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Determinants of phthalate exposure among a U.S.-based group of Latino workers.

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Abstract

Background: Phthalates are endocrine disrupting compounds linked to various adverse health effects. U.S. national biomonitoring data indicate that select minority subgroups may suffer disparate exposures to phthalates. Still, exposures and their respective determinants among these subgroups are not well characterized.

Objective: We sought to examine determinants of phthalate exposure in a subsample of US-based Latino adults.

Methods: We conducted a cross-sectional study on 94 Latino immigrant adults in Maryland. Participants were ≥18 years of age and working in a service-based industry. We administered an interviewer-administered questionnaire to capture information on potential exposure determinants (e.g., demographic characteristics, consumer product use, and workplace exposures and behaviors) and using HPLC/MS-MS we quantified concentrations of 9 urinary phthalate metabolites: monoethyl phthalate (MEP, diethyl phthalate metabolite); mono-*n*-butyl phthalate (MBP, di-n-butyl phthalate metabolite); mono-isobutyl phthalate (MiBP, di-isobutyl phthalate metabolite; monobenzyl phthalate (MBzP, benzylbutyl phthalate metabolite); molar sum of di-2-ethylhexyl phthalate or DEHP metabolites [mono-2-ethylhexyl phthalate (MEHP), mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), and

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mono-(2-ethyl-5-carboxypentyl) phthalate (MECCP)]; and mono(3-carboxypropyl) phthalate (MCPP, a non-specific metabolite of several phthalates including di-*n*-butyl phthalate and di-*n*-octyl phthalate). DEHP was analyzed as the molar sum of four metabolites (ΣDEHP=MEHP +MEHHP+MECPP+MEOHP). Spearman correlations, Wilcoxon-Mann-Whitney, and Kruskal-Wallis tests were conducted to assess bivariate associations between metabolite concentrations and potential exposure determinants. Covariates associated with metabolites at $p<0.10$ in bivariate analyses were included in multivariable linear regression models to assess the independent effects of predictors on metabolite concentrations.

Results: Uncorrected median phthalate metabolite concentrations were lower in our study population (<LOD-12.8 μg/L) compared to those reported in the US general population (1.0–28.8 μg/L) and adult populations in other countries. Geometric mean specific gravity-corrected concentrations for metabolites detected in >50% of samples ranged between 1.4 and 23.6 μg/L. While we observed some significant associations with select predictors in our bivariate analysis, select associations were attenuated in multivariable regression models. In our final multivariable linear regression models, we found that use of bleach (ß=1.15, 95%CI:0.30, 2.00) and consumption pasta/rice/noodles (ß=0.87, 95%CI: 0.27, 1.46) was positively associated with MBzP concentrations. MEP concentrations were inversely associated with use of furniture polish (ß= −1.17, 95%CI: −2.21, −0.12) and use of scented dryer sheets (ß=−1.08, 95%CI: −2.01, −0.14). Lastly, ΣDEHP concentrations were inversely associated with use of degreaser ($ß_{DEHP}$=−0.65, 95%CI: −1.25, −0.05).

Conclusions: In this predominantly U.S.-based Central American subsample of adults, we observed lower metabolite concentrations than those previously reported in other U.S. studies and other countries. Our findings could be due, in part, to temporal trends in phthalate exposures and cultural differences related to exposure-related behaviors. While some exposure determinants were identified in our bivariate analyses, results from multivariable regression models did not provide clear results as many associations were attenuated. Environmental exposures may vary within minority subgroups and should be explored further in future studies to further inform exposure mitigation strategies.

Keywords

Phthalates; Latino; adult; determinants; personal care products

INTRODUCTION

Phthalates are synthetic high production volume chemicals classified into two groups as low and high molecular weight (LMW, HMW) phthalates based on the number of carbon chains (Katsikantami et al., 2016). LMW phthalates, such as diethyl (DEP) and dimethyl (DMP) phthalate, have 1–4 carbon side chains, while HMW phthalates, such as di-2-ethylhexyl phthalate (DEHP) have ≥ 5 carbon side chains. The length of the side chain plays a role in the metabolism and excretion of phthalates, which can determine their toxicity potential (Hauser, 2005; National Research Council, 2008). LMW phthalates are mainly excreted as unconjugated monoesters, although some of them can also be further metabolized to oxidized metabolites (Koch et al. 2012). HMW phthalates undergo additional biotransformation and are excreted as oxidative metabolites (Hauser, 2005). The

glucuronidation in phase II biotransformation is reported to reduce the potential for biological toxicity (Hauser, 2005). Phthalates with 4–6 carbon side chains may be the most potent for some endpoints, such as male reproduction (National Research Council, 2006; Environmental Protection Agency (EPA), 2012; Gray, 2000).

LMW phthalates are widely used as solvents and fragrance stabilizers in products such as adhesives, detergents, personal care products, and cosmetics. HMW phthalates are used as plasticizers to impart flexibility and durability, and are commonly found in building materials, furnishings, and polyvinyl chloride plastics (PVC) (Godwin, 2010; Schettler, 2006). Phthalates are also found in medications, medical supplies, foods, and toys (Broe et al., 2018; Colacino et al., 2010; Malarvannan et al., 2019; McCombie et al., 2017). Their widespread use in consumer products has led to ubiquitous exposure in the U.S. general population and in other countries (Centers for Disease Control and Prevention (CDC), 2019; Koch et al., 2017; Shin et al., 2020). Exposure to phthalates may occur via ingestion, inhalation, and dermal and intravenous absorption (Schettler, 2006).

There are growing public health concerns related to phthalate exposures as these compounds are endocrine disruptors (Ohtani et al., 2000) that have been associated with various adverse effects, including respiratory problems (Ait Bamai et al., 2016), adverse pregnancy outcomes (Zhang et al., 2020), and metabolic-related diseases, such as type 2 diabetes, hypertension, and cardiovascular disease (Bai et al., 2017). Some phthalates are also reported to have antiandrogenic effects and there is increasing evidence from human and animal studies which suggests that *in utero* exposure to select phthalates may be associated with disorders of male reproductive development (De Falco et al., 2015). Elevated occupational exposure to both LMW and HMW phthalates may occur among select worker populations including those working in plastic manufacturing (Petrovičová et al., 2016). In the U.S. general population, national biomonitoring data indicate that women and minorities (Mexican-Americans and African Americans) are disproportionately exposed to phthalates, particularly LMW phthalates (Huang et al., 2014). Elevated exposures to phthalates among women are thought to result from personal care product use; however, it is not known why exposures are elevated among select minority groups (Silva et al., 2004; Kobrosly et al., 2012).

Identifying modifiable phthalate exposure determinants among minority subgroups is critical to mitigate potential environmental health disparities. Latinos represent a growing demographic in the United States, with projections of a steady rise in the percentage of those who are foreign-born (Colby and Ortman, 2017). While limited studies have evaluated phthalate exposures among select Latino subgroups (Mexican-Americans and Dominicans) in the U.S. (Holland et al., 2016; Whyatt et al., 2009), to our knowledge, exposure to phthalates among other Latino subgroups remains understudied. In the present study, we sought to fill a critical data gap by examining determinants of phthalate exposure in a U.S.-based subsample of Latino adults, predominantly from Central America.

METHODS

Study Population

Data for the present study was obtained from a cross-sectional study comprised of 156 Latino immigrant adults in Prince George's County, Maryland that aimed to assess workplace exposures and health behaviors among a Latino worker population. Participant recruitment was conducted between November 2017 and March 2018. Eligibility criteria for study participants included being ≥18 years of age, working in a service-based industry at the time of enrollment, and willing to provide biospecimens and complete an interviewer-administered questionnaire. The three service-based industries included facilities management (e.g., plumbers, landscapers, electricians), dining facilities (cooks and service staff in dining facilities), and custodial services in residential facilities. All study protocols were approved by the University of Maryland Institutional Review Board (IRB) prior to participant enrollment, and written informed consent was obtained from all study participants prior to any data and sample collection.

Data collection

Trained bilingual-bicultural study staff administered a questionnaire in the participant's preferred language (either English or Spanish) to capture information on demographic characteristics (e.g., age, sex, household income, length of time in the U.S., nativity), general health, workplace tasks and safety behaviors, and chemical exposures at the workplace and home (e.g., use of personal care products, cleaners, solvents). On the questionnaire, dietary and chemical exposures at home were categorized as "never," "rarely," "1–3 times per month," "1–3 times per week," "4–6 times per week," or "every day"; chemical exposures at the workplace were categorized as "never," "rarely," "1–3 days per week," or "4–5 days per week;" recent renovation projects and select home characteristics were categorized as yes/no; use of personal protective equipment at work was characterized as "never," "sometimes," "all the time" or "not necessary for my job." For the present analysis, based on the distribution of responses, we dichotomized variables for our data analysis such that "never" or "rarely" was one category and any use was another category. Lastly, we queried participants about not being able to afford balanced meals and the response options were "occurred frequently," "occurred sometimes," and "never." For our data analysis, these responses were further dichotomized such that any occurrence was categorized as "yes" and never was categorized as "no".

Exposure assessment of phthalates

To assess phthalate exposure, we collected a spot urine sample from each study participant. Samples were collected in phthalate-free polypropylene urine collection containers, aliquoted into cryovials, and stored at −80°C until laboratory analysis. Prior to storage, we measured specific gravity in each sample with a digital ATAGO refractometer (Atago USA, Inc.) to account for urine dilution in our analysis. We quantified concentrations of 9 phthalate metabolites, representing exposure to 6 parent phthalate compounds in each urine sample at the University of Maryland Exposome Small Molecule Core Facility (College Park, Maryland): monoethyl phthalate (MEP, a metabolite of diethyl phthalate, DEP); mono-*n*-butyl phthalate (MBP, a metabolite of di-n-butyl phthalate, DBP); mono-isobutyl phthalate

(MiBP, a metabolite of di-isobutyl phthalate (DiBP)); monobenzyl phthalate (MBzP, a metabolite of benzylbutyl phthalate, BBzP); four metabolites of di-2-ethylhexyl phthalate, DEHP [mono-2-ethylhexyl phthalate (MEHP), mono-(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono-(2-ethyl-5-oxohexyl) phthalate (MEOHP), and mono-(2-ethyl-5-carboxypentyl) phthalate (MECCP)]; and mono(3-carboxypropyl) phthalate (MCPP, a non-specific metabolite of several phthalates including di-*n*-butyl phthalate, DBP and di-*n*-octyl phthalate, DOP).

Concentrations of phthalate metabolites were quantified using high-performance liquid chromatography–isotope dilution–tandem mass spectrometry (HPLC/MS-MS) using a modified method based on a previously validated laboratory method (Centers for Disease Control and Prevention (CDC), 2010); limits of detection (LOD) ranged from 0.063 to 0.542 μg/L. Briefly, the laboratory method entailed thawing the frozen urine samples, which were then vortexed and sonicated for 5 minutes. Then, 100 μL of ammonium acetate buffer solution (1M, pH 6.5) containing 20 μL of a β-glucuronidase solution (enzyme from E. coli K12) and 2.5 μL internal standard (10 μg/mL) was added to 400 μL of urine. This mixture was incubated at 37 β for at least 90 min to induce the enzymatic cleavage of the conjugates. Finally, the mixture was filtrated and a 200 μL aliquot of the sample was transferred into an injection vial for further liquid chromatography with tandem mass spectrometry analysis using the Agilent 1290 Infinity II HPLC coupled with an Agilent 6470 QQQ triple-quad mass spectrometer (MS/MS). An autosampler was used to inject 10 μL of sample onto the UHPLC system and chromatographic separation was achieved using an Agilent InfinityLab Poroshell 120 Phenyl Hexyl LC column (2.1 × 100 mm, 1.9 μm). Analysis of the phthalate ester metabolites after HPLC separation was performed using negative electrospray ionization tandem mass spectrometry (ESI(-)-MS/MS) detection in dynamic multiple reaction monitoring (dMRM) mode. A nine-point calibration curve was used to quantify metabolite concentrations. The working standards were prepared in 10% acetonitrile in water. The concentration of the 13C-labeled internal standards was 50 μg/L. The recovery rate was calculated as the ratio between the experimentally observed concentration and the nominal concentration. A blank sample was processed through the sample preparation procedure and confirmed no laboratory contamination of phthalate metabolites. After every 10 sample injections, a solvent blank and spiked standard were injected for quality assurance or quality control (QA/QC) purposes.

For the present study, we assessed exposure to individual metabolites and generated a summary metric for di(2-ethylhexyl) phthalate (DEHP) devolving metabolites (ΣDEHP metabolites) since DEHP can break down into four different metabolites. The summary measure used in our analyses consisted of the molar sum of individual DEHP-devolving metabolites (MEHP, MEHHP, MECPP, MEOHP). Metabolite concentrations were corrected for dilution by using the following formula: $C_{sg} = C \times [(SG_m - 1)/(SG - 1)]$, where C_{sg} is the specific gravity-corrected phthalate metabolite concentration (in μg/L), C is the observed phthalate metabolite concentration (in μg/L), SG_m is the mean specific gravity value in our study population, and SG is the specific gravity of the urine sample (Xia et al., 2014). Concentrations below the respective metabolite LOD value were assigned the instrumental reading values when available, or replaced with a value of LOD/√2 if the instrumental reading value was not available (Lubin et al., 2004).

Data Analyses

We calculated descriptive summary statistics on participant characteristics as well as on uncorrected and specific gravity-corrected individual phthalate metabolite concentrations. We also compared our uncorrected phthalate metabolite concentrations to available health-based guidance values or biomonitoring equivalents (BE) (Koch et al., 2017). These values are based on reference doses or tolerable daily intake values and were available for five phthalates (DEP, BBzP, DnBP, DEHP, and DiNP) (Aylward et al., 2009a, b; Hays et al., 2011).

To examine associations between specific gravity-corrected urinary phthalate metabolite concentrations and each potential categorical predictor of exposure captured in the interviewer-administered questionnaire, we used Wilcoxon-Mann-Whitney (e.g., product usage at work and at home) or Kruskal-Wallis tests (e.g., worker categories). We restricted our predictors analyses to metabolites detected in ≥70% of the samples (i.e., detection frequency, DF>70%) and questionnaire items reported by at least five study participants. We used Spearman correlations to assess bivariate associations between metabolite concentrations of frequently detected metabolites and continuous variables, namely age, years in the U.S., total annual household income, and body mass index (BMI). Variables associated with metabolite concentrations in bivariate analyses at $p<0.10$ were then included in multivariable linear regression (MLR) models to assess the independent effects of each predictor on each phthalate metabolite quantified, and to evaluate the proportion of variance (R^2) explained by each model.

Statistical significance of predictor variables in the MLR models was set at $p<0.05$. The demographic factors gender, age (years), time in the U.S. (years) and work category (facilities management; dining services; and custodial work) were included *a priori* in all multivariable linear regression models. As part of our sensitivity analysis and based on the exploratory nature of our analysis, we used the Benjamini-Hochberg approach with the false discovery rate set at 0.25 to account for multiple testing (Newson, 2010; Benjamini and Hochberg, 1995). All analyses were conducted in Stata version 16.0 (Stata Corporation, College Station, Texas).

Of the 156 study participants that were recruited in the study, we had complete questionnaire and phthalate data on 94 participants. Consequently, 62 participants were dropped from the original 156 study participants for the present data analysis (n=3 participants were missing information on specific gravity due to insufficient sample volume; n=59 participants were missing information on important predictors considered). Three participants were missing information only on annual household income; thus, based on the distribution of participant responses, we assigned the lowest income category to these study participants to increase our sample size. Results did not significantly differ when these individuals with missing income information were excluded from our analyses (not shown).

RESULTS

Demographic characteristics.

General demographic characteristics for the study participants are displayed in Table 1. Study participants in our analytical sample (i.e., participants with complete data on predictors considered) were predominantly female (90%) and born in El Salvador (65%). Other countries of birth reported included Guatemala (6%), Peru (5%), Mexico (4%), Honduras (2.1%), Nicaragua (2.1%), the Dominican Republic (2%), Colombia (1%), Ecuador (1%), Cuba (1%), and the United States (1%). The mean age (SD) of these participants was 47.3 years (±9.4 years) and approximately half (51%) reported working in facilities management, 29% in residential facilities, and 20% in dining services. Participants reported living in the U.S. an average (SD) of 22.2 years (±9.9 years) and the mean (SD) total annual household income reported was $45,707 (±$32,899). A little over half (54%) of these study participants reported having no more than a high school education and the majority of them were overweight or obese (92%). Overall, except for age (p=0.046) and region of country of birth (p=0.035), participants in our analytical sample were demographically similar to the subsample of workers excluded from our analysis due to incomplete data. Participants in our analytical sample had a greater proportion of younger participants (18–39 years) and participants who originated from Central America (Table 1).

Biomarker concentrations

Summary statistics for uncorrected and specific gravity-corrected urinary phthalate metabolite concentrations detected in all study participants and the analytical sample are presented in Table 2. MCPP and MEHP were detected in less than half of the study participants (DF_{MCPP}=40% and DF_{MEHP}=5%), while the remaining 7 metabolites were detected in the majority of study participants in our analytical samples, including MEP (DF=99%), MBzP (DF=90%), MBP (DF=95%), MiBP (DF=71%), MEHHP (DF=99%), MECPP (DF=97%), and MEOHP (DF=93%). None of the phthalate metabolite concentrations measured in our study population exceeded the currently available biomonitoring equivalents (BEs) (Table 2).

Bivariate associations with demographic factors

In our bivariate analyses, we found some significant associations between work category and urinary metabolite concentrations for several metabolites. Specifically, we found that workers in facilities management had the highest median concentrations for several metabolites, including MBzP (1.77μg/L; p-value=0.02), MBP (7.22μg/L; p-value<0.001), and MiBP (3.39μg/L; p-value=0.001). Residential facilities workers had the second-highest median concentrations at 1.26μg/L for MBzP, 2.95μg/L for MBP, and 1.52μg/L for MiBP; while workers in dining services had the lowest median urinary metabolite concentrations, specifically, 0.88μg/L for MBzP, 1.42μg/L for MBP, and 1.14μg/L for MiBP (see Supplementary Information, Table S1). We also observed some statistically significant positive correlations, albeit weak correlations (ρ <0.25; p≤0.04), between age and MBP (ρ =0.23, p-value=0.02); age and MiBP(ρ =0.21, p-value=0.04); as well as BMI and MBzP (ρ =0.23, p-value=0.02) (see Supplementary Information, Supplemental Table S2). We found no statistically significant associations between urinary phthalate metabolite concentrations

and other demographic factors assessed, including sex, total annual household income, time in the U.S., and place of birth.

Bivariate associations with diet-related factors

Our results from our bivariate analyses examining associations with dietary factors are presented in Table 3 (boxplots for significant diet-related factors in the bivariate analysis are available in the Supplementary Information section, Figure S1). Briefly, compared to participants who did not consume fresh vegetables, participants who consumed fresh vegetables had a higher median concentration of MBzP (medians: 1.57μg/L vs. 0.80μg/L, p-value=0.005). Consumption of soda was positively associated with MBzP concentrations (p-value=0.05). Participants who consumed processed meats had a lower median ΣDEHP concentrations compared to those who did not (medians: 0.023μmol/L vs. 0.034μmol/L, p-value=0.03). Additionally, those who consumed sugar-sweetened beverages had lower median MiBP concentrations compared to those who did not (medians: 1.47μg/L vs. 2.86μg/L, p-value= 0.03). Lastly, we found that participants who reported not being able to afford balanced meals had a higher median concentration of MEP than those who reported being able to afford balanced meals (medians: 30.0μg/L vs. 13.3μg/L, p-value= 0.05).

Bivariate associations with chemicals used at the workplace/workplace related behaviors

Bivariate analysis results for covariates related to workplace chemical exposures and behaviors (e.g., use of specified products and use of dust masks at work) are displayed in Table 4 (boxplots for significant factors related to workplace chemical exposures and behaviors are available in the Supplementary Information section, Figure S2). Briefly, we observed an inverse association between use of furniture polish at work and MEP concentrations (p-value= 0.01). Use of bleach and window or glass cleaner was positively associated with MBzP concentrations. Similarly, use of window or glass cleaner at work was positively associated with MBP concentrations, with users having a higher median concentration than non-users (medians: 6.12μg/L vs. 1.52μg/L, p-value<0.001). Participants who reported using cleaning products at work, not including bleach, and those who reported using dust masks at work also had higher median concentrations of MBP compared to those who did not use these products or wore masks (medians $_{\text{cleaning products}}$: 5.84μg/L vs. 1.99μg/L, p-value= 0.002; medians $_{\text{masks}}$: 6.12μg/L vs. 2.12μg/L, p-value= 0.005). Use of window or glass cleaner at work was also positively associated with MiBP concentrations (medians: 2.86μg/L vs. 1.01μg/L, p-value= 0.003). Use of degreaser at work was inversely associated with MiBP concentrations (medians: 1.01μg/L vs. 2.86μg/L, p-value= 0.01). Lastly, use window or glass cleaners at work was positively associated ΣDEHP concentrations (medians: 0.02μg/L vs. 0.03μg/L, p-value= 0.03).

We did not observe any statistically significant associations between pesticide use in the past 3 months and phthalate metabolite concentrations. Home renovations within the past 6 months were positively associated with MBP concentrations (medians: 3.21μg/L vs. 5.79μg/L, p-value= 0.09). We did not analyze associations with home characteristics such as the presence of water damage, mold and peeling paint due to the low participant affirmative responses (<5 participants reported any of these in their homes).

Bivariate associations with consumer product use (personal care products and scented product use at home)

Bivariate analysis results for covariates related to consumer product use are displayed in Table 5 (boxplots for significant factors related to consumer product uses are available in the Supplementary Information section, Figure S3). When we evaluated bivariate associations with consumer product use, we found that some products, including makeup, scented dryer sheets and scented candles, were inversely associated with select metabolite concentrations (Table 5). For example, participants who used makeup had lower median concentrations of MBzP, MBP and MiBP compared to those who did not use makeup (medians $_{MBzP}$: 1.34μg/L vs. 1.78μg/L, p-values: 0.026; medians $_{MBP}$: 2.45μg/L vs. 5.79μg/L; p-values: 0.006; medians $_{MiBP}$: 1.45 μg/L vs. 2.87μg/L, p-value= 0.040). We also found that select products such as scented carpet cleaners, antibacterial soap, hairstyling products, and perfume were positively associated with some phthalate metabolites. For example, those who reported using antibacterial soap had a higher median concentration of MEP than those who did not (medians: 19.9μg/L vs. 6.03μg/L, p-value= 0.031).

Multivariable regression models

Results from our multivariable linear regression models are presented in Table 6. The proportion of the variance for target metabolite concentrations explained by our final models (R^2 values) ranged from 0.22 to 0.35, suggesting that most of the variability in phthalate exposure was not captured by our questionnaire items. In general, few predictor variables remained significant in the multivariable linear regression models. We found that concentrations of MEP were inversely associated with use of furniture polish ($ß_{MEP}$=−1.17, 95%CI: −2.21, −0.12) and with use of scented dryer sheets ($ß_{MEP}$=−1.08, 95%CI: −2.01, −0.14). ΣDEHP concentrations were inversely associated with use of degreaser ($ß_{DEHP}$= −0.65, 95%CI: −1.25, −0.05). Use of bleach and consumption of pasta, rice and noodles was positively associated with MBzP concentrations ($ß_{MBzP}$ =1.15, 95%CI:0.30, 2.00; ß=0.87, 95%CI: 0.27, 1.46). Models for MEP, MBzP, and ΣDEHP explained 29%, 35% and 22% of the variability in metabolite concentrations.

After accounting for multiple testing in our sensitivity analyses, we found that consumption of pasta, rice or noodles, consumption of low-fat milk, use of perfume and scented dryer sheets outside the workplace, and use of furniture polish at work were statistically significant predictors of MEP metabolite concentrations at a false discovery rate of 0.25. Consumption of pasta, rice or noodles and use of bleach at work were statistically significant predictors of MBzP metabolite concentrations. Statistically significant predictors of ΣDEHP concentrations included consumption of processed meat, use of degreaser at work, and use of hairstyling products and scented candles outside the workplace. After adjustment, we found no statistically significant predictors of MBP and MiBP. The Benjamini-Hochberg adjusted p-values are presented in Supplemental Table S3.

DISCUSSION

In the present study, we examined determinants of exposure to phthalates in a subsample of U.S.-based Latino adults predominantly from Central America. In general, we observed

higher phthalate metabolite concentrations in facilities management staff compared to other worker categories. Workplace exposure to bleach was positively associated with MBzP concentrations in both bivariate and final multivariable regression models. While consumption of fresh vegetables, pasta, rice or noodles, and the use of scented carpet cleaners were statistically significant predictors of select phthalate metabolites in bivariate analyses in this subsample of U.S. Latino adults, the only association that remained significant after controlling for other factors was between MBzP and consumption of pasta, rice or noodles even after adjusting for multiple comparisons. We did not observe any significant differences in phthalate metabolite concentrations based on sex, place of birth, time in the U.S., and total annual household income.

Compared to Mexican Americans from the U.S. general population, we found that uncorrected phthalate metabolite concentrations were lower in our cohort of predominantly Central American adults (Table 7); median concentrations in participants from the present study were 2 to 5 times lower than those reported among U.S. Mexican American adults in the same age range. A similar pattern was observed when comparing median metabolite concentrations to U.S. adults of the same age range, regardless of race/ethnicity (Centers for Disease Control and Prevention (CDC), 2019). Overall, we also observed lower phthalate metabolite concentrations in the present study compared to those observed in other U.S. studies (see Table 8), which could be indicative of the distinctiveness of our study population (Braun et al., 2012; Buckley et al., 2012; Duty et al., 2005; Ferguson et al., 2015; Hauser et al., 2004; Hoppin et al., 2002; Meeker et al., 2012; Peck et al., 2010; Whyatt et al., 2009; Wu et al., 2017). In general, similar trends (i.e., lower median concentrations in our study population) were observed when comparing metabolite concentrations in our study population to those reported in adult populations from other countries (see Supplementary Information, Table S4) (Berman et al., 2013; Choi, 2017; Haines et al., 2017; Koch et al., 2017; Philippat et al., 2012; Philips et al., 2018). Differences in metabolite concentrations across studies could reflect differences in cultural norms and behaviors that may impact exposure to phthalates, as well as differences in excretion patterns or differences in overall declining exposure trends based on the year in which samples were collected. For example, beauty norms, product preferences, and consumer options based on sociodemographic advantage have been documented to influence the sources of exposure to phthalates among minority groups (Mitro et al., 2019). Mitro et al. reported significant positive associations between time in the US and concentrations of MCPP and MBzP, and negative associations with MBP and MiBP concentrations among a diverse group of foreign-born individuals. However, we did not observe such trends within our study population. A prior study on U.S. adults using data from the National Health and Nutrition Examination Survey (NHANES) also reported significant differences in phthalate levels based on sex and obesity status, but we did not observe this in our study population (Buser et al., 2014). It is important to note, however, that our study population consisted of mostly females (90%) who were also mostly overweight or obese, which could have limited our ability to assess differences in metabolite concentrations in our study population. Moreover, differences in metabolite concentrations across studies may also be due, in part, to temporal trends based on when samples were collected. For example, Koch et al. compared phthalate metabolite concentrations in the German general population to those in the U.S. general population and reported that

exposure to select phthalates decreased between 1999 and 2012 (Koch et al., 2017). The lower metabolite concentrations in our study may also explain, in part, the weaker associations we found between phthalate metabolite concentrations and questionnaire items compared to other studies. In our multivariable linear regression models, for example, we found a positive association between consumption of pasta, rice, or noodles and concentrations of MBzP. This finding stands in contrast with those of Serrano et. al, who reported that this group of food items generally have low phthalate concentrations (Serrano et al., 2014). Similarly, Serrano et al. also reported that vegetables had low phthalate concentrations, whereas we found a positive association between consumption of fresh vegetables and MBzP concentrations in both the bivariate and multivariable analyses. This disparity in findings could be the result of the high frequency of consumption of these food items reported among our study participants, 85% of whom reported consuming fresh vegetables at least 1–3 times a week. For example, according to the CDC, food crops may absorb benzylbutyl phthalate (parent compound for MBzP) and diet is the major source of exposure in the general population (Centers for Disease Control and Prevention (CDC), 2020). Diethyl phthalate (parent compound for MEP) is also found in food packaging (Castle et al., 1988). Use of phthalates in some food packaging materials for these commodities may have played a role in phthalate exposure in our study population (Cao, 2010).

A systematic review of studies conducted in Japan, Saudi Arabia, and countries in Europe, North America, and South America reported no evidence of a significant association between ∑DEHP levels and the intake of foods and beverages in plastic packaging (Erythropel et al., 2014), which is consistent with our findings between phthalate concentrations and consumption of soda, sugar-sweetened beverages and foods stored in plastic packaging. We found an inverse association between some phthalate metabolites (MBzP, MiBP) and consumption of regular soda and sugar-sweetened beverages, but these associations were no longer present in the multivariable analysis. A review on the phthalate parent compounds DBP, BBP, and DEHP also reported no associations between heating food in plastics and phthalate contamination, attributing their finding to the relatively low temperatures reached by the plastic containers compared to the foods when heated in a microwave (Fasano et al., 2015). In our study, storing foods in plastic containers and bags was associated with higher levels of MBzP and MBP in bivariate analysis; however, storage in plastic containers was no longer significant after controlling for other factors in multivariable regression models. The mixed results observed in this study on the association of foods in plastic packaging and phthalates should be explored in future studies to ascertain the extent to which phthalates in food packaging may increase exposure risk by migrating to food commodities.

Contrary to the findings of Buckley et. al, we found an inverse association between the use of scented dryer sheets and urinary concentrations of MEP (Buckley et al., 2012), which is the metabolite most frequently associated with fragrances (Koo and Lee, 2004). Similarly, we expected to observe positive associations between MEP concentrations and the use of other scented products including detergent, fabric softener, carpet cleaner, and household cleaning products; however, we did not. The positive association we found between scented

carpet cleaner use and MBP concentrations is in line with other findings reported previously on the parent compound DBP in consumer products containing fragrances (Koniecki et al., 2011); however, this association was only observed in our bivariate analysis.

We found an inverse association between the use of degreaser and concentrations of ∑DEHP in both bivariate and full multivariable linear regression models. Further investigation, however, revealed that degreaser use at work was low for each worker category in our study (a total of 24 participants out of 94 reported using degreaser at work), so we cannot dismiss the possibility of a random finding. In our bivariate analyses, we found that work category was an important determinant of exposure to MBzP, MBP, and MiBP, with facilities management staff consistently having the highest concentrations, followed by residential services staff and lastly, dining services staff; however, this association did not remain significant in the full models. Still, MiBP is a metabolite of dibutyl phthalate which is present in industrial solvents or additives used in many personal care products such as nail polish and cosmetics, and also in some printing inks, pharmaceutical coatings, and insecticides. Workers in the facilities management worker category represent workers who do plumbing, electrical work, as well as landscaping so workplace exposures on the job to solvents or insecticides may have led to higher exposures in this workgroup.

Our study was subject to some limitations. First, our exclusion of study participants with incomplete data resulted in a smaller sample size, which may have greatly reduced our statistical power. Our study design was also cross-sectional and relied on self-reported behaviors; thus, recall and social desirability biases could be present. To counter the latter, we ensured that all bilingual-bicultural staff were properly trained and were culturally sensitive to our study population, so we do not expect this to have influenced participant responses. Also, phthalates are rapidly metabolized so concentrations in urine likely reflect recent exposures (Mittermeier et al., 2016). Phthalate concentrations recorded in our study were based on a single spot urine sample and may thus not be representative of the study participants' general patterns of behavior reported on the questionnaire. We also cannot rule out the possibility of unmeasured variables or random findings in our study. Our study sample consisted of a Latino cohort of workers in the service sector predominantly from Central America and living in Maryland, with a high female to male gender ratio, and mostly overweight or obese individuals. Thus, our results may not necessarily be generalizable to other Latino subgroups outside the study area and with differing demographic characteristics. Finally, while metabolite concentrations in our study population did not exceed currently published BEs, it should be noted that BEs are not intended to delineate thresholds between safe and unsafe exposures. Rather, BEs are used as a screening tool to inform risk management efforts and further exposure assessment and epidemiologic studies. Although exposures in our study population did not exceed published BEs, studies indicate that endocrine active phthalates act in a dose additive manner; thus, the cumulative effects of exposure to select phthalates could still exceed levels of concern (Hays et al., 2008; Lioy et al., 2015; National Research Council, 2008).

Despite the study limitations noted, our study has several strengths. To our knowledge, this is the first study to assess determinants of phthalate exposure in a sample of U.S. immigrant Latino adults. Prior studies on Latino populations have focused on Mexican-American and

Dominican women (Holland et al., 2016; Whyatt et al., 2009), while our study included adults from several Central American countries. We also examined several potential exposure determinants, including factors associated with acculturation (e.g., time in the U.S.); occupational exposures and behaviors; and personal consumer behaviors, including diet-related behaviors and personal care product use.

In our study population, select predictors of phthalate exposure were related to occupational factors, including chemicals used at work (e.g. bleach) and diet (e.g., consumption of pasta/rice/noodles). In this study of U.S. Latino adults predominantly originating from Central America, we generally found that several determinants of exposure to phthalates were not always consistent with those reported in prior studies, suggesting that cultural differences could, in part, explain our findings; although we cannot dismiss our small sample size nor temporal trends in exposure. Our findings also highlight the need for future studies to include a diverse sample of Latino adults as environmental exposures may vary by Latino subgroups, which could influence health inequities and also inform exposure mitigation strategies. This is particularly important because many Latino subgroups are understudied in public health research even though they represent a growing demographic in the U.S. (González Burchard et al., 2005).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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List of Abbreviations

BE	Biomonitoring equivalents
BMI	Body mass index
BzBP	Benzylbutyl phthalate
CDC	Centers for Disease Control and Prevention

DBP	Di-n-butyl phthalate
DEHP	Di(2-ethylhexyl) phthalate
DEP	Di-ethyl phthalate
DF	Detection frequency
DiBP	Di-isobutyl phthalate
DOP	Di-n-octyl phthalate
HPLC/MS-MS	High performance liquid chromatography tandem mass spectrometry
HMW	High molecular weight
LOD	Limits of detection
LMW	Low molecular weight
MBP	Mono-n-butyl phthalate
MBzP	Monobenzyl phthalate
MCPP	Mono(3-carboxypropyl) phthalate
MECPP	Mono-(2-ethyl-5-carboxypentyl) phthalate
MEHHP	Mono-(2-ethyl-5-hydroxyhexyl) phthalate
MEHP	Mono-2-ethylhexyl phthalate
MEOHP	Mono-(2-ethyl-5-oxohexyl) phthalate
MEP	Monoethyl phthalate
MiBP	Mono-isobutyl phthalate
MOP	Mono-n-octyl phthalate
NHANES	National Health and Nutrition Examination Survey
PVC	Polyvinyl chloride

REFERENCES

Ait Bamai Y, Araki A, Kawai T, Tsuboi T, Saito I, Yoshioka E, Cong S, Kishi R, 2016. Exposure to phthalates in house dust and associated allergies in children aged 6–12years. Environment International 96, 16–23. [PubMed: 27588698]

Aylward LL, Hays SM, Gagné M, Krishnan K, 2009a. Derivation of Biomonitoring Equivalents for di-n-butyl phthalate (DBP), benzylbutyl phthalate (BzBP), and diethyl phthalate (DEP). Regul Toxicol Pharmacol 55, 259–267. [PubMed: 19751787]

Aylward LL, Hays SM, Gagné M, Krishnan K, 2009b. Derivation of Biomonitoring Equivalents for di(2-ethylhexyl)phthalate (CAS No. 117-81-7). Regul Toxicol Pharmacol 55, 249–258. [PubMed: 19751789]

Bai PY, Wittert G, Taylor AW, Martin SA, Milne RW, Jenkins AJ, Januszewski AS, Shi Z, 2017. The association between total phthalate concentration and non-communicable diseases and chronic inflammation in South Australian urban dwelling men. Environmental Research 158, 366–372. [PubMed: 28686951]

Benjamini Y, Hochberg Y, 1995. Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. Journal of the Royal Statistical Society. Series B (Methodological) 57, 289–300.

Berman T, Goldsmith R, Göen T, Spungen J, Novack L, Levine H, Amitai Y, Shohat T, Grotto I, 2013. Urinary concentrations of environmental contaminants and phytoestrogens in adults in Israel. Environment International 59, 478–484. [PubMed: 23962452]

Braun JM, Smith KW, Williams PL, Calafat AM, Berry K, Ehrlich S, Hauser R, 2012. Variability of Urinary Phthalate Metabolite and Bisphenol A Concentrations before and during Pregnancy. Environmental Health Perspectives 120, 739–745. [PubMed: 22262702]

Broe A, Pottegård A, Hallas J, Ahern TP, Fedder J, Damkier P, 2018. Association between use of phthalate-containing medication and semen quality among men in couples referred for assisted reproduction. Human Reproduction 33, 503–511. [PubMed: 29425332]

Buckley JP, Palmieri RT, Matuszewski JM, Herring AH, Baird DD, Hartmann KE, Hoppin JA, 2012. Consumer product exposures associated with urinary phthalate levels in pregnant women. Journal of Exposure Science & Environmental Epidemiology 22, 468–475. [PubMed: 22760436]

Buser MC, Murray HE, Scinicariello F, 2014. Age and sex differences in childhood and adulthood obesity association with phthalates: analyses of NHANES 2007–2010. International journal of hygiene and environmental health 217, 687–694. [PubMed: 24657244]

Cao X-L, 2010. Phthalate Esters in Foods: Sources, Occurrence, and Analytical Methods. Comprehensive Reviews in Food Science and Food Safety 9, 21–43. [PubMed: 33467808]

Castle L, Mercer AJ, Startin JR, Gilbert J, 1988. Migration from plasticized films into foods 3. Migration of phthalate, sebacate, citrate and phosphate esters from films used for retail food packaging. Food Additives & Contaminants 5, 9–20. [PubMed: 3356285]

Centers for Disease Control and Prevention (CDC), 2010. Laboratory Procedure Manual: Phthalate Metabolites in Urine. National Center for Health Statistics (NCHS), Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

Centers for Disease Control and Prevention (CDC), 2019. National Health and Nutrition Examination Survey Data. National Center for Health Statistics (NCHS), Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

Centers for Disease Control and Prevention (CDC), 2020. Biomonitoring Summary: Phthalates Overview. National Center for Health Statistics (NCHS), Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.

Choi WK, S.; Baek Y-W; Choi K; Lee K; Kim S; Yu SD; Choi K, 2017. Exposure to environmental chemicals among Korean adults-updates from the second Korean National Environmental Health Survey (2012–2014). International Journal of Hygiene and Environmental Health 220, 29–35.

Colacino JA, Harris TR, Schecter A, 2010. Dietary Intake Is Associated with Phthalate Body Burden in a Nationally Representative Sample. Environmental Health Perspectives 118, 998–1003. [PubMed: 20392686]

Colby SL, Ortman JM, 2017. Projections of the size and composition of the US population: 2014 to 2060: Population estimates and projections.

National Research Council, 2006. Human Biomonitoring for Environmental Chemicals. The National Academies Press.

De Falco M, Forte M, Laforgia V, 2015. Estrogenic and anti-androgenic endocrine disrupting chemicals and their impact on the male reproductive system. Frontiers in Environmental Science 3.

Duty SM, Calafat AM, Silva MJ, Ryan L, Hauser R, 2005. Phthalate exposure and reproductive hormones in adult men. Human Reproduction 20, 604–610. [PubMed: 15591081]

Environmental Protection Agency (EPA), 2012. Phthalates Action Plan.

Erythropel HC, Maric M, Nicell JA, Leask RL, Yargeau V, 2014. Leaching of the plasticizer di(2-ethylhexyl)phthalate (DEHP) from plastic containers and the question of human exposure. Applied Microbiology and Biotechnology 98, 9967–9981. [PubMed: 25376446]

Fasano E, Cirillo T, Esposito F, Lacorte S, 2015. Migration of monomers and plasticizers from packed foods and heated microwave foods using QuEChERS sample preparation and gas chromatography/mass spectrometry. LWT - Food Science and Technology 64, 1015–1021.

Ferguson KK, McElrath TF, Chen Y-H, Mukherjee B, Meeker JD, 2015. Urinary Phthalate Metabolites and Biomarkers of Oxidative Stress in Pregnant Women: A Repeated Measures Analysis. Environmental Health Perspectives 123, 210–216. [PubMed: 25402001]

Godwin A, 2010. Uses of phthalates and other plasticizers. Chronic Hazard Advisory Panel (CHAP) on Phthalates.

González Burchard E, Borrell LN, Choudhry S, Naqvi M, Tsai H-J, Rodriguez-Santana JR, Chapela R, Rogers SD, Mei R, Rodriguez-Cintron W, Arena JF, Kittles R, Perez-Stable EJ, Ziv E, Risch N, 2005. Latino Populations: A Unique Opportunity for the Study of Race, Genetics, and Social Environment in Epidemiological Research. American Journal of Public Health 95, 2161–2168. [PubMed: 16257940]

Gray LE, 2000. Perinatal Exposure to the Phthalates DEHP, BBP, and DINP, but Not DEP, DMP, or DOTP, Alters Sexual Differentiation of the Male Rat. Toxicological Sciences 58, 350–365. [PubMed: 11099647]

Haines DA, Saravanabhavan G, Werry K, Khoury C, 2017. An overview of human biomonitoring of environmental chemicals in the Canadian Health Measures Survey: 2007–2019. International Journal of Hygiene and Environmental Health 220, 13–28. [PubMed: 27601095]

Hauser R, 2005. Phthalates and human health. Occupational and Environmental Medicine 62, 806–818. [PubMed: 16234408]

Hauser R, Meeker JD, Park S, Silva MJ, Calafat AM, 2004. Temporal Variability of Urinary Phthalate Metabolite Levels in Men of Reproductive Age. Environmental Health Perspectives 112, 1734–1740. [PubMed: 15579421]

Hays SM, Aylward LL, Kirman CR, Krishnan K, Nong A, 2011. Biomonitoring equivalents for di-isononyl phthalate (DINP). Regul Toxicol Pharmacol 60, 181–188. [PubMed: 21466828]

Hays SM, Aylward LL, LaKind JS, Bartels MJ, Barton HA, Boogaard PJ, Brunk C, DiZio S, Dourson M, Goldstein DA, Lipscomb J, Kilpatrick ME, Krewski D, Krishnan K, Nordberg M, Okino M, Tan Y-M, Viau C, Yager JW, 2008. Guidelines for the derivation of Biomonitoring Equivalents: Report from the Biomonitoring Equivalents Expert Workshop. Regulatory Toxicology and Pharmacology 51, S4–S15. [PubMed: 18583008]

Holland N, Huen K, Tran V, Street K, Nguyen B, Bradman A, Eskenazi B, 2016. Urinary Phthalate Metabolites and Biomarkers of Oxidative Stress in a Mexican-American Cohort: Variability in Early and Late Pregnancy. 4, 7.

Hoppin JA, Brock JW, Davis BJ, Baird DD, 2002. Reproducibility of urinary phthalate metabolites in first morning urine samples. Environmental Health Perspectives 110, 515–518. [PubMed: 12003755]

Huang T, Saxena AR, Isganaitis E, James-Todd T, 2014. Gender and racial/ethnic differences in the associations of urinary phthalate metabolites with markers of diabetes risk: national health and nutrition examination survey 2001–2008. Environmental Health 13, 6. [PubMed: 24499162]

Huffman AM, Wu H, Rosati A, Rahil T, Sites CK, Whitcomb BW, Richard Pilsner J, 2018. Associations of urinary phthalate metabolites and lipid peroxidation with sperm mitochondrial DNA copy number and deletions. Environmental Research 163, 10–15. [PubMed: 29421168]

Katsikantami I, Sifakis S, Tzatzarakis MN, Vakonaki E, Kalantzi OI, Tsatsakis AM, Rizos AK, 2016. A global assessment of phthalates burden and related links to health effects. Environ Int 97, 212–236. [PubMed: 27669632]

Koch HM, Christensen KL, Harth V, Lorber M, Brüning T Di-n-butyl phthalate (DnBP) and diisobutyl phthalate (DiBP) metabolism in a human volunteer after single oral doses. Arch Toxicol. 2012 12;86(12):1829–39. [PubMed: 22820759]

Koch HM, Rüther M, Schütze A, Conrad A, Pälmke C, Apel P, Brüning T, Kolossa-Gehring M, 2017. Phthalate metabolites in 24-h urine samples of the German Environmental Specimen Bank (ESB) from 1988 to 2015 and a comparison with US NHANES data from 1999 to 2012. International Journal of Hygiene and Environmental Health 220, 130–141. [PubMed: 27863804]

Kolena B, Petrovičová I, Šidlovská M, Pilka T, Neuschlová M, Valentová I, Rybanský L, Trnovec T, 2017. Occupational phthalate exposure and health outcomes among hairdressing apprentices. Hum Exp Toxicol 36, 1100–1112. [PubMed: 27852937]

Koniecki D, Wang R, Moody RP, Zhu J, 2011. Phthalates in cosmetic and personal care products: Concentrations and possible dermal exposure. Environmental Research 111, 329–336. [PubMed: 21315328]

Koo HJ, Lee BM, 2004. Estimated exposure to phthalates in cosmetics and risk assessment. Journal of Toxicology and Environmental Health, Part A 67, 1901–1914. [PubMed: 15513891]

Lioy PJ, Hauser R, Gennings C, Koch HM, Mirkes PE, Schwetz BA, Kortenkamp A, 2015. Assessment of phthalates/phthalate alternatives in children's toys and childcare articles: Review of the report including conclusions and recommendation of the Chronic Hazard Advisory Panel of the Consumer Product Safety Commission. Journal of Exposure Science & Environmental Epidemiology 25, 343–353. [PubMed: 25944701]

Lubin JH, Colt JS, Camann D, Davis S, Cerhan JR, Severson RK, Bernstein L, Hartge P, 2004. Epidemiologic Evaluation of Measurement Data in the Presence of Detection Limits. Environmental Health Perspectives 112, 1691–1696. [PubMed: 15579415]

Malarvannan G, Onghena M, Verstraete S, Van Puffelen E, Jacobs A, Vanhorebeek I, Verbruggen SCAT, Joosten KFM, Van Den Berghe G, Jorens PG, Covaci A, 2019. Phthalate and alternative plasticizers in indwelling medical devices in pediatric intensive care units. Journal of Hazardous Materials 363, 64–72. [PubMed: 30308366]

McCombie G, Biedermann S, Suter G, Biedermann M, 2017. Survey on plasticizers currently found in PVC toys on the Swiss market: Banned phthalates are only a minor concern. Journal of Environmental Science and Health, Part A 52, 491–496.

Meeker JD, Calafat AM, Hauser R, 2012. Urinary phthalate metabolites and their biotransformation products: predictors and temporal variability among men and women. Journal of exposure science & environmental epidemiology 22, 376–385. [PubMed: 22354176]

Mitro SD, Chu MT, Dodson RE, Adamkiewicz G, Chie L, Brown FM, James-Todd TM, 2019. Phthalate metabolite exposures among immigrants living in the United States: findings from NHANES, 1999–2014. Journal of Exposure Science & Environmental Epidemiology 29, 71–82. [PubMed: 29572484]

Mittermeier A, Völkel W, Fromme H, 2016. Kinetics of the phthalate metabolites mono-2-ethylhexyl phthalate (MEHP) and mono-n-butyl phthalate (MnBP) in male subjects after a single oral dose. Toxicology Letters 252, 22–28. [PubMed: 27091076]

Newson RB, 2010. Frequentist q-values for multiple-test procedures. Stata Journal 10, 568–584.

Ohtani H, Miura I, Ichikawa Y, 2000. Effects of dibutyl phthalate as an environmental endocrine disruptor on gonadal sex differentiation of genetic males of the frog Rana rugosa. Environmental Health Perspectives 108, 1189–1193. [PubMed: 11133400]

Peck JD, Sweeney AM, Symanski E, Gardiner J, Silva MJ, Calafat AM, Schantz SL, 2010. Intra- and inter-individual variability of urinary phthalate metabolite concentrations in Hmong women of reproductive age. Journal of Exposure Science & Environmental Epidemiology 20, 90–100. [PubMed: 19223940]

Petrovičová I, Kolena B, Šidlovská M, Pilka T, Wimmerová S, Trnovec T, 2016. Occupational exposure to phthalates in relation to gender, consumer practices and body composition. Environmental Science and Pollution Research 23, 24125–24134. [PubMed: 27640056]

Philippat C, Mortamais M, Chevrier C, Petit C, Calafat AM, Ye X, Silva MJ, Brambilla C, Pin I, Charles M-A, Cordier S, Slama R, 2012. Exposure to Phthalates and Phenols during Pregnancy and Offspring Size at Birth. Environmental Health Perspectives 120, 464–470. [PubMed: 21900077]

Philips EM, Kahn LG, Jaddoe VWV, Shao Y, Asimakopoulos AG, Kannan K, Steegers EAP, Trasande L, 2018. First Trimester Urinary Bisphenol and Phthalate Concentrations and Time to Pregnancy: A Population-Based Cohort Analysis. The Journal of Clinical Endocrinology & Metabolism 103, 3540–3547. [PubMed: 30016447]

National Research Council, 2008. Phthalates and Cumulative Risk Assessment: The Tasks Ahead. National Academies Press (US), Washington, DC.

Schettler T, 2006. Human exposure to phthalates via consumer products. International Journal of Andrology 29, 134–139. [PubMed: 16466533]

Serrano SE, Braun J, Trasande L, Dills R, Sathyanarayana S, 2014. Phthalates and diet: a review of the food monitoring and epidemiology data. Environmental Health 13, 43. [PubMed: 24894065]

Shin H-M, Dhar U, Calafat AM, Nguyen V, Schmidt RJ, Hertz-Picciotto I, 2020. Temporal Trends of Exposure to Phthalates and Phthalate Alternatives in California Pregnant Women during 2007–2013: Comparison with Other Populations. Environmental Science & Technology 54, 13157–13166. [PubMed: 32940456]

Silva MJ, Barr DB, Reidy JA, Malek NA, Hodge CC, Caudill SP, Brock JW, Needham LL, Calafat AM: Urinary Levels of Seven Phthalate Metabolites in the U.S. Population from the National Health and Nutrition Examination Survey (NHANES) 1999–2000. Environ Health Perspect. 2004, 112: 331–338. [PubMed: 14998749]

Kobrosly RW, Parlett LE, Stahlhut RW, Barrett ES, Swan SH: Socioeconomic factors and phthalate metabolite concentrations among United States women of reproductive age. Environ Res. 2012, 115: 11–17. [PubMed: 22472009]

Whyatt RM, Adibi JJ, Calafat AM, Camann DE, Rauh V, Bhat HK, Perera FP, Andrews H, Just AC, Hoepner L, Tang D, Hauser R, 2009. Prenatal Di(2-ethylhexyl)Phthalate Exposure and Length of Gestation Among an Inner-City Cohort. Pediatrics 124, e1213–e1220. [PubMed: 19948620]

Wu H, Estill MS, Shershebnev A, Suvorov A, Krawetz SA, Whitcomb BW, Dinnie H, Rahil T, Sites CK, Pilsner JR, 2017. Preconception urinary phthalate concentrations and sperm DNA methylation profiles among men undergoing IVF treatment: a cross-sectional study. Human Reproduction 32, 2159–2169. [PubMed: 29024969]

Xia Y, Wong L-Y, Bunker BC, Bernert JT, 2014. Comparison of Creatinine and Specific Gravity for Hydration Corrections on Measurement of the Tobacco-Specific Nitrosamine 4-(Methylnitrosamino)-1-(3-Pyridyl)-1-Butanol (NNAL) in Urine. 28, 353–363.

Zhang Y, Mustieles V, Yland J, Braun JM, Williams PL, Attaman JA, Ford JB, Calafat AM, Hauser R, Messerlian C, 2020. Association of Parental Preconception Exposure to Phthalates and Phthalate Substitutes With Preterm Birth. JAMA Network Open 3, e202159. [PubMed: 32259265]

HIGHLIGHTS

- Phthalate exposure varied based on worker category.
- We observed lower phthalate exposures than adults in the US general population.
- Bleach and select food products were associated with higher MBzP concentrations.

Table 1.

Study population characteristics.[a]

	All study participants N=153	Participants with incomplete predictor data N=59	Participants with complete predictor data N=94	p-value*
Gender				0.290
Male	18 (11.8%)	9 (16.3%)	9 (9.57%)	
Female	135 (88.2%)	50 (84.7%)	85 (90.4%)	
Age				0.046
18–39 years	19 (12.4%)	3 (5.08%)	16 (17.0%)	
40–49 years	56 (36.3%)	19 (32.2%)	37 (39.4%)	
50–59 years	60 (39.2%)	27 (45.8%)	33 (35.1%)	
60+ years	18 (11.8%)	10 (16.9%)	8 (8.51%)	
Work category				0.055
Facilities Management	80 (52.3%)	32 (54.2%)	48 (51.1%)	
Residential Facilities	35 (22.9%)	8 (13.6%)	27 (28.7%)	
Dining Services	38 (24.8%)	19 (32.2%)	19 (20.2%)	
Region of Country of Birth				0.035
USA	2 (1.31%)	1 (1.69%)	1 (1.06%)	
Mexico	10 (6.54%)	6 (10.2%)	4 (4.26%)	
Central America[b]	116 (75.8%)	37 (62.7%)	79 (84.0%)	
South America	16 (10.5%)	9 (15.3%)	7 (7.45%)	
Caribbean	9 (5.88%)	6 (10.2%)	3 (3.19%)	
Time in the US				0.340
≤19 years	52 (34.0%)	16 (27.1%)	36 (38.3%)	
20–29 years	66 (43.1%)	29 (49.2%)	37 (39.4%)	
≥30 years	35 (22.9%)	14 (23.7%)	21 (22.3%)	
Total annual household income[c]				
≤$29,999	67 (43.8%)	24 (40.7%)	43 (45.7%)	0.190
$30,000–$59,999	47 (30.7%)	23 (39.0%)	24 (25.5%)	
≥$60,000	39 (25.5%)	12 (20.3%)	27 (28.7%)	
Highest level of education				0.820
Junior high or less	71 (46.4%)	28 (47.5%)	43 (45.7%)	
High school/vocational school	51 (33.3%)	18 (30.5%)	33 (35.1%)	
College or more	31 (20.3%)	13 (22.0%)	18 (19.1%)	
Body Mass Index (inches^2/pounds)				0.266
Normal weight (18.5–24.9)	13 (8.50%)	5 (8.47%)	8 (8.51%)	
Overweight (25.0–29.9)	48 (31.4%)	17 (28.8%)	31 (33.0%)	
Class I obesity (30.0–34.9)	56 (36.6%)	19 (32.2%)	37 (39.4%)	
Class II obesity (35.0–39.9)	28 (18.3%)	16 (27.1%)	12 (12.8%)	
Class III obesity (≥40)	8 (5.23%)	2 (3.39%)	6 (6.38%)	

[a] A total of 156 participants were recruited into the parent study. Of those 156 participants, 153 had measurements on phthalate metabolites. Thus, data presented above refers to 153 participants with phthalate data, 53 participants who were excluded from this subset due to incomplete data on predictors assessed, and the 94 participants in our analytical sample with complete data on potential predictors and phthalate measurements.

[b] Central America includes participants from El Salvador, Guatemala, Honduras, and Nicaragua; South America includes participants from Peru, Colombia, and Ecuador; the Caribbean includes participants from the Dominican Republic and Cuba.

[c] Three study participants did not report total annual household income and were included in the most frequently reported category of ≤$29,999.

[*] p-values from Chi-square tests (Pearson's and Fisher's exact tests) to assess differences in demographic characteristics between participants included in our determinants analyses.

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Table 2.

Summary statistics for uncorrected and specific gravity-corrected urinary phthalate metabolite concentrations among all study participants (n=156) and the analytical sample (n=94).[a]

Parent Compound	Phthalate Metabolite	LOD (µg/L)	n>LOD	DF %	Uncorrected concentrations, µg/L*				Biomonitoring Equivalents (BE)		Specific gravity-corrected concentrations, µg/L*			
					GM (GSD)	P_{50}	$P_{25,75}$	Max	BE value, ug/L[a]	% above BE value	GM (GSD)	P_{50}	$P_{25,75}$	Max
Di-ethyl phthalate (DEP)	MEP	0.24	152	99.4	17.2 (5.5)	14.9	5.3, 54.7	1734.8	18,000	0	22.4 (4.5)	17.7	1.1, 56.9	1060.2
			94	100.0	17.7 (5.9)	12.8	5.9, 59.9	1734.0			23.6 (4.9)	18.3	7.3, 61.2	1060.0
Benzylbutyl phthalate (BzBP)	MBzP	0.06	138	90.2	1.1 (4.0)	1.3	0.58, 2.8	21.6	3,800	0	1.5 (2.8)	1.5	0.79, 0.18	13.6
			87	92.6	1.1 (4.3)	1.3	0.53, 3.0	21.6			1.4 (2.8)	1.5	0.8, 2.7	13.6
Di-n-butyl phthalate (DBP)	MBP	0.25	145	94.8	2.9 (5.0)	3.0	1.2, 7.4	168.3	200	0	3.7 (3.4)	3.7	2.0, 8.2	145.1
			83	88.3	3.0 (5.6)	3.2	1.3, 9.5	168.0			4.0 (3.8)	4.4	1.9, 9.4	91.5
Di-isobutyl phthalate (DiBP)	MiBP	0.54	109	71.2	1.9 (4.0)	1.8	<LOD, 4.34	120.3	--	0	2.2 (3.4)	2.2	<LOD, 4.7	76.9
			67	71.3	1.9 (4.4)	1.7	<LOD, 4.8	120.0			2.4 (3.7)	2.3	<LOD, 4.8	76.9
Di-n-octyl phthalate (DOP) Di-n-butyl phthalate (DBP) Other HMW phthalates	MCPP	0.19	61	39.9	0.24 (3.4)	<LOD	<LOD, 0.45	24.3	--	0	0.29 (3.2)	<LOD	<LOD, 0.60	22.5
			40	42.6	<LOD	<LOD	<LOD, 0.48	24.3			<LOD	<LOD	<LOD, 0.61	22.5
Di(2-ethylhexyl) phthalate (DEHP)*	MEHHP	0.20	152	99.4	2.8 (3.0)	2.8	1.4, 5.4	238.2	--	0	3.7 (2.4)	3.4	2.1,6.1	162.6
			93	98.9	2.8 (2.9)	3.0	1.4, 5.7	41.0			3.8 (2.3)	3.4	2.2, 6.4	78.7
	MECPP	0.16	148	96.7	2.5 (4.0)	2.9	1.2, 5.9	244.9	--	0	3.3 (2.6)	3.1	1.9, 4.8	167.2
			91	96.8	2.4 (4.2)	3.1	1.1, 5.8	56.2			3.3 (2.6)	3.2	1.9, 5.7	88.5
	MEOHP	0.09	142	92.8	1.2 (4.1)	1.5	0.58, 5.7	132.2	--	0	1.6 (2.8)	1.5	0.80, 3.0	90.2
			87	92.6	1.3 (3.8)	1.5	0.60, 3.2	21.9			1.7 (2.8)	1.6	0.88, 3.6	39.1
	MEHP	0.29	7	4.6	<LOD	<LOD	<LOD, <LOD	54.9	--	0	<LOD	<LOD	<LOD, <LOD	37.5
			2	2.1	<LOD	<LOD	<LOD, <LOD	5.5			<LOD	<LOD	<LOD, <LOD	4.4
	ΣDEHP	--	--	--	0.02 (3.1)	0.02	0.01,0.05	2.3	400	0	0.03 (2.4)	0.03	0.02, 0.05	1.5

Parent Compound	Phthalate Metabolite	LOD (µg/L)	n>LOD	DF %	Uncorrected concentrations, µg/L *				Biomonitoring Equivalents (BE)		Specific gravity-corrected concentrations, µg/L *			
					GM (GSD)	P_{50}	$P_{25,75}$	Max	BE value, ug/L [a]	% above BE value	GM (GSD)	P_{50}	$P_{25,75}$	Max
		--		--	0.03 (2.3)	0.03	0.01,0.05	0.42			0.03 (2.3)	0.03	0.02, 0.05	0.70

[a] The values reported on the first row for every metabolite reflect summary statistics for the entire study population, whereas the 2nd row reflects summary statistics for our analytical sample (i.e., study participants with complete data).

Abbreviations: LOD, limit of detection; DF%, detection frequency percentage; GM, geometric mean; GSD, geometric standard deviation; $P_{25,50,75}$, 25th, 50th, and 75th percentiles, respectively.

* =units for ∑DEHP are µmol/L.

Table 3.

Bivariate associations between phthalate metabolite concentrations and diet-related predictors considered.

Diet-related factors	No	Yes	MEP	MBzP	MBP	MiBP	ΣDEHP
Baked goods	37	57					
Beef, pork, or lamb	21	73					
Canned food	71	23					
Deep-fried food	46	48					
Diet soda	81	13					
Fast food	56	38					
Fish	35	59					
Fresh fruits	6	88					
Fresh vegetables	10	84		+**			
Low-fat milk	40	54	+*				
Pasta, rice, or noodles	32	62	+*	+*			
Processed meat	67	27					−**
Soda	78	16		−**		−*	
Sugar-sweetened beverage	66	28				−**	−*
Whole grains	12	82					
Whole milk	38	56					
Consume foods and drinks in plastic packaging	62	32					
Could not afford to eat balanced meals[a]	54	40	+**				
Heat food in plastic in the microwave	45	49					
Store food in plastic containers and bags[b]	49	45		+*	+*		

[a] For the questionnaire item “could not afford to eat balanced meals”, the yes category corresponds to occurred sometimes and occurred frequently, while the no category corresponds to never.

[b] The answer choices for storing food in plastics were yes and no. For all other exposures listed, the exposure category of no corresponds to consumption never or rarely and yes corresponds to consumption 1–3 times per month, 1–3 times per week, 4–6 times per week, or every day.

+**/−** Positive/negative association between questionnaire item and metabolite at $P<0.05$.

+*/−* Positive/negative association between questionnaire item and metabolite at $0.05 \leq P<0.1$.

Table 4.

Bivariate associations between phthalate metabolite concentrations and occupational chemical exposures and workplace behaviors considered.[a]

Chemical use/Workplace behavior	No	Yes	MEP	MBzP	MBP	MiBP	ΣDEHP
Air freshener	60	34					
Bleach	82	12		+**			
Carpet or rug cleaning product	82	12					
Cement dust	81	13					
Degreaser or grease remover	70	24		−*		−**	−*
Drywall	78	16					
Furniture polish	68	26	−**				
Non-bleach cleaning products	22	72			+**		
Products to remove wax	86	8					
Products to wax floor	85	9					
Whiteboard cleaner	76	18	−*				
Window or glass cleaner	20	74		+**	+**	+**	+**
Wears dust masks at work	24	70			+**	+*	

[a]For the use of personal protective equipment, in this case dust masks, the no category refers to the responses “never” or “not required for my job.”

+**/−** Positive/negative association between questionnaire item and metabolite at P<0.05.

+*/−* Positive/negative association between questionnaire item and metabolite at 0.05≤P<0.1.

Table 5.

Bivariate associations between phthalate metabolite concentrations and predictors associated with consumer behaviors outside the workplace.[a]

Consumer product used outside the workplace	No	Yes	MEP	MBzP	MBP	MiBP	ΣDEHP
Air freshener	43	51					
Incense	89	5					
Scented candles	64	30					−**
Scented carpet cleaner	82	12			+*		
Scented detergent	17	77					
Scented dryer sheets	37	57	−**				
Scented fabric softener	16	78					
Scented household cleaning products	33	61					
Antibacterial soap	9	85	+**				
Hair styling products	31	63					+*
Makeup	51	43		−**	−**	−**	
Perfume	19	75	+*				

[a]For products listed, the exposure category of “no” corresponds to “never” or “rarely” and “yes” corresponds to use “1–3 times per month,” “1–3 times per week,” “4–6 times per week,” or “every day.”

+**/−** Positive/negative association between questionnaire item and metabolite at P<0.05.

+*/−* Positive/negative association between questionnaire item and metabolite at 0.05≤P<0.1.

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Table 6.

Multivariable linear regression results and proportion of variance explained (R^2) for urinary phthalate metabolites and questionnaire items.[a,b]

Phthalate metabolite	MEP			MBzP			MBP			MiBP			DEHP		
Model R^2	0.29			0.35			0.32			0.24			0.22		
Intercept	2.61			0.17			2.52			0.95			−5.02		
	β	**95% CI**	**p-value**	***β***	**95% CI**	**p-value**	***β***	**95% CI**	**p-value**	***β***	**95% CI**	**p-value**	***β***	**95% CI**	**p-value**
Chemical use/workplace behavior															
Bleach	--			1.15	(0.30 – 2.00)	**0.008**	--			--			--		
Degreaser	--			−0.40	(−1.10 – 0.29)	0.248	--			−0.84	(−1.76 – 0.09)	0.075	−0.65	(−1.25 – −0.05)	**0.033**
Furniture polish	−1.17	(−2.21 – −0.12)	**0.029**	--			--			--			--		
Non-bleach cleaning products	--			--			0.54	(−0.62 – 1.70)	0.358	--			--		
Whiteboard cleaner	−0.58	(−1.77 – 0.60)	0.327	--			--			--			--		
Window or glass cleaner	--			0.48	(−0.51 – 1.47)	0.339	0.79	(−0.68 – 2.25)	0.288	0.78	(−0.57 – 2.13)	0.256	0.57	(−0.26 – 1.40)	0.176
Wears dust masks at work	--			--			−0.23	(−1.53 – 1.07)	0.723	−0.24	(−1.52 – 1.05)	0.716	--		
Consumer product used outside the workplace															
Antibacterial soap	1.14	(−0.43 – 2.70)	0.153	--						--			--		
Hair styling products	--			--			--			--			0.46	(−0.06 – 0.98)	0.084
Makeup	--			−0.51	(−1.12 – 0.10)	0.102	−0.47	(−1.29 – 0.34)	0.247	−0.36	(−1.19 – 0.47)	0.390	--		
Perfume	0.91	(−0.22 – 2.04)	0.110	--			--			--			--		
Scented candles	--			--			--			--			−0.49	(−1.05 – 0.07)	0.085
Scented carpet cleaner	--			--			0.93	(−0.23 – 2.09)	0.116	--			--		

Scented dryer sheets	−1.08	(−2.01 – 0.14)	**0.025**	--			--			--			--		
Diet-related behaviors															
Could not afford balanced meals	0.64	(−0.34 – 1.63)	0.199	--			--			--			--		
Fresh vegetables	--			0.77	(−0.25 – 1.79)	0.135	--			--			--		
Low-fat milk	0.82	(−0.09 – 1.73)	0.078	--			--			--			--		
Pasta, rice, or noodles	0.81	(−0.16 – 1.77)	0.100	0.87	(0.27 – 1.46)	**0.005**	--			--			--		
Processed meat	--			--			--			--			−0.48	(−1.04 – 0.09)	0.098
Soda	--			−0.37	(−1.19 – 0.45)	0.374	--			−0.28	(−1.30 – 0.75)	0.593	--		
Store food in plastic containers/bags	--			0.40	(−0.17 – 0.96)	0.166	0.51	(−0.21 – 1.23)	0.160	--			--		
Sugar-sweetened beverages	--			--			--			−0.41	(−1.27 – 0.46)	0.354	0.10	(−0.47 – 0.67)	0.728
Home renovations in past 6 months	--			--			−0.32	(−1.40 – 0.76)	0.557	--			--		
Demography-related variables															
Age	−0.01	(−0.07 – 0.06)	0.799	−0.03	(−0.07 – 0.01)	0.180	0.01	(−0.04 – 0.07)	0.627	0.03	(−0.02 – 0.08)	0.279	−0.02	(−0.05 – 0.02)	0.298
Gender	0.35	(−1.22 – 1.91)	0.660	0.31	(−0.71 – 1.34)	0.544	−0.84	(−2.24 – 0.55)	0.232	−0.20	(−1.63 – 1.22)	0.776	0.41	(−0.46 – 1.27)	0.353
Income	$3.44e^{-6}$	($-1.14e^{-5}$ – 1.82^{-5})	0.645	$-3.47e^{-6}$	($-1.27e^{-5}$ – $5.75e^{-6}$)	0.456	$-3.12e^{-6}$	($-1.5e^{-5}$ – $8.72e^{-6}$)	0.602	$2.78e^{-6}$	($-9.45e^{-6}$ – $1.50e^{-5}$)	0.652	$-1.27e^{-6}$	($-9.44e^{-6}$ – $6.91e^{-6}$)	0.758
Time in the U.S.	−0.01	(−0.07 – −0.06)	0.847	0.01	(−0.03 – 0.05)	0.608	−0.03	(−0.08 – 0.02)	0.267	−0.02	(−0.08 – 0.03)	0.395	0.01	(−0.02 – 0.05)	0.539
Work category															
Residential facilities	0.20	(−0.46 – 1.71)	0.255	−0.54	(−1.20 – 0.12)	0.109	−0.80	(−1.66 – 0.07)	0.070	−0.81	(−1.71 – 0.09)	0.077	0.11	(−0.47 – 0.70)	0.703
Dining services	−0.37	(−1.79 – 1.06)	0.612	−0.55	(−1.66 – 0.57)	0.335	−1.39	(−3.03 – 0.24)	0.094	−0.86	(−2.44 – 0.72)	0.283	−0.04	(−1.01 – 0.93)	0.936

[a] All models were adjusted *a priori* for age, gender, income, time in the U.S., work category (facilities management, residential facilities, dining services).

[b] Reference categories for covariates: work category (facilities management), and all other covariates (never/rarely used).

-- Denotes that the covariate was not included in the model.

Table 7.

Comparison of median uncorrected concentrations (μg/L) to a representative sample of adults from the U.S. general population (NHANES 2015–2016).

	Present study (2017–2018)			National Health and Nutrition Examination Survey (NHANES, 2015–2016)								
	Adults aged 19–65 years (n=94)			Adults aged 19–65 years (n=1373)					Mexican American adults aged 19–65 years (n=234)			
				Unweighted				Weighted[a]	Unweighted			Weighted[a]
Phthalate metabolite	**LOD (μg/L)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**LOD (μg/L)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**
MEP	0.24	100	12.8 (5.9, 59.9)	1.2	99.5	35.9 (14.5, 105.7)	99.7	28.8 (12.2, 84.3)	98.7	26.1 (9.9, 73.5)	98.9	26.6 (9.9, 86.4)
MBzP	0.06	92.6	1.3 (0.53, 3.0)	0.3	97.1	4.1 (1.7, 9.8)	97.7	3.9 (1.6, 9.2)	94.9	3.4 (1.3, 7.6)	95.9	3.3 (1.8, 8.9)
MBP	0.25	88.3	3.2(1.3, 9.5)	0.4	98.9	10.9 (5.4, 20.2)	98.8	9.6 (5.0, 18.3)	99.6	10.6 (5.6, 21.2)	99.6	10.2 (5.5, 20.5)
MiBP	0.54	71.3	1.7 (<LOD, 4.8)	0.8	98.1	9.5 (4.6, 18.2)	97.7	8.9 (3.9, 16.0)	98.7	9.3 (4, 18.9)	98.9	9.0 (4.1, 18.8)
MCPP	0.19	42.6	<LOD (<LOD, 0.48)	0.4	76.5	1.0 (<LOD, 2.0)	75.7	1.0 (<LOD, 2.1)	67.5	0.8 (<LOD, 1.8)	66.1	0.7 (<LOD, 1.8)
MEHHP	0.20	98.9	3.0 (1.43, 5.7)	0.4	62.3	5.9 (3.1, 11.5)	60.1	5.5 (2.6, 10.4)	63.7	6.1 (2.9, 12.5)	66.7	6.1 (2.5, 12.0)
MECPP	0.16	96.8	3.1 (1.1, 5.8)	0.4	99.6	9.1 (4.6, 17.2)	99.7	8.3 (4.1, 16.2)	100	9.2 (4.4, 18.8)	100	8.3 (4.9, 16.9)
MEOHP	0.09	92.6	1.5 (0.60, 3.2)	0.2	99.1	3.7 (1.8, 7.1)	99.3	3.5 (1.6, 6.7)	100	3.8 (1.7, 8.6)	100	3.6 (1.5, 7.2)
MEHP	0.29	2.1	<LOD (<LOD, <LOD)	0.8	99.3	1.2 (<LOD, 2.5)	99.5	1.1 (<LOD, 2.4)	99.6	1.5 (<LOD, 3.2)	99.6	1.5 (<LOD, 3.0)

[a] Values reported are weighted to account for the stratified multistage probability sampling design.

Abbreviations: LOD, limit of detection; DF%, detection frequency percentage; $P_{25,50,75}$, 25^{th}, 50^{th}, and 75^{th} percentiles, respectively.

Table 8.

Comparison of median phthalate metabolite concentrations (μg/L) with those reported in other U.S. studies.

	Present study (Sampling period: 2017–2018)						New York Inner-City Cohort (Sampling period: 2000–2006) (Whyatt et al., 2009)		Pregnant women in Right From The Start Cohort (Sampling period: 2000–2004) (Buckley et al., 2012)		Before and during pregnancy concentrations from Massachusetts General Hospital Fertility Center (Sampling period: 2004–2009) (Braun et al., 2012)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		African American and Dominican women (n=311)		Females ≥18 years, 46% White, 40% Black (n=50)		Females 18–45 years, 91% White (n=137)	
Phthalate metabolite	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50}**	**DF %**	**Phthalate metabolite concentration, μg/L P50 ($P_{25,75}$)**
MBP	88.3	U: 3.17 (1.27, 9.54) SG: 4.35 (1.86, 9.41)	100	U: 7.22 (3.13, 22.2) SG: 6.36 (4.70, 17.2)	87.1	U: 2.97 (1.20, 9.01) SG: 3.68 (1.85, 9.09)	--	--	90	U: 18.2	--	SG: 14 (9.0, 22) SG: 16 (11, 24)
MBzP	92.6	U: 1.33 (0.53, 3.01) SG: 1.51 (0.78, 2.66)	100	U: 1.77 (1.38, 3.30) SG: 2.33 (0.88, 3.22)	91.8	U: 1.29 (0.53, 2.81) SG: 1.49 (0.76, 2.65)	--	--	90	U: 7.6	--	SG: 3.2 (1.8, 5.2) SG: 3.7 (2.0, 6.8)
MCPP	42.6	U: <LOD (<LOD, 0.48) SG: <LOD (<LOD, 0.61)	66.7	U: 0.44 (<LOD, 0.59) SG: 0.38 (<LOD, 0.60)	40.0	U: <LOD (<LOD , 0.45) SG: <LOD (<LOD, 0.66)	--	--	70	U: 1.3	--	--
MECPP	96.8	U: 3.06 (1.09, 5.77) SG: 3.24 (1.88, 5.71)	100	U: 3.03 (2.11, 3.46) SG: 2.87 (2.67, 3.02)	96.5	U: 3.12 (1.06, 6.11) SG: 3.47 (1.88, 6.49)	100	SG: 35.7 (18.7, 76.2)	--	--	--	--
MEHHP	98.9	U: 2.98 (1.43, 5.67) SG: 3.44 (2.24, 6.39)	100	U: 2.68 (1.87, 3.27) SG: 2.37 (1.94, 2.74)	98.8	U: 3.15 (1.40, 6.21) SG: 3.61 (2.27, 6.44)	100	SG: 20.3 (10.3, 44.4)	94	U: 17.1	--	--
MEHP	2.1	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	0	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	2.35	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	83.0	SG: 4.8 (1.8, 12.8)	82	U: 6.2	--	SG: 5.0 (2.8, 7.7) SG: 5.9 (3.2, 13)
MEOHP	92.6	U: 1.49 (0.60, 3.21) SG: 1.58 (0.88, 3.57)	100	U: 1.41 (0.88, 1.57) SG: 1.35 (0.94, 1.44)	91.8	U: 1.52 (0.57, 3.45) SG: 1.73 (0.88, 3.74)	99.6	SG: 17.2 (8.9, 35.1)	94	U: 14.0	--	--

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	Present study (Sampling period: 2017–2018)						New York Inner-City Cohort (Sampling period: 2000–2006) (Whyatt et al., 2009)		Pregnant women in Right From The Start Cohort (Sampling period: 2000–2004) (Buckley et al., 2012)		Before and during pregnancy concentrations from Massachusetts General Hospital Fertility Center (Sampling period: 2004–2009) (Braun et al., 2012)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		African American and Dominican women (n=311)		Females ≥18 years, 46% White, 40% Black (n=50)		Females 18–45 years, 91% White (n=137)	
Phthalate metabolite	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50}**	**DF %**	**Phthalate metabolite concentration, µg/L P50 ($P_{25,75}$)**
MEP	100	U: 12.8 (5.85, 59.9) SG: 18.3 (7.31, 61.2)	100	U: 12.6 (8.70, 35.0) SG: 16.9 (7.31, 35.9)	100	U: 13.0 (5.31, 66.3) SG: 19.2 (7.42, 67.9)	--	--	100	U: 61.5	--	SG: 61 (37, 145) SG: 55 (24, 116)
MiBP	71.3	U: 1.73 (<LOD, 4.79) SG: 2.30 (<LOD, 4.77)	88.9	U: 2.30 (2.00, 5.62) SG: 2.23 (1.68, 3.34)	69.4	U: 1.56 (<LOD, 4.62) SG: 2.32 (<LOD, 4.77)	--	--	54	U: 1.3	--	SG: 5.4 (3.2, 8.9) SG: 5.9 (4.0, 9.0)

	Present study (Sampling period: 2017–2018)						Sperm Environmental Epigenetics and Development Study (SEEDS) Cohort (Sampling period: 2014 and 2017) (Huffman et al., 2018)		Patients at Massachusetts General Hospital Fertility Left (Sampling period: 2004–2008) (Meeker et al., 2012)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		Males, 77% White (n=48)		Males and females, 87% White (n=269)	
Phthalate metabolite	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**
MBP	88.3	U: 3.17 (1.27, 9.54) SG: 4.35 (1.86, 9.41)	100	U: 7.22 (3.13, 22.2) SG: 6.36 (4.70, 17.2)	87.1	U: 2.97 (1.20, 9.01) SG: 3.68 (1.85, 9.09)	98	SG: 7.99 (6.04, 11.8)	--	--
MBzP	92.6	U: 1.33 (0.53, 3.01) SG: 1.51 (0.78, 2.66)	100	U: 1.77 (1.38, 3.30) SG: 2.33 (0.88, 3.22)	91.8	U: 1.29 (0.53, 2.81) SG: 1.49 (0.76, 2.65)	100	SG: 3.94 (2.15, 8.69)	--	--
MCPP	42.6	U: <LOD (<LOD, 0.48) SG: <LOD (<LOD, 0.61)	66.7	U: 0.44 (<LOD, 0.59) SG: 0.38 (<LOD, 0.60)	40.0	U: <LOD (<LOD , 0.45) SG: <LOD (<LOD, 0.66)	100	SG: 1.98 (1.22, 4.09)	--	SG: 3.4 (1.9, 6.7)
MECPP	96.8	U: 3.06 (1.09, 5.77) SG: 3.24 (1.88, 5.71)	100	U: 3.03 (2.11, 3.46) SG: 2.87 (2.67, 3.02)	96.5	U: 3.12 (1.06, 6.11) SG: 3.47 (1.88, 6.49)	100	SG: 9.87 (7.12, 13.8)	--	SG: 82.9 (36.3, 197)

	Present study (Sampling period: 2017–2018)						Sperm Environmental Epigenetics and Development Study (SEEDS) Cohort (Sampling period: 2014 and 2017) (Huffman et al., 2018)		Patients at Massachusetts General Hospital Fertility Left (Sampling period: 2004–2008) (Meeker et al., 2012)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		Males, 77% White (n=48)		Males and females, 87% White (n=269)	
Phthalate metabolite	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)
MEHHP	98.9	U: 2.98 (1.43, 5.67) SG: 3.44 (2.24, 6.39)	100	U: 2.68 (1.87, 3.27) SG: 2.37 (1.94, 2.74)	98.8	U: 3.15 (1.40, 6.21) SG: 3.61 (2.27, 6.44)	100	SG: 6.84 (4.52, 9.27)	--	SG: 51.7 (23.7, 134)
MEHP	2.1	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	0	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	2.35	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	77	SG: 1.14 (0.72, 1.86)	--	SG: 8.0 (3.2, 23.2)
MEOHP	92.6	U: 1.49 (0.60, 3.21) SG: 1.58 (0.88, 3.57)	100	U: 1.41 (0.88, 1.57) SG: 1.35 (0.94, 1.44)	91.8	U: 1.52 (0.57, 3.45) SG: 1.73 (0.88, 3.74)	100	SG: 4.41 (3.23, 5.62)	--	SG: 33.9 (14.5, 88.3)
MEP	100	U: 12.8 (5.85, 59.9) SG: 18.3 (7.31, 61.2)	100	U: 12.6 (8.70, 35.0) SG: 16.9 (7.31, 35.9)	100	U: 13.0 (5.31, 66.3) SG: 19.2 (7.42, 67.9)	100	SG: 19.3 (9.84, 54.5)	--	SG: 173 (71.0, 512)
MiBP	71.3	U: 1.73 (<LOD, 4.79) SG: 2.30 (<LOD, 4.77)	88.9	U: 2.30 (2.00, 5.62) SG: 2.23 (1.68, 3.34)	69.4	U: 1.56 (<LOD, 4.62) SG: 2.32 (<LOD, 4.77)	100	SG: 7.11 (4.53, 11.0)	--	--

	Present study (Sampling period: 2017–2018)						Massachusetts General Hospital Andrology Laboratory (Sampling period: 2000–2001) (Hauser et al., 2004)		Random sample of members of a prepaid health plan (Sampling period: 1996–1997) (Hoppin et al., 2002)		Fox River Environment and Diet Study (FRIENDS) (Sampling period: 1999–2005) (Peck et al., 2010)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		Males in the New England area (n=369)		African-American females in Washington, DC (n=46)		Hmong women in Wisconsin (n=45)	
Phthalate metabolite	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)	DF %	Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)
MBP	88.3	U: 3.17 (1.27, 9.54) SG: 4.35 (1.86, 9.41)	100	U: 7.22 (3.13, 22.2) SG: 6.36 (4.70, 17.2)	87.1	U: 2.97 (1.20, 9.01) SG: 3.68 (1.85, 9.09)	--	U: 13.6 (7.0, 29.3) SG: 16 (9.8, 29.2)	100	U: 53.0	100	U: 26.1 (14.1, 55.1)
MBzP	92.6	U: 1.33 (0.53, 3.01) SG: 1.51 (0.78, 2.66)	100	U: 1.77 (1.38, 3.30) SG: 2.33 (0.88, 3.22)	91.8	U: 1.29 (0.53, 2.81) SG: 1.49 (0.76, 2.65)	--	U: 6.0 (2.4, 13.7) SG: 7.2 (3.8, 14.0)	100	U: 31.5	100	U: 30.1 (12.8, 48.9)
MCPP	42.6	U: <LOD (<LOD, 0.48)	66.7	U: 0.44 (<LOD, 0.59)	40.0	U: <LOD (<LOD , 0.45)	--	--	--	--	93	U: 2.2 (1.2, 3.9)

	Present study (Sampling period: 2017–2018)						Massachusetts General Hospital Andrology Laboratory (Sampling period: 2000–2001) (Hauser et al., 2004)		Random sample of members of a prepaid health plan (Sampling period: 1996–1997) (Hoppin et al., 2002)		Fox River Environment and Diet Study (FRIENDS) (Sampling period: 1999–2005) (Peck et al., 2010)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		Males in the New England area (n=369)		African-American females in Washington, DC (n=46)		Hmong women in Wisconsin (n=45)	
Phthalate metabolite	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, µg/L P_{50} ($P_{25,75}$)**
		SG: <LOD (<LOD, 0.61)		SG: 0.38 (<LOD, 0.60)		SG: <LOD (<LOD, 0.66)						
MECPP	96.8	U: 3.06 (1.09, 5.77) SG: 3.24 (1.88, 5.71)	100	U: 3.03 (2.11, 3.46) SG: 2.87 (2.67, 3.02)	96.5	U: 3.12 (1.06, 6.11) SG: 3.47 (1.88, 6.49)	--	--	--	--	100	U: 36.0 (16.9, 82.5)
MEHHP	98.9	U: 2.98 (1.43, 5.67) SG: 3.44 (2.24, 6.39)	100	U: 2.68 (1.87, 3.27) SG: 2.37 (1.94, 2.74)	98.8	U: 3.15 (1.40, 6.21) SG: 3.61 (2.27, 6.44)	--	--	--	--	100	U: 21.4 (11.3, 51.6)
MEHP	2.1	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	0	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	2.35	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	--	U: 5.2 (1.9, 17.2) SG: 6.5 (2.4, 19.5)	100	U: 7.3	81	U: 4.5 (2.6, 7.7)
MEOHP	92.6	U: 1.49 (0.60, 3.21) SG: 1.58 (0.88, 3.57)	100	U: 1.41 (0.88, 1.57) SG: 1.35 (0.94, 1.44)	91.8	U: 1.52 (0.57, 3.45) SG: 1.73 (0.88, 3.74)	--	--	--	--	100	U: 13.5 (8.6, 36.5)
MEP	100	U: 12.8 (5.85, 59.9) SG: 18.3 (7.31, 61.2)	100	U: 12.6 (8.70, 35.0) SG: 16.9 (7.31, 35.9)	100	U: 13.0 (5.31, 66.3) SG: 19.2 (7.42, 67.9)	--	U: 128 (46.1, 444) SG: 153 (58.7, 495)	76.1	U: 211.4	100	U: 63.0 (32.9, 116.9)
MiBP	71.3	U: 1.73 (<LOD, 4.79) SG: 2.30 (<LOD, 4.77)	88.9	U: 2.30 (2.00, 5.62) SG: 2.23 (1.68, 3.34)	69.4	U: 1.56 (<LOD, 4.62) SG: 2.32 (<LOD, 4.77)	--	--	--	--	100	U: 8.9 (5.5, 13.5)

	Present study (Sampling period: 2017–2018)						Pregnant women from Brigham and Women's Hospital in Boston, Massachusetts (Sampling period: 2006–2008) (Ferguson et al., 2015)		Cohort from Massachusetts General Hospital (Sampling period: 1999–2003) (Duty et al., 2005)	
	Adults aged 19–65 years (n=94)		Males 19–65 years (n=9)		Females 19–65 years (n=85)		Females 59% White, 16% Black (n=1, 683)		Males 18 to 54 years, 82% White (n=295)	
Phthalate metabolite	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**	**DF %**	**Phthalate metabolite concentration, μg/L P_{50} ($P_{25,75}$)**
MBP	88.3	U: 3.17 (1.27, 9.54) SG: 4.35 (1.86, 9.41)	100	U: 7.22 (3.13, 22.2) SG: 6.36 (4.70, 17.2)	87.1	U: 2.97 (1.20, 9.01) SG: 3.68 (1.85, 9.09)	99.7	SG: 16.5 (10.9, 27.8)	100	U: 14.3 (7.3, 33.1) SG: 16.2 (10.2, 31.7)
MBzP	92.6	U: 1.33 (0.53, 3.01) SG: 1.51 (0.78, 2.66)	100	U: 1.77 (1.38, 3.30) SG: 2.33 (0.88, 3.22)	91.8	U: 1.29 (0.53, 2.81) SG: 1.49 (0.76, 2.65)	98.9	SG: 6.38 (3.47, 13.2)	100	U: 6.9 (3.0, 14.9) SG: 7.9 (4.2, 14.3)
MCPP	42.6	U: <LOD (<LOD, 0.48) SG: <LOD (<LOD, 0.61)	66.7	U: 0.44 (<LOD, 0.59) SG: 0.38 (<LOD, 0.60)	40.0	U: <LOD (<LOD, 0.45) SG: <LOD (<LOD, 0.66)	96.8	SG: 1.68 (1.03, 3.50)	--	-
MECPP	96.8	U: 3.06 (1.09, 5.77) SG: 3.24 (1.88, 5.71)	100	U: 3.03 (2.11, 3.46) SG: 2.87 (2.67, 3.02)	96.5	U: 3.12 (1.06, 6.11) SG: 3.47 (1.88, 6.49)	100	SG: 34.9 (17.7, 99.4)	--	--
MEHHP	98.9	U: 2.98 (1.43, 5.67) SG: 3.44 (2.24, 6.39)	100	U: 2.68 (1.87, 3.27) SG: 2.37 (1.94, 2.74)	98.8	U: 3.15 (1.40, 6.21) SG: 3.61 (2.27, 6.44)	100	SG: 27.5 (14.9, 70.3)	--	--
MEHP	2.1	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	0	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	2.35	U: <LOD (<LOD, <LOD) SG: <LOD (<LOD, <LOD)	95.3	SG: 9.07 (4.63, 21.0)	100	U: 5.0 (2.0, 20.2) SG: 6.3 (2.4, 19.5)
MEOHP	92.6	U: 1.49 (0.60, 3.21) SG: 1.58 (0.88, 3.57)	100	U: 1.41 (0.88, 1.57) SG: 1.35 (0.94, 1.44)	91.8	U: 1.52 (0.57, 3.45) SG: 1.73 (0.88, 3.74)	99.9	SG: 15.3 (8.33, 37.6)	--	--
MEP	100	U: 12.8 (5.85, 59.9) SG: 18.3 (7.31, 61.2)	100	U: 12.6 (8.70, 35.0) SG: 16.9 (7.31, 35.9)	100	U: 13.0 (5.31, 66.3) SG: 19.2 (7.42, 67.9)	99.9	SG: 121 (47.3, 383)	100	U: 149 (48.4, 469) SG: 160 (60.0, 508)
MiBP	71.3	U: 1.73 (<LOD, 4.79) SG: 2.30 (<LOD, 4.77)	88.9	U: 2.30 (2.00, 5.62) SG: 2.23 (1.68, 3.34)	69.4	U: 1.56 (<LOD, 4.62) SG: 2.32 (<LOD, 4.77)	99.6	SG: 7.57 (4.74, 12.0)	--	--

Abbreviations: U, uncorrected metabolite concentrations, (μg/L); SG, Specific-gravity corrected metabolite concentrations, (μg/L); LOD, limit of detection; DF%, detection frequency percentage; $P_{25,50,75}$, 25th, 50th, and 75th percentiles, respectively.