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Article

Occupational Exposures to Phthalates among Black and Latina U.S. Hairdressers Serving an Ethnically Diverse Clientele: A Pilot Study

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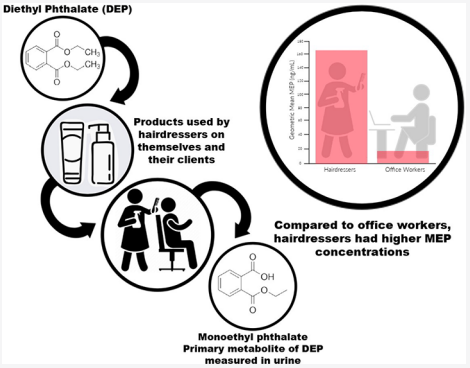
ABSTRACT: Hairdressers may be differentially exposed to phthalates through hair salon services provided and products used, yet no U.S. studies have investigated these exposures in this population. We characterized concentrations and exposure determinants to nine phthalate metabolites in postshift urine samples among 23 hairdressers from three Black and three Dominican salons, as well as a comparison group of 17 female office workers from the Maryland/Washington D.C. metropolitan area. Overall, hairdressers had higher metabolite concentrations than office workers. The geometric mean (GM) for monoethyl phthalate (MEP) was 10 times higher in hairdressers (161.4 ng/mL) than office workers (15.3 ng/mL). Hairdressers providing select services and using certain products had higher GM MEP concentrations than those who did not: permanent waves/texturizing (200.2 vs 115.4 ng/mL), chemical straightening/relaxing (181.6 vs 92.1 ng/mL), bleaching (182.3 vs 71.6 ng/mL), permanent hair color (171.9 vs 83.2 ng/mL), and Brazilian blowout/keratin treatments (181.4 vs 134.6 ng/mL). Interestingly, hairdressers providing natural services had lower GM MEP concentrations than those who did not: twists (129.1 vs 215.8 ng/mL), sister locs/locs (86.0 vs 241.9 ng/mL), and afros (94.7 vs 203.9 ng/mL). Larger studies are warranted to confirm our findings and identify disparities in occupational phthalate exposures.



KEYWORDS: *phthalates, hairdressers, occupational exposure, personal care products, women, endocrine disruptors, Black, Latina*

INTRODUCTION

Phthalates are a class of chemicals commonly found in consumer products, including food packaging and cosmetics.[1,2] High-molecular-weight phthalates, such as di(2-ethylhexyl)phthalate (DEHP), diisobutyl phthalate (DiNP), and di-*n*-octyl phthalate (DnOP) are used to impart flexibility and durability to vinyl products, while low-molecular-weight phthalates such as diethyl phthalate (DEP), dibutyl phthalate (DBP), and butyl benzyl phthalate (BBzP) are used in many personal care products (PCPs) in the form of fragrance, including in cosmetics and personal hygiene products (e.g., skin creams and lotions, nail polish, shampoos, oils, perfume/fragranced products, and other hair styling products such as hair sprays).[1,3,4] The main routes of phthalate exposures are ingestion, inhalation, and dermal absorption.[1,5−8] Exposure to phthalates is of increasing public health concern because they are known endocrine-disrupting compounds that have been linked to adverse health effects in humans, including respiratory and reproductive effects.[9−12] For example, there is mounting evidence which suggests that phthalates impact male and female fertility.[13] Prenatal exposure to some phthalates, including to DEP which is heavily used in personal care products, has been linked to higher odds of preterm birth,[13−15] decreased anogenital distance among male infants,[16] and pregnancy complications including risk factors for gestational diabetes,[17] anemia,[18,19] and preeclampsia.[20] Although phthalate exposure is ubiquitous in the general population,[21−23] gender and racial/ethnic disparities are reported.[21,24] Some of these differences could be due to varying exposures through PCP use. Black/African American females report using more hair products, especially hair oil, root stimulator, and lye-free perms and relaxers than white females, and many of these products are known to contain phthalates.[25−28]

Occupational groups such as hairdressers may have higher levels of exposure to chemicals in hair products, which could increase their risk of adverse health effects. More than 800,000 workers are employed as hairdressers or cosmetologists in the U.S., the majority (92.3%) are female and 31% are Black or Hispanic/Latina.[29] Disparate phthalate exposure is a concern among racially and ethnically diverse female hairdressers who primarily serve women of color as personal and occupational use

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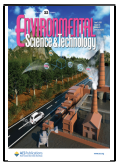

Table 1. Phthalate Parent Compounds, Metabolites, and General Sources of Exposure[37−41]

parent compound	metabolite	metabolite abbreviation	general sources of exposure	approximate human biological half-life (h)
diethyl phthalate	monoethyl phthalate	MEP	soaps, lotions, fragrances, cosmetics, hair products, medications, and industrial solvents	2.1−2.7
di-*n*-octyl phthalate	mono-3-carboxypropyl phthalate	MCPP	soft plastics, dental molding, and nail polish	6.9
di(2-ethylhexyl)phthalate	mono(2-ethyl-5-carboxypentyl)phthalate	MECPP	soft plastics used for household items, building materials, and medical supplies	8.9−15
	mono(2-ethyl-5-hydroxyhexyl)phthalate	MEHHP		6−10
	mono(2-ethylhexyl)phthalate	MEHP		3.5−5
	mono(2-ethyl-5-oxohexyl)phthalate	MEOHP		6−10
di-*n*-butyl phthalate	monobutyl phthalate	MnBP	adhesives, caulk, cosmetics, medications, and industrial solvents	1.9−3.9
diisobutyl phthalate	monoisobutyl phthalate	MiBP	paints, varnishes, caulk, adhesives, and cosmetics	3.9
butyl benzyl phthalate	monobenzyl phthalate	MBzP	plastics, vinyl flooring, carpet tiles, adhesives, sealants, and industrial solvents	<24 h[a]

[a]No half-life of butyl benzyl phthalate in the body has been calculated; however, the available data indicate a half-life of less than 24 h.

of products containing these chemicals could be elevated in this population. Occupational exposure to phthalates could occur through several pathways, including dermal absorption and inhalation. Phthalates are semivolatile and have been detected in the air and dust collected from hair salons in the U.S. and other countries.[30−32] Despite the potential for disproportionate exposures, to our knowledge, only two studies to date measured phthalates among hairdressers via biomonitoring conducted in Slovakia.[33,34] Authors reported higher urinary phthalate metabolite concentrations among apprentice hairdressers compared to controls.[33] Notably, no U.S. studies have assessed phthalate exposures among women working in hair salons.

Given increasing public health concerns of phthalate exposures, the exposure disparities reported among women of color thought to arise partly due to PCP use,[35] and the paucity of biomonitoring data among female hairdressers, we sought to characterize phthalate exposures and possible exposure disparities among hairdressers primarily serving ethnically diverse clientele. Our aims were to evaluate workplace behaviors, salon products used, and services associated with phthalate metabolite concentrations among hairdressers and to compare phthalate metabolite concentrations between hairdressers and office workers and a representative sample of women from the U.S. general population to assess whether hairdressers primarily serving ethnically diverse clientele experience elevated exposures to phthalates.

MATERIALS AND METHODS

Participant Recruitment. We recruited a convenience sample of 23 hairdressers from December 2018 to May 2019. Hairdressers were recruited from six hair salons primarily serving an ethnically diverse clientele in the Maryland/Washington, D.C. metropolitan area. Eleven hairdressers worked in salons primarily serving Black/African-American clientele (i.e., women of African descent) which provided routine hair relaxing, hair texturizing, and other services catered to the needs of this clientele. Twelve hairdressers worked in salons primarily serving Latinx clientele and provided the "Dominican Blowout", a service that requires hair washing, setting hair in rollers, blow-drying and, at the client's request, flat ironing to style it. Herein, we will refer to the salons these hairdressers worked in as Black and Dominican salons, respectively. It is important to note that Dominican salons also served Black clientele and may also provide similar services as those provided in Black hair salons, although to a lesser extent, including hair relaxing and texturizing. To serve as a comparison group, we also recruited a convenience sample of 17 office workers between May and July 2019 from the University of Maryland, College Park, via word of mouth and electronic mail communication. Eligibility criteria for hairdressers and office workers included women ≥18 years who were willing to complete two interviewer-administered questionnaires in English or Spanish and provide a urine biospecimen. In addition, hairdressers had to be employed in the hair salon for at least 1 year prior to study enrollment to ensure that hairdressers were experienced with a high volume of clientele and provided a wide array of hair services. While our pilot study consisted of a convenience sample of study participants, we aimed to recruit a comparison group of office workers that were demographically similar to the hairdressers recruited in our study. All study protocols were reviewed and approved by the University of Maryland Institutional Review Board, and written informed consent was obtained from salon owners and individual study participants prior to study enrollment.

Data Collection. Trained bilingual study staff administered two questionnaires to study participants. An initial baseline questionnaire was administered to capture information on hairdresser demographics (e.g., age, race/ethnicity, level of education, income, and smoking status), health information (e.g., respiratory and reproductive health), and personal and workplace behaviors (e.g., use of cosmetics, hair products, and other PCPs in the previous 24−48 h, hair salon services provided, hair salon products used, personal protective equipment (PPE) used, dietary-consumption related factors, home cleaning, and fragranced product use). Personal care product use was assessed for with two yes/no questions that asked, for example, "Did you use shampoo today?" and "Did you use shampoo yesterday?" Based on response frequency, we combined responses to these two questions and created a variable to serve as a proxy for use of these products in the past 24−48 h. In the baseline questionnaire, workplace behaviors were assessed using a series of yes/no questions on the hair salon services typically provided in a usual workday (e.g., haircut, hair relaxing, braids, and Brazilian blowout), products used (e.g., shampoo, gel, bleach, and hair dye), and PPE (e.g., gloves, apron, and mask) used at work. A postshift questionnaire on the day of biospecimen collection captured information on services provided and PPE used during the workday. Similar data collection procedures were employed for the office workers; however, office workers were not asked about specific workplace

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behaviors such as the use of PPE. A description of hair salon services provided by participating hairdressers is available in Supporting Information, Table S1.

Exposure Assessment of Phthalates. Urine samples were obtained at the end of the workday (postshift) from all study participants. The exact day of sample collection for each hairdresser was based on their availability with preference given to a day when they expected a high clientele volume. Whenever possible, we aimed to schedule as many hairdressers from the same salon on the same sample collection day. All postshift spot urine samples were collected in phthalate-free polypropylene collection containers. Participants were asked to wear powder-free gloves during urine collection to minimize potential contamination from products used on their hands. Study staff transferred samples in a cooler with ice packs to the laboratory within 1 h, where they were aliquoted into 2 mL cryovials and stored at −80 °C until laboratory analyses for phthalate metabolites. Specific gravity was measured using an ATAGO 3741 refractometer pen (ATAGO3741, Tokyo, Japan) to control for dilution in our analysis.

Laboratory analysis was conducted at the University of Maryland Exposome Small Molecule Core Facility using liquid chromatography−tandem mass spectrometry (LC−MS/MS) using a validated method previously described by Allotey et al. 2021.[36] Nine phthalate metabolites were measured, representing exposure to six parent compounds (Table 1). The measured metabolites and their parent compounds included monoethyl phthalate (MEP, a metabolite of diethyl phthalate, DEP); mono-*n*-butyl phthalate (MnBP, a metabolite of di-*n*-butyl phthalate, DnBP); mono-isobutyl phthalate (MiBP, a metabolite of diisobutyl phthalate, DiBP); monobenzyl phthalate (MBzP, a metabolite of butylbenzyl 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 nonspecific metabolite of several phthalates including DnBP, di-*n*-octyl phthalate, DnOP, and a minor metabolite of DiBP). A blank sample was processed following the sample preparation procedure to confirm no laboratory contamination of phthalate metabolites, and a solvent blank and spiked standard were injected for QA/QC purposes after every 10 sample injections. Machine-read values were used for values below the limit of detection (LOD) in our analyses. The LODs ranged between 0.063 and 0.542 ng/mL.

We evaluated concentrations of individual phthalate metabolites and the molar sum of the di(2-ethylhexyl)phthalate (ΣDEHP)-devolving metabolites (MEHP, MEHHP, MEOHP, and MECPP) using the following formula as reported previously:[22,42,43] $\Sigma\text{DEHP}\ (\mu\text{mol/L}) = C_{\text{MEHP}}\ (\text{ng/mL}) \times (1/\text{MW}_{\text{MEHP}}) + C_{\text{MEHHP}}\ (\text{ng/mL}) \times (1/\text{MW}_{\text{MEHHP}}) + C_{\text{MEOHP}}\ (\text{ng/mL}) \times (1/\text{MW}_{\text{MEOHP}}) + C_{\text{MECPP}}\ (\text{ng/mL}) \times (1/\text{MW}_{\text{MECPP}})$, where C_{MEHP} (ng/mL), for example, is the individual's urinary concentration of MEHP in ng/mL and MW_{MEHP} is the molecular weight of MEHP in g/mol. To facilitate comparison with the other phthalate metabolites reported in units of ng/mL, we multiplied the ΣDEHP (μmol/L) values by the mean molecular weight of the DEHP metabolites (MW = 293.337 μg/μmol) resulting in the ΣDEHP being expressed in the same units as individual metabolites.[22,42,43]

To account for urinary dilution, we used specific gravity-corrected phthalate metabolite concentrations using the following formula: $C_{sg} = [(C \times 1.019 - 1)/(\text{SG} - 1)]$, where C_{sg} is the specific gravity-corrected phthalate metabolite concentration (ng/mL), C is the observed phthalate metabolite concentration (ng/mL), 1.019 is the mean specific gravity for our study population, and SG is the specific gravity for an individual's urine sample.[44]

Statistical Analysis. We calculated descriptive statistics, including frequencies, means, standard deviations (SD), and range to summarize demographic characteristics among hairdressers and office workers. We assessed differences in demographic characteristics between hairdressers and office workers and between hairdressers from Black versus Dominican salons using χ-square, Fisher's exact, and Student's t-tests.

We determined detection frequency (DF), geometric means (GM), percentiles (p25, p50, and p75), and range for phthalate metabolite concentrations. Phthalate metabolite concentrations were right-skewed, so concentrations were $\log_2$-transformed. We used the Shapiro−Wilk test to assess normality. Five of the nine phthalates were not log-normally distributed; therefore, we used the nonparametric Wilcoxon rank sum for statistical tests. Both uncorrected and specific gravity-corrected phthalate metabolite concentrations were compared between hairdressers and office workers and hairdressers from Black versus Dominican salons for phthalate metabolites detected in >70% of samples.

To examine the relationship between workplace behaviors and phthalate metabolite concentrations, we calculated frequency of hair salon services provided, products used, and PPE used in general as assessed in the baseline survey and hair salon services provided and PPE used on the day of biospecimen collection as assessed in the postshift surveys. GM phthalate metabolite concentrations were calculated for each level (yes vs no) of workplace behavior. Due to our small sample size and the low frequency of reported hair salon services, products used, and PPE among hairdressers, we did not perform statistical tests to compare the phthalate metabolite concentrations by hair salon service, products used, or PPE. All analyses were conducted in Stata SE 14.2 for Mac (StataCorp, College Station, TX), and an alpha of 0.05 was used as our criteria for statistical significance.

RESULTS AND DISCUSSION

Study Participant Characteristics. The majority of hairdressers (95.6%) self-identified as either non-Hispanic (NH) Black (47.8%) or Hispanic/Latina (47.8%) reported earning ≤$30,000 per year (52.6%) and were nonsmokers (82.6%) (Table 2). Similar to hairdressers, most office workers (82.4%) self-identified as either NH-Black (41.2%) or Hispanic/Latina (41.2%). However, office workers were younger (mean age: 33.6 and range: 21−56 years) than hairdressers (mean age: 40.2 and range: 22−58 years) and were more likely to be college educated (70.6% vs 21.7%). The mean number of cosmetic products and PCPs used for personal use were not statistically significantly different between hairdressers [cosmetics: 3.4 (range: 0−9); hair products: 2.1 (range: 0−4); and PCPs: 10.5 (range: 0−26)] and office workers [cosmetics: 2.5 (range: 0−5); hair products: 1.5 (range: 0−3); and PCPs: 10.6 (range: 7−14)]. There were no statistically significant differences in dietary consumption-related factors or home cleaning and fragrance use (data not shown). Hairdressers reported working in a hair salon for an average of 15.1 (range: 3−40) years and working 44.3 (range: 9−91) hours per week. However, hairdressers were more likely to receive ≥2 hair salon services in the past 12 months compared to office workers (43.5% vs 11.8%). Hairdressers from Dominican salons reported serving

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Table 2. Study Participant Characteristics (n = 40, 2018−2019)

		hairdressers		
	all (n = 23)	Black salons (n = 11)	Dominican salons (n = 12)	office workers (n = 17)
characteristic		N (%)		
Race/Ethnicity[a,b]				
Hispanic/Latina	11 (47.8)	1 (9.1)	10 (83.3)	7 (41.2)
non-Hispanic Black	11 (47.8)	10 (90.9)	1 (8.3)	7 (41.2)
other	1 (4.4)	0 (0.0)	1 (8.3)	3 (17.6)
Education[c]				
less than high school	4 (17.4)	0 (0.0)	4 (33.3)	0 (0.0)
high school or GED	6 (26.1)	4 (36.4)	2 (16.7)	1 (5.9)
trade school	8 (34.8)	4 (36.4)	4 (33.3)	1 (5.9)
college	5 (21.7)	3 (27.3)	2 (16.7)	12 (70.6)
other	0 (0.0)	0 (0.0)	0 (0.0)	3 (17.7)
Income				
≤$30,000	10 (52.6)	5 (45.5)	5 (62.5)	3 (17.7)
$30,001−$50,000	4 (21.1)	2 (18.2)	2 (25.0)	3 (17.7)
$50,001−$75,000	2 (10.5)	1 (9.1)	1 (12.5)	4 (23.5)
>$75,000	3 (15.8)	3 (27.3)	0 (0.0)	7 (41.2)
Current Smoker[b]				
no	19 (82.6)	7 (63.6)	12 (100.0)	16 (94.1)
yes	4 (17.4)	4 (36.4)	0 (0.0)	1 (5.9)
Hair Salon Services Received in the Past 12 Months[c,d]				
0 services	7 (30.4)	6 (54.6)	1 (8.3)	12 (70.6)
1 service	6 (26.1)	2 (18.2)	4 (33.3)	3 (17.7)
2−3 services	10 (43.5)	3 (27.3)	7 (58.3)	2 (11.8)
characteristic		mean (SD)		
age (years)[c]	40.2 (10.6)	37.3 (10.2)	42.8 (10.6)	33.6 (7.9)
years working in hair salons	15.1 (9.5)	14.9 (9.4)	15.3 (10.1)	n/a
hours worked per week	44.3 (18.7)	46.2 (23.7)	42.6 (13.4)	40.4 (10.4)
clients per week[b]	26.2 (12.1)	19.2 (8.9)	32.7 (11.4)	n/a
personal use in the past 24−48 h				
cosmetics	3.4 (3.1)	2.7 (2.0)	4.1 (3.8)	2.5 (2.1)
hair products	2.1 (1.5)	1.8 (1.4)	2.4 (1.7)	1.5 (1.1)
personal care products[e]	10.5 (4.7)	10.3 (3.4)	10.8 (5.8)	10.6 (2.0)

[a]Other race category includes White, American Indian or Alaska Native, and other. [b]$p < 0.05$ for comparisons between hairdressers from Black and Dominican salons using Fisher's exact test for categorical variables and the Wilcoxon rank sum test for continuous variables. [c]$p < 0.05$ for comparisons between all hairdressers and office workers using Fisher's exact test for categorical variables and the Wilcoxon rank sum test for continuous variables. [d]Hair salon services in the past 12 months included bleach or highlights, hair straightening/relaxing, permanent waves/texturizing, Brazilian blow-out/keratin treatments, and hair color. [e]Personal care products included a total of 31 noncosmetic and nonhair products, such as soap, body wash, shaving cream, deodorant, body lotion, and perfume.

more clients per week (mean: 32.7 and range: 7−50 clients/week) than hairdressers from Black salons (mean: 18.7; range: 7−37 clients/week; and $p < 0.05$) (Table 2).

Both hairdressers and office workers reported infrequent use of hair products on themselves in the past 24−48 h. This is not a surprising finding as women of color typically wash and style their hair weekly or monthly to minimize damaging and drying out the hair due to hair texture.[45]

Phthalate Metabolite Concentrations. All nine phthalate metabolites were detected in >50% of hairdressers, while six of the nine phthalate metabolites measured were detected in >50% of office workers (Table 3). GM concentrations were significantly higher among hairdressers than office workers for five phthalates and ΣDEHP (MEP: 161.4 ng/mL vs 15.3 ng/mL; MECPP: 7.5 ng/mL vs 2.0 ng/mL; MEHHP: 7.2 ng/mL vs 2.2 ng/mL; MEOHP: 4.2 ng/mL vs 1.2 ng/mL; MnBP: 9.5 ng/mL vs 3.7 ng/mL; ΣDEHP: 22.0 ng/mL vs 5.9 ng/mL; and $p < 0.05$). GM MEP concentrations were more than 10 times higher, while MEHHP and MEOHP were three times higher among hairdressers compared to office workers. In contrast, MBzP levels were similar between the two occupational groups. Similar results were observed using uncorrected phthalate metabolite concentrations (Table S2).

We found that urinary phthalate metabolite concentrations were higher among hairdressers compared to women who worked in an office setting. Notably, we found concentrations for three DEHP-devolving metabolites and the ΣDEHP values were also higher among hairdressers compared to office workers. Diet is thought to be the dominant source of individual DEHP-devolving metabolites which were found to be higher among hairdressers compared to office workers, although they may also result from exposure to other sources such as vinyl flooring, furniture, and wall coverings. Thus, differences in concentrations between hairdressers and office workers could be due, in part, to other diet-related behaviors and environmental factors (e.g., exposure to building materials and other sources) both in and outside the workplace not captured in our study.

Hairdressers had higher uncorrected GM MEP concentrations compared to a representative sample of women of color of similar age (22−58 years) in the U.S. general population participating in the 2015−2016 National Health Nutrition and Examination Survey (n = 429)[46] (143.9 ng/mL vs 47.2 ng/mL). We also observed similar unadjusted GM MEP concentrations in our hairdressers compared to those reported among a group of 26 nail salon workers (143.9 ng/mL vs 140.0 ng/mL) who were predominantly female (65%) and of Asian descent (88%),[47] while they were five times lower than those reported in another study in a group of 17 Vietnamese nail salon workers, the majority of whom were female (88%).[48] Compared to two other studies among nonpregnant women of reproductive age, hairdressers in our study had 2.3 to 40.5 times higher uncorrected median MEP concentrations (122.7 ng/mL).[49,50] Specifically, in a case-control study among Chinese women aged 16−45 years, Cao et al. reported a median MEP concentration of 3.0 and 3.3 μg/L among 173 women with premature ovarian failure and 246 control women, respectively;[49] Hauser et al. reported a median MEP concentration of 52.2 μg/L among 256 US women undergoing in vitro fertilization.[50] Similarly, compared to studies that reported GM values among women of reproductive age, we observed higher GM MEP concentrations among hairdressers in our study.[36,48,51] For example, specific gravity-corrected GM MEP concentrations were seven times higher among hairdressers compared to a sample of Latino adults, the majority of which were female.[36] Notably, MEP is a metabolite of DEP which is a low molecular phthalate commonly used in personal care products,[4] including hair products,[28] which may explain the higher MEP concentrations observed among hairdressers. A 2018 study measured endocrine disrupting compounds in hair products typically used by Black

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Table 3. Summary Statistics for Specific Gravity-Corrected Phthalate Metabolite Concentrations in ng/mL among Study Participants (n = 40, 2018−2019)

		hairdressers (n = 23) specific gravity-corrected				office workers (n = 17) specific gravity-corrected				
metabolite	LOD	DF %	GM	p50 (p25, p75)	range	DF %	GM	p50 (p25, p75)	range	p-value[b]
MEP	0.237	100	161.4	163.9 (62.0, 475.2)	34.4−897.1	100	15.3	18.8 (5.1, 30.3)	1.8−183.7	<0.001
MCPP	0.187	60.9	0.4	0.3 (0.01, 1.1)	0−3.9	35.3	0.2	0.2 (0.1, 0.3)	0.1−2.9	--
MECPP	0.156	100	7.5	6.6 (3.2, 17.8)	1.2−52.2	100	2.0	1.5 (1.3, 1.9)	0.8−16.1	<0.001
MEHHP	0.197	100	7.2	6.8 (3.5, 13.4)	1.4−89.8	100	2.2	2.1 (1.4, 3.2)	1.0−7.6	<0.001
MEHP	0.291	52.2	0.9	1.0 (0.1, 6.4)	0.1−30.7	23.5	0.3	0.2 (0.1, 0.4)	0.1−3.2	--
MEOHP	0.089	100	4.2	4.5 (2.4, 7.2)	0.9−20.1	94.1	1.2	0.9 (0.6, 1.9)	0.1−9.1	<0.001
MnBP	0.246	100	9.5	10.3 (5.8, 16.2)	0.7−102.1	100	3.7	4.1 (1.8, 7.2)	0.6−24.5	0.005
MiBP	0.542	91.3	3.4	4.3 (1.8, 8.1)	0.2−24.5	47.1	0.8	0.7 (0.3, 1.6)	0.2−8.5	--
MBzP	0.063	91.3	0.9	0.9 (0.5, 2.1)	0.2−5.0	94.1	0.9	1.03 (0.7, 2.1)	0.03−8.1	0.968
ΣDEHP[a]	--	--	22.0	22.0 (10.0, 45.2)	3.5−142.9	--	5.9	4.5 (3.2, 10.3)	2.7−29.1	<0.001

[a]ΣDEHP represents the molar sum of MEHP, MEHHP, MEOHP, and MECPP metabolites. [b]p-values from the Wilcoxon rank sum test comparing specific gravity-corrected phthalate biomarker concentrations between hairdressers and office workers; p-values ($p < 0.05$) are bolded; MCPP, MEHP, and MiBP had DF < 70% for hairdressers and/or office workers and were not compared using statistical tests, the p-value is noted as -- . Abbreviations: LOD: limit of detection; DF: detection frequency; GM: geometric mean; MEP: monoethyl 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; MnBP: monobutyl phthalate; MiBP: monoisobutyl phthalate; and MBzP: monobenzyl phthalate.

women (e.g., hair oils, root stimulators, hair lotion, and relaxers) and detected DEP in 78% of all the products tested.[28]

We did not observe any statistically significant differences in phthalate metabolite concentrations between hairdressers from Black versus Dominican salons, although we cannot dismiss the possibility that our small sample size could have limited these comparisons (Table S3). While this is the first U.S. study to assess phthalate exposures among female hairdressers, two studies conducted by Kolena et al. examined phthalate biomarker concentrations among Slovakian hairdressing apprentices.[33,34] Compared to hairdressers in our study, Kolena et al. 2016 reported lower median MEP concentrations (122.7 ng/mL vs 87.1 ng/mL) and higher median MiBP (3.1 ng/mL vs 40.3 ng/mL), MEHP (1.4 ng/mL vs 4.3 ng/mL), and MnBP (11.8 ng/mL vs 81.2 ng/mL) concentrations among 68 majority female (97.1%) hairdressing apprenticies.[33] Similarly, Kolena et al. 2019 also reported lower median MEP concentrations (108 ng/mL) and higher MnBP (109 ng/mL) and MEHP (4.2 ng/mL) among 74 majority female (89.2%) hairdressing apprentices compared to hairdressers in our study.[34] Differences between these studies may be due to different product regulations and formulations in Europe versus the United States, as well as differences in study population demographics. For example, Kolena et al. included young hairdressing apprentices, with a mean age of 18 years. In contrast, our study population was older, with a mean age of 40 years. Based on the more frequent PCP use reported among adolescents,[52,53] we might expect the younger hairdressing apprentices in the Kolena et al. study to have higher median MEP concentrations, but their concentrations were lower than those observed among hairdressers in our study. For example, Parlett et al. reported that women of reproductive age used a median of seven products in the previous 24 h, while Berger et al. reported that 71% of adolescent Latinas 14−18 years used 9−19 products in the previous 48 h.[52,53] Frequent PCP use has also been positively associated with phthalate metabolite concentrations among women, specifically MEP, MiBP, and MnBP.[52,53] Another potential explanation for the higher MEP levels observed among hairdressers in our study could be due to differences in the type of products used by our ethnically diverse population.[28]

General Workplace Behaviors and Phthalate Metabolite Concentrations among Hairdressers. We observed higher phthalate metabolite concentrations for several hair salon services provided (Table 4), products used (Table 5), and PPE used while performing chemical services (Table 6).

In the baseline survey, most hairdressers reported providing many chemical-based services in general, including permanent waves/texturizing (60.9%), chemical straightening/relaxing (82.6%), permanent hair color (91.3%), and Brazilian blowout/keratin (60.9%) to their clients, while less hairdressers provided natural hair services, including braids (52.2%), twists (56.5%), sister locs/locs (39.1%), and afros (30.4%). MEP concentrations were higher among hairdressers who reported providing services that involved the use of chemicals in the baseline survey (Table 4). In particular, GM MEP concentrations were higher for hairdressers who provided permanent waves/texturizing (200.2 ng/mL vs 115.4 ng/mL), chemical straightening/relaxing (181.6 ng/mL vs 92.1 ng/mL), bleaching (182.3 ng/mL vs 71.6 ng/mL), permanent hair color (171.9 ng/mL vs 83.2 ng/mL), and Brazilian blowout/keratin treatments (181.4 ng/mL vs 134.6 ng/mL) compared to hairdressers who did not report providing those services. GM MCPP and MEHP concentrations were also higher among hairdressers who reported providing chemical straightening/relaxing (MCPP: 0.5 ng/mL vs 0.2 ng/mL and MEHP: 1.1 ng/mL vs 0.5 ng/mL), bleaching (MCPP: 0.6 ng/mL vs 0.1 ng/mL and MEHP: 1.3 ng/mL vs 0.1 ng/mL), and permanent hair coloring (MCPP: 0.5 ng/mL vs 0.1 ng/mL and MEHP: 1.1 ng/mL vs 0.1 ng/mL) compared to those who did not report providing those services. Eight of the nine phthalate metabolite concentrations and ΣDEHP were higher among hairdressers who reported providing haircuts compared to those who did not provide this service (Table 4).

GM MEP concentrations were lower among hairdressers who reported providing twists (129.1 ng/mL vs 215.8 ng/mL), sister locs/locs (86.0 ng/mL vs 241.9 ng/mL), and afros (94.7 ng/mL vs 203.9) compared to hairdressers who did not report providing those services (Table 4). To our knowledge, this is the first study to report that several natural hairstyles were associated with lower phthalate metabolite concentrations.

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Table 4. Specific Gravity-Corrected Geometric Mean Phthalate Metabolite Concentrations (ng/mL) Based on Hair Salon Services Provided (n = 23, 2018−2019)

services provided	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	ΣDEHP[a]
Permanent Waves/Texturizing											
yes	60.9	200.2	0.4	7.8	6.4	1.0	4.1	9.6	3.3	0.6	21.5
no	39.1	115.4	0.5	7.1	8.5	0.8	4.3	9.3	3.5	1.7	22.9
Chemical Straightening or Relaxing											
yes	82.6	181.6	0.5	7.0	6.4	1.1	4.2	10.3	3.6	0.9	20.5
no	17.4	92.1	0.2	10.9	12.6	0.5	3.9	6.3	2.6	0.7	31.4
Bleaching											
yes	13.0	182.3	0.6	7.4	6.8	1.3	4.4	9.9	3.8	1.0	21.9
no	87.0	71.6	0.1	8.0	10.6	0.1	2.9	6.9	1.5	0.5	23.2
Semipermanent Hair Color											
yes	78.3	143.7	0.4	6.9	6.3	0.7	3.6	8.1	2.9	0.8	19.7
no	21.7	245.4	0.4	10.5	11.1	2.4	6.8	16.9	5.8	1.3	33.3
Permanent Hair Color											
yes	91.3	171.9	0.5	7.2	6.5	1.1	4.3	10.0	3.6	0.9	20.9
no	8.7	83.2	0.1	12.7	18.6	0.1	3.3	5.1	1.9	0.6	37.8
Hair Extensions (No Glue)											
yes	60.9	144.9	0.3	8.3	8.0	0.9	4.4	9.9	3.2	0.7	24.5
no	39.1	190.8	0.6	6.4	6.0	1.0	3.9	8.8	3.8	1.3	18.6
Hair Extensions (with Glue)											
yes	52.2	136.3	0.4	6.0	5.6	0.9	3.8	10.6	3.3	0.7	18.0
no	47.8	194.2	0.4	9.6	9.5	1.0	4.6	8.4	3.5	1.3	27.5
Flat Iron											
yes	95.7	169.7	0.5	8.2	7.7	1.0	4.5	10.7	3.8	0.8	23.9
no	4.4	53.9	0.1	1.2	1.4	0.1	0.9	0.7	0.2	5.0	3.5
Putting Hair in Rollers											
yes	82.6	162.5	0.4	7.3	6.9	0.9	4.0	8.5	3.3	0.8	21.4
no	17.4	156.5	0.6	8.9	8.5	1.3	5.2	15.8	4.1	1.5	25.2
Brazilian Blowout or Keratin											
yes	60.9	181.4	0.5	7.7	9.1	1.7	4.7	12.4	4.5	0.9	25.1
no	39.1	134.6	0.3	7.3	4.2	0.4	3.4	6.2	2.2	1.0	18.0
Braids											
yes	52.2	145.7	0.4	8.5	8.2	1.0	4.5	13.3	4.3	0.8	25.2
no	47.8	180.5	0.4	6.6	6.2	0.9	3.9	6.5	2.6	1.0	19.0
Twists											
yes	56.5	129.1	0.4	9.9	8.4	0.7	4.6	10.5	3.3	0.7	26.8
no	43.5	215.8	0.5	5.3	5.8	1.3	3.6	8.2	3.5	1.2	17.1
Sister Locs/Locs											
yes	39.1	86.0	0.3	7.5	7.6	0.5	3.8	9.4	2.6	0.7	21.5
no	60.9	241.9	0.5	7.5	6.9	1.4	4.5	9.5	4.1	1.1	22.4
Afros											
yes	30.4	94.7	0.3	10.0	9.9	0.4	4.3	10.9	2.8	0.8	27.6
no	69.6	203.9	0.5	6.6	6.2	1.3	4.1	8.9	3.7	0.9	20.0
Haircut											
yes	78.3	195.0	0.5	8.9	8.2	1.2	4.5	10.1	3.9	0.8	26.0
no	21.7	81.7	0.2	4.1	4.4	0.3	3.1	7.5	2.1	1.3	12.1
Deep Conditioning											
yes	95.7	32.2	0.4	7.2	6.9	0.8	4.0	8.5	3.1	0.8	21.2
no	4.4	897.1	0.8	19.6	16.5	7.3	10.9	102.0	24.5	3.1	53.8

[a]ΣDEHP represents the molar sum of MEHP, MEHHP, MEOHP, and MECPP metabolites. Abbreviations: MEP: monoethyl 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; MnBP: monobutyl phthalate; MiBP: monoisobutyl phthalate; and MBzP: monobenzyl phthalate.

Natural hairstyles are perceived to be an alternative to other chemical-intensive processes such as chemical straightening or relaxing. However, hair products such as hair oils and lotions are used in natural hairstyles, so our finding does not imply that natural hairstyles would also result in lower exposure to other chemical ingredients of potential concern in these products.[54]

Overall, we found that hairdressers who reported performing chemical-based hair salon services in general, such as permanent waves/texturizing, relaxing, bleaching, permanent hair color, and Brazilian blowouts, had higher MEP concentrations compared to hairdressers who did not perform the services. In contrast, hairdressers who reported performing low/no

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Table 5. Specific Gravity-Corrected Geometric Mean Phthalate Metabolite Concentrations (ng/mL) Based on Hair Salon Products Used (n = 23, 2018−2019)

products used	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	ΣDEHP[a]
Leave-in Conditioner											
yes	91.3	168.6	0.4	7.4	7.1	0.9	4.1	9.6	3.4	0.9	21.7
no	8.7	101.9	1.1	9.4	8.6	1.9	4.6	7.9	3.6	0.9	26.1
Hair Spray											
yes	78.3	165.4	0.6	9.1	8.4	1.1	4.7	11.4	4.0	0.9	26.6
no	21.7	147.7	0.2	3.8	4.1	0.5	2.7	4.9	1.9	0.8	11.3
Hair Oil											
yes	95.7	161.3	0.5	7.8	7.4	1.0	4.2	9.7	3.5	0.9	22.8
no	4.4	163.9	0.1	3.1	3.9	0.1	3.1	5.8	2.1	0.9	10.0
Hair Gel or Pomade											
yes	91.3	169.9	0.5	8.7	8.0	1.1	4.5	11.9	4.0	0.8	25.0
no	8.7	94.0	0.1	1.9	2.3	0.1	1.7	2.0	0.7	2.1	5.9
Hair Mousse											
yes	95.7	161.3	0.5	7.8	7.4	1.0	4.2	9.7	3.5	0.9	22.8
no	4.4	163.9	0.1	3.1	3.9	0.1	3.1	5.8	2.1	0.9	10.0
Bleach											
yes	82.6	191.1	0.6	7.1	6.5	1.3	4.3	9.8	3.7	1.0	21.2
no	17.4	72.5	0.1	9.8	11.3	0.2	3.6	8.0	2.2	0.6	26.3
Hair Dye											
yes	95.7	161.3	0.5	7.8	7.4	1.0	4.2	9.7	3.5	0.9	22.8
no	4.4	163.9	0.1	3.1	3.9	0.1	3.1	5.8	2.1	0.9	10.0
Chemical Straightener or Relaxer											
yes	82.6	181.6	0.5	7.0	6.4	1.1	4.2	10.3	3.6	0.9	20.5
no	17.4	92.1	0.2	10.9	12.7	0.5	3.9	6.3	2.7	0.7	31.4
Products for Permanent Waves or Texturizers											
yes	56.5	167.3	0.5	7.2	7.3	1.2	4.5	9.3	3.2	0.9	21.8
no	43.5	154.1	0.4	8.0	7.0	0.7	3.8	9.7	3.7	0.9	22.4
Keratin Treatment											
yes	43.5	174.8	0.5	9.1	11.2	1.2	5.5	17.7	4.9	1.1	29.6
no	56.5	151.8	0.4	6.5	5.1	0.8	3.4	5.8	2.6	0.8	17.6

[a]ΣDEHP represents the molar sum of MEHP, MEHHP, MEOHP, and MECPP metabolites. Abbreviations: MEP: monoethyl 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; MnBP: monobutyl phthalate; MiBP: monoisobutyl phthalate; and MBzP: monobenzyl phthalate.

Table 6. Specific Gravity-Corrected Geometric Mean Phthalate Metabolite Concentrations (ng/mL) Based on PPE Used in General (n = 23, 2018−2019)

PPE used while performing chemical services	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	ΣDEHP[a]
Apron or Smock											
yes	90.9	162.2	0.4	7.7	7.1	0.9	4.0	9.0	3.1	0.8	22.0
no	9.1	152.9	1.2	9.0	10.4	5.1	8.3	20.6	10.1	4.1	32.7
Gloves											
yes	95.4	171.9	0.5	7.2	6.5	1.1	4.3	10.1	3.6	0.9	20.9
no	4.6	42.3	0.1	52.3	89.8	0.1	3.6	4.5	1.8	0.4	142.9
Mask											
yes	22.7	194.9	0.6	6.3	7.7	2.3	4.4	7.5	3.2	1.8	21.5
no	77.3	152.6	0.4	8.4	7.3	0.8	4.2	10.4	3.6	0.7	23.5
Mask during Brazilian Blowout[b]											
yes	13.0	572.0	0.9	15.2	17.0	4.2	10.1	25.5	10.2	1.7	46.7
no	87.0	116.8	0.3	6.7	6.6	0.8	3.6	9.3	3.0	0.6	20.2

[a]ΣDEHP represents the molar sum of MEHP, MEHHP, MEOHP, and MECPP metabolites. [b]Only includes hairdressers who provide Brazilian blowout or keratin treatments (n = 15). Abbreviations: MEP: monoethyl 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; MnBP: monobutyl phthalate; MiBP: monoisobutyl phthalate; and MBzP: monobenzyl phthalate.

chemical-intensive services, such as twists, sister locs/locs, and afros, had lower MEP concentrations than hairdressers who did not perform these services. However, we did not assess the intersection of chemical and natural services among hairdressers. Furthermore, hairdressers reported an average of 26 clients per week and provided an array of services making it difficult to parse the impact of each individual service on phthalate metabolite concentrations.

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Hairdressers reported generally using an array of products while providing hair salon services for their clients (Table 5). For example more than 75% of hairdressers reported using the leave-in conditioner (91.3%), hair spray (78.3%), hair oil (95.7%), hair gel/pomade (91.3%), hair mousse (95.7%), bleach (82.6%), hair dye (95.7%), and chemical straightener/relaxer (82.6%). Hairdressers who reported using hair gel or pomade in the baseline survey had higher GM concentrations for all frequently detected phthalate metabolites except MBzP [e.g., MEP (169.9 ng/mL vs 94.0 ng/mL), MECPP (8.7 ng/mL vs 1.9 ng/mL), MEHHP (8.0 ng/mL vs 2.3 ng/mL), MnBP (11.9 ng/mL vs 2.0 ng/mL), and SDEHP (25.0 ng/mL vs 5.9 ng/mL)] compared to those who did not. GM MEP concentrations were also higher among hairdressers who reported using bleach (191.1 ng/mL vs 72.5 ng/mL) and chemical straightener/relaxer (181.6 ng/mL vs 92.1 ng/mL) compared to hairdressers who did not use these products.

General PPE Use while Performing Chemical Services. Nearly all (95.4%) hairdressers reported using gloves in the baseline survey during hair treatments that entailed chemical use, which precluded statistical comparisons (Table 6). We found that hairdressers who reported wearing a mask (22.7%) when providing chemical services had lower GM MECPP (6.3 ng/mL vs 8.4 ng/mL) and GM MnBP (7.5 ng/mL vs 10.4 ng/mL) concentrations compared to those who reported not wearing a mask. However, we did not query participants on the type of gloves and masks used at work.

Hair Salon Services Provided and PPE Used on the Day of Biospecimen Collection. Similar to hair salon services provided in general, GM MEP concentrations were higher among hairdressers who reported providing chemical straightening/relaxing (222.9 ng/mL vs 147.6 ng/mL) and permanent hair color (295.6 ng/mL vs 136.4 ng/mL) on the day of biospecimen collection compared to hairdressers who did not provide these services. In addition, GM MEP concentrations were higher among hairdressers who reported providing flat ironing (198.7 ng/mL vs 152.3 ng/mL), putting hair in rollers (261.3 ng/mL vs 136.2 ng/mL), and haircuts (204.1 ng/mL vs 134.7 ng/mL) on the day of biospecimen collection compared to hairdressers who did not provide these services (Table S4). Both GM MEP and GM MnBP concentrations were higher among hairdressers who reported providing hair extensions without glue (MEP: 234.5 ng/mL vs 149.2 ng/mL and MnBP: 20.6 ng/mL vs 8.0 ng/mL) and permanent hair color (MEP: 295.6 ng/mL vs 136.4 ng/mL and MnBP: 16.0 ng/mL vs 8.2 ng/mL) compared to hairdressers who did not. GM MnBP concentrations were higher for hairdressers who provided semipermanent hair color (13.1 ng/mL vs 8.8 ng/mL) compared to hairdressers who did not provide these services. Hairdressers providing braids (49.0 ng/mL vs 193.0 ng/mL) and hair washing (119.3 ng/mL vs 258.2 ng/mL) had GM MEP levels that were lower than those who did not provide these services. Hairdressers who reported wearing gloves on the day of sample collection (63.6%) had lower GM metabolite concentrations of MEHP (0.6 ng/mL vs 1.5 ng/mL), MnBP (7.4 ng/mL vs 14.3 ng/mL), MiBP (2.5 ng/mL vs 5.1 ng/mL), and MBzP (0.6 ng/mL vs 1.4 ng/mL) compared to hairdressers who did not wear gloves (Table S4). These results suggest that the use of gloves may be effective in decreasing the dose of several phthalates compared with those who did not report the use of gloves on the day of biospecimen collection. However, we did not collect information on the type of gloves used.

This is the first study to assess phthalates in biospecimens among female hairdressers of color and, to our knowledge, to conduct biomonitoring of phthalates in a subsample of hairdressers in the U.S. Our preliminary findings suggest that interventions to reduce occupational exposures may be warranted. Individual-level changes in personal care product use shows great promise as an intervention to decrease exposure. A study by Harley et al. on PCP use found that switching to phthalate-free products can decrease a person's exposure to phthalates by up to 27%, thus identifying that the potential sources of exposure could inform the development of targeted interventions that focus on the hierarchy of controls (elimination, substitution, engineering controls, administrative controls, and PPE) with preference to those controls that eliminate the hazard rather than placing the onus on workers.[55] For example, policy-level interventions could include elimination of these chemicals from hair products or improving product labeling to help hairdressers identify products without phthalates and allow them to identify potential substitution products. However, phthalate-free products may not be available for all ethnic hair products; therefore, it may also be necessary to explore engineering and administrative controls, such as the adding/improving ventilation systems and timing of when chemical-based services are scheduled (e.g., limiting types of services provided and conducting select services when there are less hairdressers and clients in the salon). Finally, individual-level PPE interventions are important to understand the extent to which we are able to modify exposure for the more than half million U.S. women working in hair salons. However, hairdressers may face pressure to not wear PPE in front of their clients, which could impact compliance. In the present study, there was limited variability in glove use, so we were unable to assess the extent to which wearing gloves may mitigate phthalate exposures. Overall, hairdressers reported low mask use—22.7% of hairdressers reported mask use in general and 13.0% reported mask use during Brazilian blowouts. PPE use may offer some protection, but our small sample size limited our ability to determine the extent to which workplace exposures to phthalates may be mitigated among hairdressers.

Our study findings should be interpreted with caution, given several limitations. First, while we included office workers as our comparison group, we were unable to include hairdressers serving majority Caucasian clientele to explore exposure disparities among hairdressers. In addition, the majority of our office workers were college-educated and younger than our hairdressers. These differences and our small sample size may have limited our comparisons between hairdressers and office workers. Nonetheless, we were able to carry out comparisons with a representative sample of women in the U.S. general population. In addition, hairdressers reported receiving more hair salon services on themselves in the past 12 months compared to office workers. Given the short half-life of phthalate metabolites, it is unlikely that the differences in phthalate metabolite concentrations between hairdressers and office workers were due to personal hair salon services. While there were not any statistically significant differences in PCP, cosmetic, hair product use, dietary-consumption-related factors, or home cleaning and fragranced product use between hairdressers and office workers, we cannot rule out the possibility of unmeasured confounding. We also focused on Black and Latina hairdressers; therefore, our results may not be generalizable to women in other demographic groups. In addition, phthalate exposure was based on a single spot urine

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sample collected at the end of the shift. While phthalates are rapidly metabolized and reported to be mostly excreted in less than 24 h,[39,40] we were not able to account for variability or temporal trends within and between our workgroups (e.g., seasonal differences in sampling collection could also, in part, influence exposures). For example, because we collected end-of-shift urine samples, the services provided or products used near the end of the shift may not have been captured in the samples collected. Larger future studies should include multiple urine samples among a more diverse sample of hairdressers to better characterize exposures in this occupational population.

Despite the limitations noted, our pilot study is the first to show that Black and Hispanic/Latina hairdressers have higher concentrations of MEP, MECPP, MEHHP, MEOHP, MnBP, and ΣDEHP compared to office workers. Additionally, except for one study on nail salon workers where MEP concentrations were similar to those observed among hairdressers in our study, we found that hairdressers in our study had higher MEP concentrations compared to women in the U.S. general population and other studies among nonpregnant women of reproductive age. Our study also provides novel data on potential occupational sources, such as hair salon services and products used among minority hairdressers, and highlights the need to further assess occupational exposures to phthalates in this potentially vulnerable occupational population.

Disparities in exposures from PCP use are an increasing concern and may reflect an additional facet of environmental justice.[35] Our findings indicate that hairdressers of color may be disproportionately exposed to select phthalates which may, in part, be due to their occupation. Larger studies composed of diverse ethnic cohorts of hairdressers are warranted to confirm our findings and identify areas for intervention to protect this occupationally exposed group of women. Our findings are also of great public health relevance as many hairdressers are women of reproductive age, so exposures to phthalates and other chemicals during critical windows of vulnerability, including preconception and pregnancy, could also impact children's health.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.1c00427.

Additional tables including a description of hair salon services, summary statistics for uncorrected phthalate metabolite concentrations, summary statistics for phthalate metabolite concentrations by the type of salon, and specific gravity-corrected GM phthalate metabolite concentrations for hair salon services provided on the day of biospecimen collection (PDF)

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Notes

The authors declare no competing financial interest.

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