environmental chemical biomarkers. As a result, starting with the 2015–2016 survey cycle, the NHANES biomonitoring program was expanded to include urinary biomarkers for 3–5 year old participants (CDC, 2016). These biomonitoring data may assist in identifying main exposure sources among young children and inform future research in children's environmental health.

Many of the biomarkers evaluated eliminate in urine after exposure to ubiquitous environmental chemicals (e.g., phthalates, parabens, bisphenol A), but exposure to or contamination with these chemicals could also occur during urine collection, particularly because of the additional provisions necessary to collect the urine from young children compared to adults (Lee and Arbuckle, 2009). To minimize external contamination during the collection and processing of the urine, the protocol was designed to avoid materials known to contain the target analytes (e.g., wipe-containing parabens) and urine was collected only after the MEC staff instructed the child's parent/guardian regarding the proper procedures. To further evaluate the adequacy of the collection protocol, we determined the detection frequencies, concentration ranges and correlations among the various biomarkers in this group of children and compared them to available data for other populations of North American children (CDC, 2015; Health Canada, 2013). Because the biomarkers urinary concentrations result from normal daily activities (e.g., use of products, food consumption), detection and concentrations of these biomarkers tend to be quite comparable by chemical class and age group regardless of the nature and sample size of the population. For example, BPA has consistently been detected in the urine of children in the United States and Canada with geometric mean concentrations between ~1.5–3 μg/L during similar time periods (CDC, 2015; Health Canada, 2013; Hoepner et al., 2013; Stacy et al., 2016; Wolff et al., 2010). However, contamination, if it occurred, would most likely only affect select biomarkers thus altering the expected detection patterns, concentration ranges and correlations among the various biomarkers. As discussed below, the results of the present study suggest that contamination did not occur and confirm the success of the designed approach for collecting and analyzing urine from young children for biomonitoring purposes.

In this convenience sample of American children 3–5 years of age, we detected 12 biomarkers (methyl paraben, benzophenone-3, four PAH metabolites, six phthalate metabolites) in all children, and 13 other biomarkers, including BPA, propyl paraben, 2,4- and 2,5 dichlorophenol, p-nitrophenol, five PAH metabolites, and three phthalate metabolites, in more than 90% of children.

Median concentrations in these 3–5 year old children appear to be similar to national estimates reported previously in NHANES participants 6–11 years of age (CDC, 2015) and among children 3–5 years of age who participated in the Canadian Health Measures Survey (Health Canada, 2013) (Fig. 2). The interquartile ranges varied depending on the biomarker. Use of certain household and personal care products can result in exposures to phthalates, parabens, phenols and pesticides among infants and young children (Dyk et al., 2011; Larsson et al., 2014; Lewis et al., 2013; Philippat et al., 2015; Sathyanarayana et al., 2008). Interestingly, the reported concentrations among different populations of children, regardless of sample size and location, are fairly uniform in developed countries (CDC, 2015; Frederiksen et al., 2014; Fromme et al., 2016; Health Canada, 2013; Stacy et al., 2016; Wolff et al., 2010) suggesting widespread and likely similar exposures and exposure sources among children to these chemicals. Therefore, in this sample of pre-school aged children, like in other populations of children before, the observed wide range of concentrations for methyl and propyl paraben, triclosan, benzophenone-3 and DCBA likely suggest that consumer and personal care products could have contributed to higher than average exposures to these chemicals or their precursors at least in some of these children. Future research may shed light to identify relevant sources of exposure to these chemicals among children.

PCA has been used to a certain extent to quantify correlations among exposures to environmental chemicals (Frederiksen et al., 2009; Kim et al., 2015; Robinson et al., 2015); recently, PCA was used to assess patterns of exposure to biomarkers of phthalates, parabens, certain pesticides and BPA among young children (Myridakis et al., 2015,2016). For this group of 3–5 year olds, PCA suggested seven distinct principal components which described almost 75% of the variance. A loading plot of the two major components (Fig. 3) suggested clear groupings among the biomarkers in agreement with the groupings expected from true exposures and not spurious sources such as external contamination. These results provide further proof of the success of this feasibility study. All PAH metabolites as well as the DINCH and most phthalates metabolites, with the exception of monomethyl and monobenzyl phthalates, clearly separated in two major groups. Several other biomarkers loosely grouped together: all of the pesticides biomarkers, the two dichlorophenols, chemical intermediates used in many industrial and consumer products applications including pesticides manufacturing (Ye et al., 2014), monomethyl phthalate (the major metabolite of dimethyl phthalate which can be used in some pesticide formulations (Zota et al., 2014)), monobenzyl phthalate whose precursor is used as a plasticizer (Zota et al., 2014), the industrial intermediate BPA, and the sunscreen agent benzophenone-3. Lastly, the antibacterial agent triclosan and the two preservatives methyl- and propylparaben appeared to cluster in one other group. These grouping patterns might have reflected common exposure sources or groups of biomarkers that were detected at consistently similar concentrations or concentration ranges among this group of children. For example, the

triclosan/parabens relationship may relate to exposures by use of personal care products, while the relationships within phthalates, PAHs and pesticides could reflect sources such as diet and household-related exposures (e.g., dust, housing materials). The fact that chemical classes generally loaded on a single PCA component suggested high within-class correlation among biomarkers; we speculate that such correlation is related to diet and other lifestyle habits.

In conclusion, we report that urine collected from 122 children 3–5 years old from an NHANES feasibility study could successfully be analyzed for 52 environmental chemicals. We detected 25 biomarkers of plasticizers, combustion products, personal-care product chemicals, and pesticides in more than 90% of this convenience sample of American children. Starting with NHANES 2015–2016, analysis of the urine biomarker data collected from 3 to 5 year olds will provide important information about exposure to select chemicals at the national level among this age group.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

BPA	bisphenol A
CDC	Centers for Disease Control and Prevention
DCBA	3-diethyl-carbamoyl benzoic acid
DINCH	di(isononyl) cyclohexane-1,2-dicarboxylate
DEET	*N,N*-diethyl-*m*-toluamide
EPA	Environmental Protection Agency
ERB	Ethics Review Board
GM	geometric mean
LOD	limit of detection
MEC	Mobile Examination Center
NCEH	National Center for Environmental Health
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey

PAH	polycyclic aromatic hydrocarbon
PCA	principal components analysis
RDC	Research Data Center

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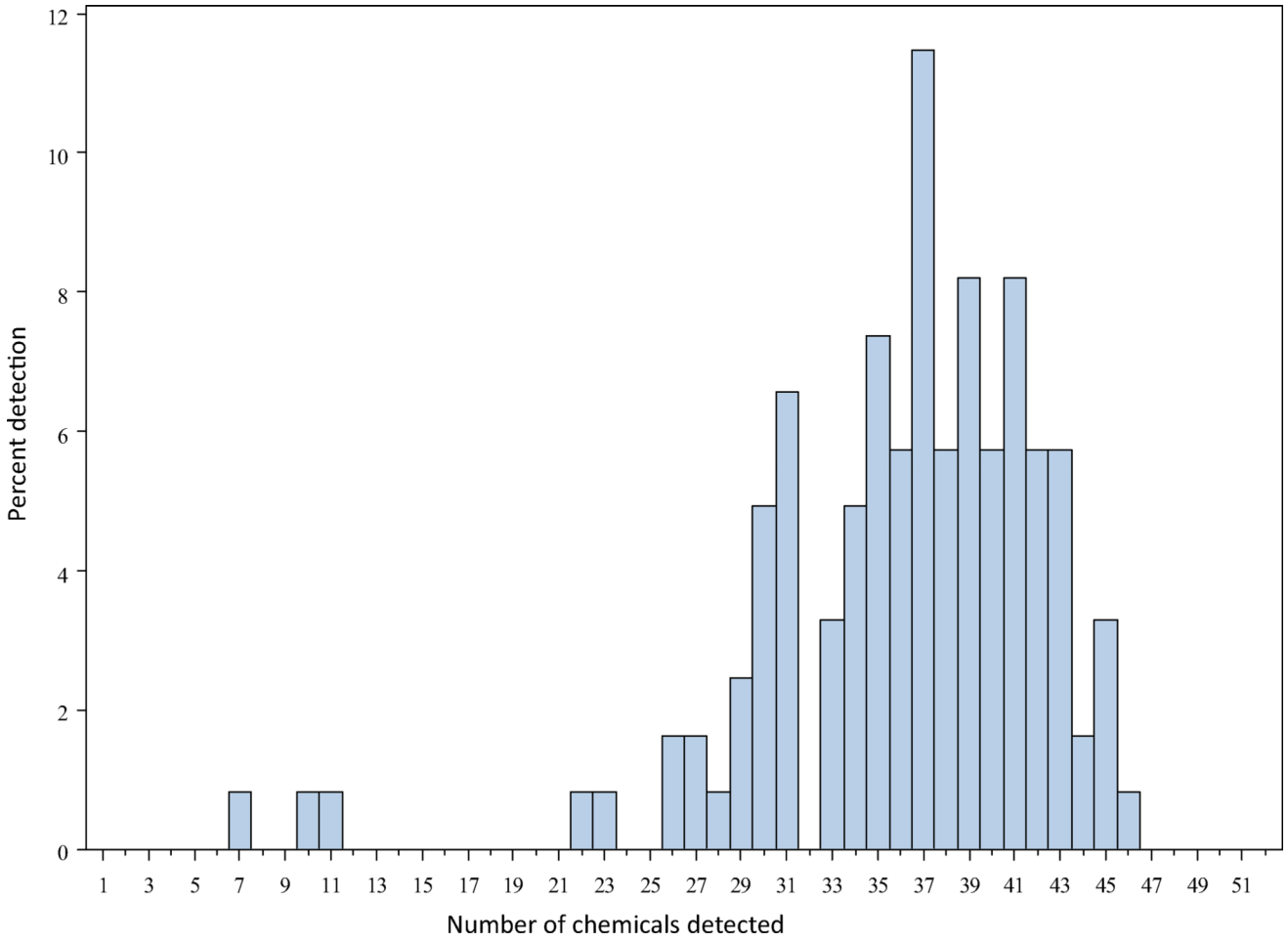

Fig. 1.

Distribution of the total number of biomarkers detected in a convenience sample of American children 3–5 years of age (n = 122).

Some of the biomarkers measured (e.g., dialkylphosphates) are metabolites of more than one parent compound while certain parent compounds (e.g., di(2-ethylhexyl phthalate)) may have multiple metabolites/biomarkers measured.

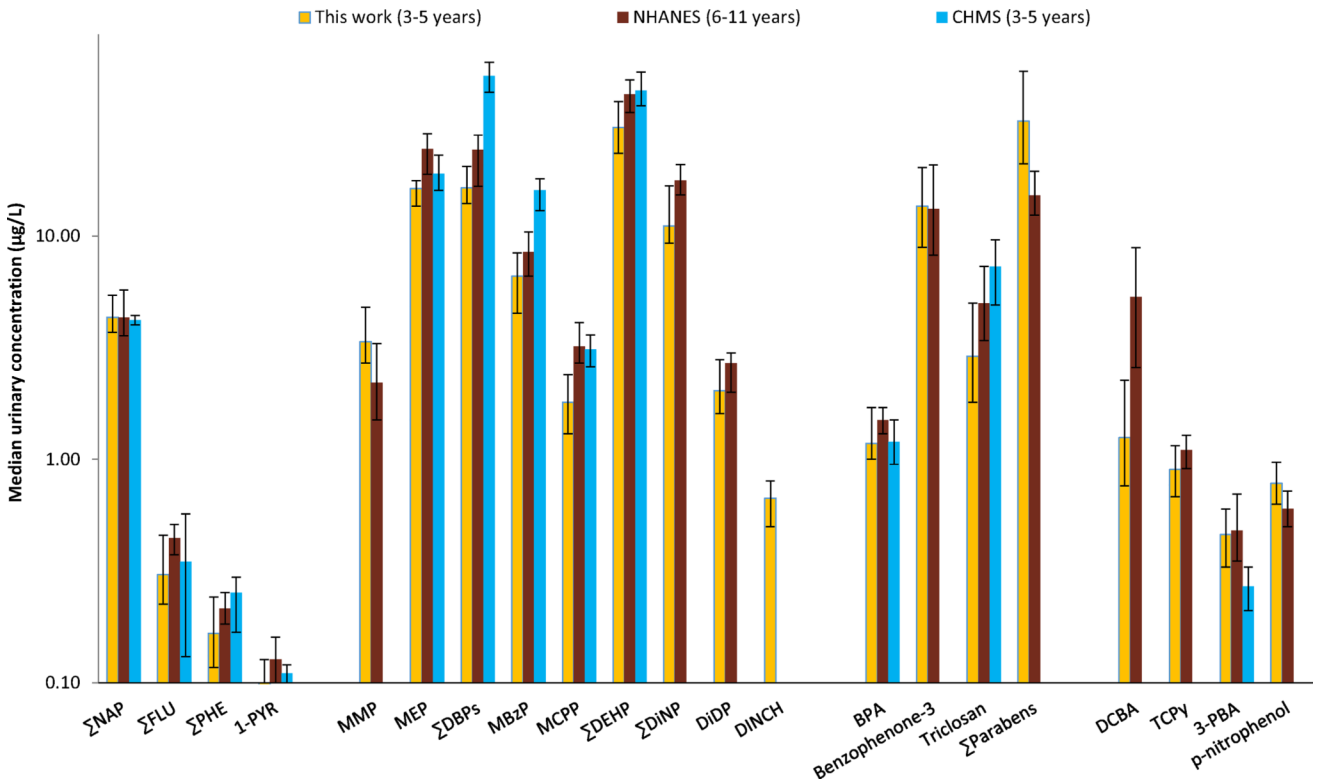

Fig. 2.

Median concentrations of select biomarkers measured as part of the National Health and Nutrition Examination Survey (NHANES), the Canadian Health Measures Survey (CHMS) and the present study of a convenience sample of American children 3–5 years of age. CHMS data are from 2009 to 2011 (Health Canada, 2013) and NHANES data are all weighted estimates from 2011 to 2012 (except for the pesticide biomarkers (2009–2010)) (CDC, 2015). Medians are not shown in the figure if values were below LOD (e.g., DINCH biomarkers in NHANES) or if biomarkers were not measured (e.g., DCBA, TCPy, di-isononyl phthalate (DiNP), di-isodecyl phthalate (DiDP), DINCH, *p*-nitrophenol, parabens, monomethyl phthalate (MMP), and benzophenone-3 in CHMS).

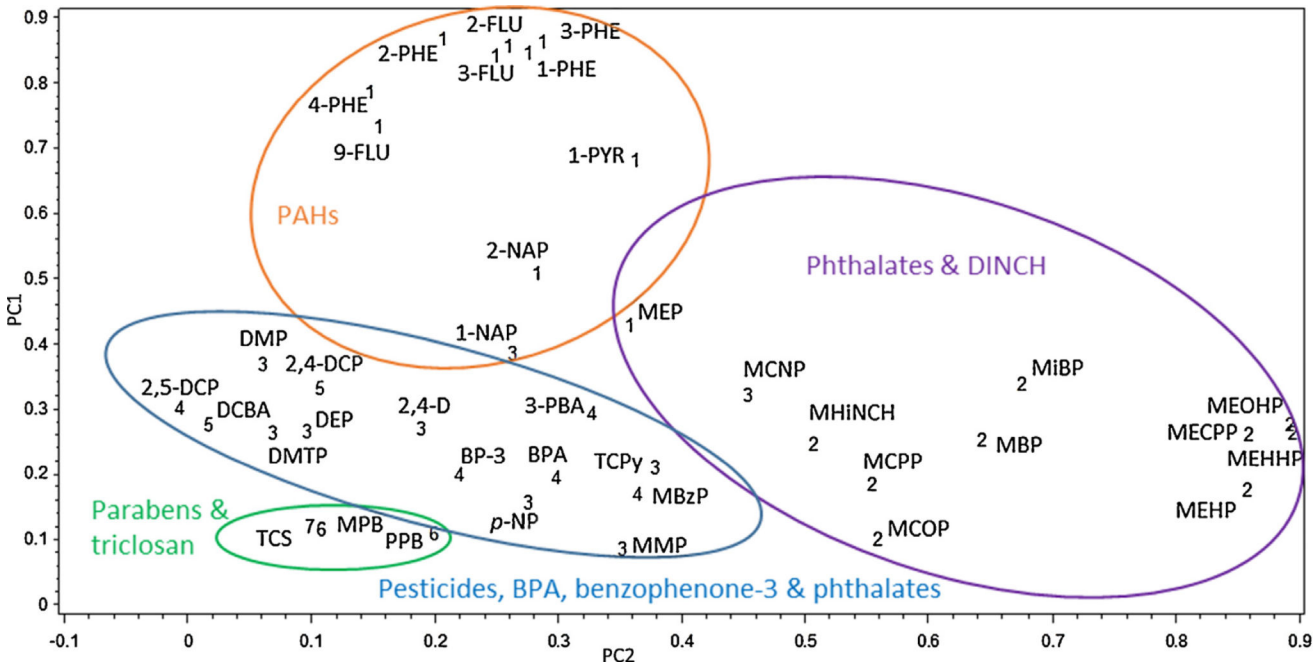

Fig. 3.

A loading plot of principal components analysis (PC1 vs PC2) of 38 urinary biomarkers in a convenience sample of American children 3–5 years of age. The numbers next to the abbreviated name of the biomarker represent the PCA component with the highest factor loading for that specific biomarker.

Table 1

Demographic characteristics and biomarkers measured in urine of a convenience sample of American children 3–5 years old.

Parent compound categories	Biomarkers No.	Sample size	Sex (%)		Race/ethnicity (%)		
			Male	Female	Non-Hispanic white & other	Non-Hispanic black	All Hispanic
Environmental phenols[a]	5	118	59.3	40.7	20.3	13.6	66.1
Parabens	4	118	59.3	40.7	20.3	13.6	66.1
Phthalates & DINCH	14	118	59.3	40.7	20.3	13.6	66.1
Herbicides	2	122	59	41	21.3	13.9	64.8
Insect repellents	3	122	59	41	21.3	13.9	64.8
Organophosphate Insecticides	10	122	59	41	21.3	13.9	64.8
Pyrethroid insecticides	4	122	59	41	21.3	13.9	64.8
PAHs	10	119	59.7	40.3	20.2	14.3	65.5

[a]Include 2,4-dichlorophenol and 2,5-dichlorophenol, chemical intermediates used in many industrial and consumer products applications.

Table 2

Geometric mean and selected percentiles of biomarkers concentrations in urine (in μg/L) of a convenience sample of American children 3–5 years of age (n= 122)[a].

Analyte	Abbreviated name	LODμg/L)	Detection frequency (%)	Geometric mean (μg/L)	25th percentile (μg/L)	50th percentile (μg/L)	75th percentile (μg/L)	95th percentile (μg/L)
Phthalates & DINCH								
Monomethyl phthalate	MMP	0.5	88.1	3 (1.9–4.8)	1.4 (0.7, 2.1)	3.4 (2.7, 4.2)	6.6 (5.3, 7.7)	23.8 (10.7, 415)
Monoethyl phthalate	MEP	0.6	100	19.3 (12.5–29.8)	8.8 (6.6, 10.7)	16.4 (13.3, 20)	29.9 (27.2, 42.9)	239 (124, 1396)
Mono-*n*-butyl phthalate	MnBP	0.4	100	10.4 (6.7–16.1)	4.3 (3.2, 5.9)	9 (7.5, 12.6)	23.6 (16.3, 29.9)	123 (60.5, 344)
Mono-isobutyl phthalate	MiBP	0.2	100	7.9 (5.1–12.2)	3.9 (2.8, 4.8)	8 (5.5, 10.6)	17 (13, 24.7)	45.4 (29.4, 1517)
Monobenzyl phthalate	MBzP	0.3	99.2	6.2 (3.9–9.9)	2.8 (1.6, 4.2)	6.65 (5, 9.9)	16.6 (11.4, 23.4)	43.3 (30.8, 125)
Mono-3-carboxypropyl phthalate	MCPP	0.2	91.5	1.8 (1.1–2.8)	0.9 (0.5, 1.1)	1.85 (1.4, 2.7)	4.4 (3.4, 6)	15.8 (8.3, 45.9)
Mono-2-ethylhexyl phthalate	MEHP	0.5	70.3	1 (0.7–1.4)	<LOD	0.8 (0.7, 1)	1.6 (1.2, 2.4)	7.8 (4.2, 30.1)
Mono-2-ethyl-5-hydroxyhexyl phthalate	MEHHP	0.2	100	9.2 (6.1–13.9)	5.1 (3.3, 5.7)	8.1 (6.8, 11.3)	17.6 (14.1, 25.9)	85.9 (40.1, 242)
Mono-2-ethyl-5-oxohexyl phthalate	MEOHP	0.2	100	6 (4–8.9)	3 (1.9, 3.8)	5.75 (4.6, 7.7)	12 (9, 16)	52.2 (24.4, 148)
Mono-2-ethyl-5-carboxypentyl phthalate	MECPP	0.2	100	17.4 (12–25.3)	8.7 (7.2, 9.6)	16.8 (12.8, 22.2)	33.7 (24.5, 47.9)	92.6 (68.9, 350)
Mono-isononyl phthalate	MiNP	0.5	43.2	*	<LOD	<LOD	0.8 (0.7, 1)	4.8 (1.7, 62.4)
Monocarboxyoctyl phthalate	MCOP	0.2	100	11.9 (7.6–18.7)	5.3 (3, 6.8)	11.2 (9.4, 16.9)	27.5 (21.1, 42.8)	82.6 (53.5, 373)
Monocarboxynonyl phthalate	MCNP	0.2	98.3	2 (1.4–3)	1.1 (0.7, 1.3)	2.1 (1.6, 2.8)	4.4 (3.2, 5.7)	12.6 (8.5, 57.8)
Cyclohexane-1,2-dicarboxylic acid monohydroxy isononyl ester	MHiNCH	0.4	66.1	0.8 (0.6–1.2)	<LOD	0.7 (0.5, 1)	1.4 (1.1, 2.6)	9.8 (3.9, 17)
Polycyclic aromatic hydrocarbons								
1-Hydroxynapthalene	1-NAP	0.044	99.2	0.819 (0.535–1.25)	0.368 (0.250, 0.443)	0.796 (0.607, 1.16)	1.89 (1.51, 2.42)	6.19 (3.61, 23.3)
2-Hydroxynapthalene	2-NAP	0.04	100	3.74 (2.63–5.32)	1.77 (1.50, 2.39)	3.58 (3.02, 4.50)	6.94 (5.77, 9.47)	19.9 (14.8, 60.2)
2-Hydroxyfluorene[b]	2-FLU	10[b]	100	130 (96.6–176)	74 (58, 83)	131 (104, 159)	223 (203, 283)	528 (423, 887)
3-Hydroxyfluorene[b]	3-FLU	10[b]	99.2	61.2 (45.9–81.6)	35 (30, 42)	53 (47, 67)	104 (84, 131)	294 (200, 467)
9-Hydroxyfluorene[b]	9-FLU	10b	100	126 (94.3–168)	73 (55, 87)	123 (99, 153)	229 (181, 288)	474 (422, 1058)
1-Hydroxyphenanthrene[b]	1-PHEN	10[b]	99.2	75.3 (55.8–102)	43 (33, 54)	78 (61, 90)	133 (111, 151)	339 (230, 878)
2-Hydroxyphenanthrene[b]	2-PHEN	10[b]	93.3	31.3 (23.9–41.1)	18 (16, 22)	31 (25, 37)	49 (42, 65)	128 (103, 229)
3-Hydroxyphenanthrene[b]	3-PHEN	10b	95.8	46.8 (34.3–63.8)	26 (21, 31)	48 (36, 60)	89 (68, 101)	203 (159, 489)
4-Hydroxyphenanthrene[b]	4-PHEN	10[b]	69.7	16.2 (12.4–21)	<LOD	15 (12, 18)	27 (23, 31)	72 (48, 165)
1-Hydroxypyrene[b]	1-PYR	10[b]	100	91.4 (67–125)	45 (41, 63)	95 (74, 116)	162 (140, 197)	430 (271, 857)

Analyte	Abbreviated name	LODμg/L)	Detection frequency (%)	Geometric mean (μg/L)	25th percentile (μg/L)	50th percentile (μg/L)	75th percentile (μg/L)	95th percentile (μg/L)
1-Hydroxynapthalene	1-NAP	0.044	99.2	0.819 (0.535–1.25)	0.368 (0.250, 0.443)	0.796 (0.607, 1.16)	1.89 (1.51, 2.42)	6.19 (3.61, 23.3)
2-Hydroxynapthalene	2-NAP	0.04	100	3.74 (2.63–5.32)	1.77 (1.50, 2.39)	3.58 (3.02, 4.50)	6.94 (5.77, 9.47)	19.9 (14.8, 60.2)
2-Hydroxyfluorene[b]	2-FLU	10[b]	100	130 (96.6–176)	74 (58, 83)	131 (104, 159)	223 (203, 283)	528 (423, 887)
Parabens								
Butyl paraben	BPB	0.1	26.3	*	<LOD	<LOD	0.1 (0.07, 0.2)	2.1 (0.7, 266)
Ethyl paraben	EPB	1	32.2	*	<LOD	<LOD	1.5 (0.71, 4.4)	79.4 (10.5, 634)
Methyl paraben	MPB	1	100	40.8 (20.9–79.5)	9.9 (5.7, 13.3)	30.1 (18.3, 53.7)	203 (80.2, 371)	992 (685, 2650)
Propyl paraben	PPB	0.1	99.2	4.5 (2.2–9)	1.1 (0.7, 1.7)	3.3 (1.9, 6.9)	14.6 (9.4, 38.7)	245 (71.4, 688)
Environmental phenols								
Benzophenone-3	BP-3	0.2	100	16.7 (9.1–30.6)	5.1 (3.2, 7.6)	14.0 (9.6, 20.6)	41.7 (31.4, 93.5)	509 (300, 1250)
Bisphenol A	BPA	0.1	98.3	1.4 (0.9–2)	0.7 (0.5, 0.9)	1.2 (1.1, 1.7)	2.9 (2.3, 4.2)	9.6 (6.1, 13.2)
Triclosan	TCS	1	78.8	4.6 (2.5–8.6)	1.1 (0.71, 1.5)	3.1 (2.1, 4.7)	11.7 (7.7, 35)	211 (67.1, 931)
Other pesticides								
2,4-dichlorophenol	2,4-DCP	0.1	96.6	0.5 (0.3–0.8)	0.2 (0.2, 0.3)	0.5 (0.3, 0.6)	1.1 (0.8, 1.6)	10.5 (2.8, 39.5)
2,5-dichlorophenol	2,5-DCP	0.1	97.5	1.8 (0.9–3.6)	0.5 (0.4, 0.6)	1.25 (0.8, 1.7)	3.9 (2, 8.2)	142 (43.9, 1680)
Herbicides								
2,4-Dichlorophenoxyacetic acid	2,4-D	0.15	61.5	0.2 (0.2–0.3)	<LOD	0.21 (0.16, 0.28)	0.42 (0.35, 0.53)	1.3 (0.92, 4.25)
2,4,5-Trichlorophenoxyacetic acid	2,4,5-T	0.1	0	*	<LOD	<LOD	<LOD	<LOD
Insect repellent								
N,N-diethyl-m-toluamide	DEET	0.083	3.3	*	<LOD	<LOD	<LOD	<LOD
3-diethyl-carbamoyl benzoic acid	DCBA	0.475	68	2.3 (1.1–5.1)	<LOD	1.25 (0.76, 2.26)	6.8 (4.35, 20.5)	63.4 (47.7, 12600)
N,N-diethyl-3-hydroxymethylbenzamide	DHMB	0.089	9.8	*	<LOD	<LOD	<LOD	0.399 (0.109, 38.6)
Pyrethroid insecticides								
3-phenoxybenzoic acid	3-PBA	0.1	70.5	0.4 (0.2–0.6)	<LOD	0.46 (0.33, 0.6)	0.89 (0.77, 1.32)	3.72 (3.36, 37.5)
4-fluoro-3-phenoxybenzoic	4-F-3-PBA	0.1	10.7	*	<LOD	<LOD	<LOD	0.21 (0.14, 0.61)
cis-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid	DBCA	0.5	3.3	*	<LOD	<LOD	<LOD	<LOD
trans-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid	trans-DCCA	0.6	15.6	*	<LOD	<LOD	<LOD	2.52 (1.5, 17.6)
Organophosphate insecticides								
3,5,6-trichloropyridinol	TCPy	0.1	89.3	0.8 (0.5–1.2)	0.4 (0.18, 0.52)	0.9 (0.68, 1.15)	1.79 (1.55, 2.46)	3.99 (3.6, 10.5)
Malathion dicarboxylic acid	MDA	0.5	25.4	*	<LOD	<LOD	0.5 (0.35, 0.58)	1.12 (0.85, 19.9)
2-isopropyl-4-methyl-6-hydroxypyrimidine (Oxypyrimidine)	IMPY	0.1	18	*	<LOD	<LOD	<LOD	0.35 (0.28, 1.9)

Analyte	Abbreviated name	LODμg/L)	Detection frequency (%)	Geometric mean (μg/L)	25th percentile (μg/L)	50th percentile (μg/L)	75th percentile (μg/L)	95th percentile (μg/L)
para-Nitrophenol	PNP	0.1	95.9	0.8 (0.5–1.1)	0.46 (0.27, 0.56)	0.775 (0.63, 1.07)	1.37 (1.22, 1.62)	3.81 (2.42, 10.1)
Dimethylphosphate	DMP	0.1	60.7	1.5 (0.9–2.6)	0.354 (0.354, 0.354)	1.31 (0.612, 1.99)	3.78 (2.71, 6.98)	24.1 (20.7, 87.3)
Diethylphosphate	DEP	0.1	84.4	1.7 (0.9–3.2)	0.631 (0.171, 1.01)	1.80 (1.41, 2.89)	5.74 (4.19, 11.7)	26.1 (21.4, 81.5)
Dimethylthiophosphate[c]	DMTP	0.1	78.2	1.3 (0.6–2.6)	0.174 (0.071, 0.696)	1.58 (1.17, 2.35)	5.88 (3.26, 8.14)	44.1 (14.1, 409)
Diethylthiophosphate	DETP	0.25	39.3	*	<LOD	<LOD	0.509 (0.419, 1.4)	4.01 (3.46, 13.9)
Dimethyldithiophosphate[c]	DMDTP	0.5	19.8	*	<LOD	<LOD	<LOD	2.42 (1.64, 54.6)
Diethyldithiophosphate	DEDTP	0.5	0	*	<LOD	<LOD	<LOD	<LOD

*Not calculated; percentage of results <LOD too high.

[a]95% confidence intervals are shown in parenthesis.

[b]Concentrations are in ng/L.

[c]Three DMTP and one DMDTP results were missing.

Table 3

Rotated component matrix in principal components analysis and total variance explained.[a]

Analyte		Factor loading						
		PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
2-Hydroxyphenanthrene	2-PHE	**0.87**	0.21	0.19	0.12	0.12	0.1	0.12
3-Hydroxyphenanthrene	3-PHE	**0.86**	0.29	0.21	0.16	0.15	0.1	0.1
2-Hydroxyfluorene	2-FLU	**0.86**	0.26	0.24	0.04	0.22	0.1	0.05
1-Hydroxyphenanthrene	1-PHE	**0.84**	0.28	0.2	0.22	0.17	0.05	0.11
3-Hydroxyfluorene	3-FLU	**0.84**	0.25	0.23	0.03	0.16	0.04	0
4-Hydroxyphenanthrene	4-PHE	**0.79**	0.15	0.35	0.23	0.03	0.06	0.07
9-Hydroxyfluorene	9-FLU	**0.73**	0.15	0.37	0.3	0.05	0.07	0.22
1-Hydroxypyrene	1-PYR	**0.68**	0.36	0.25	0.33	0.23	0.08	0.05
2-Hydroxynapthalene	2-NAP	**0.51**	0.28	0.12	0.12	0.35	0.25	−0.09
Monoethyl phthalate	MEP	0.43	0.36	0.16	0.27	0.1	0.29	0.04
Mono-2-ethyl-5-hydroxyhexyl phthalate	MEHHP	0.26	**0.9**	0.16	0.17	0.01	0.12	0.07
Mono-2-ethyl-5-oxohexyl phthalate	MEOHP	0.28	**0.89**	0.18	0.16	0.01	0.11	0.07
Mono-2-ethyl-5-carboxypentyl phthalate	MECPP	0.26	**0.86**	0.24	0.12	0.06	0.13	0.11
Mono-2-ethylhexyl phthalate	MEHP	0.18	**0.86**	0.18	−0.03	0	0.17	0.07
Mono-isobutyl phthalate	MiBP	0.34	**0.68**	0.03	0.41	0.13	−0.02	−0.21
Mono-n-butyl phthalate	MBP	0.25	**0.64**	0.03	0.44	0	−0.03	−0.06
Monocarboxyoctyl phthalate	MCOP	0.1	**0.56**	0.47	0.27	0.22	0.07	0.29
Mono-3-carboxypropyl phthalate	MCPP	0.18	**0.55**	0.42	0.35	0.24	−0.09	0.25
Cyclohexane-1,2-dicarboxylic acid	MHiNCH	0.24	**0.51**	0.2	0.26	0.19	0.19	−0.03
monohydroxy isononyl ester Dimethyl thiophosphate	DMTP	0.26	0.07	**0.76**	0.01	−0.09	0.09	0.16
Dimethylphosphate	DMP	0.37	0.06	**0.7**	0.01	−0.19	0.04	0.31
para-Nitrophenol	p-NP	0.16	0.28	**0.61**	0.36	0.05	−0.06	−0.06
Diethylphosphate	DEP	0.27	0.1	**0.58**	0.17	0.15	0.1	−0.1
2,4-Dichlorophenoxy acetic acid	2,4-D	0.27	0.19	**0.53**	0.26	0.33	0.06	0.08
1-Hydroxynapthalene	1-NAP	0.38	0.26	**0.53**	0.13	0.13	0.01	−0.16
Monocarboxynonyl phthalate	MCNP	0.32	0.45	**0.51**	0.2	0.24	0.06	0.21
Monomethyl phthalate	MMP	0.08	0.35	**0.5**	−0.15	0.16	0.22	−0.06

Analyte		Factor loading						
		PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
3,5,6-trichloropyridinol	TCPy	0.21	0.38	0.41	0.2	0.24	0.08	0.14
Monobenzyl phthalate	MBzP	0.17	0.37	0.24	**0.62**	0.03	0.15	−0.13
3-phenoxybenzoic acid	3-PBA	0.29	0.33	0.08	**0.62**	−0.08	−0.07	0.28
Benzophenone-3	BP-3	0.2	0.22	0.22	**0.54**	0.15	0.23	0.07
3-diethyl-carbamoyl benzoic acid	DCBA	0.3	−0.01	−0.01	0.45	0.2	0.33	0.35
Bisphenol A	BPA	0.19	0.3	0.26	0.36	0.32	0.15	0
2,5-dichlorophenol	2,5-DCP	0.28	0.02	0.09	0.07	**0.84**	0.07	0.07
2,4-dichlorophenol	2,4-DCP	0.33	0.11	0.07	0.04	**0.72**	0.04	0.45
Propyl paraben	PPB	0.11	0.2	0.02	0.11	0	**0.9**	−0.03
Methyl paraben	MPB	0.12	0.11	0.17	0.07	0.11	**0.89**	0.1
Triclosan	TCS	0.12	0.1	0.11	0.06	0.18	0.04	**0.83**
Eigenvalue		16.9	2.95	1.93	1.84	1.6	1.22	1.11
Total variance (%)		44.4	7.77	5.09	4.84	4.21	3.21	2.93
Cumulative (%)		44.4	52.2	57.3	62.1	66.3	69.5	74.5

[a]Factor loadings are bolded if > 0.50. Only analytes detected in at least 60% of samples were included in the PCA.