ABSTRACT

Title of Dissertation:	EXAMINING CONSUMER PRODUCT USE AND PHTHALATE EXPOSURE AMONG VULNERABLE POPULATIONS
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One in 13 Americans have asthma, and higher rates have been reported among women and Black children.[1] In addition, hairdressers who are exposed to chemicals through products used on themselves and their clients frequently report respiratory symptoms and conditions.[2–10] Limited studies indicate that chemicals in personal care and consumer products (PCP) may impact respiratory health.[11–14] The goal of this dissertation is to describe PCP use and exposures to recognized and suspected respiratory irritants (phthalates) among vulnerable populations who may experience disparate exposures. The aims are to: 1) characterize PCP use among 110 children with asthma, 2) examine associations between PCP use and asthma morbidity among 110 children with asthma, and 3) characterize concentrations and exposure determinants to phthalate metabolites in post-shift urine samples among 23 female hairdressers and 17 female office workers. In aim 1, participants were majority Black (87%), males (56%), and aged 8-11 years (66%). Adolescents (12-17 years) and

females reported more frequent use of hair, face, and body products compared to children (8-11 years) and males. Participants used chemical treatments on their hair as young as 4 years and females 11-16 years used feminine wipes, spray, and regular deodorant in the genital area. For aim 2, use of aerosol products, hair products, and nail polish were positively associated with maximal symptom days [number of aerosol products (aOR: 1.36; CI: 1.17, 1.59), hairspray (aOR: 1.63; CI: 1.14, 2.33), perfume (aOR: 1.40; CI: 1.11,1.77); shampoo (aOR: 1.34; CI: 1.05,1.73), hair sheen (aOR: 1.41; CI: 1.00, 2.00), nail polish (aOR: 2.42; CI: 1.72, 3.41)] among children with asthma. For Aim 3, the geometric mean (GM) for monoethyl phthalate (MEP) was 10 times higher among hairdressers (161.4 ng/mL) than office workers (15.3 ng/mL). Hairdressers who provided chemical services had higher GM MEP concentrations than those who did not: texturizing (200.2 vs. 115.4 ng/mL), relaxing (181.6 vs. 92.1 ng/mL), bleaching (182.3 vs. 71.6 ng/mL), hair color (171.9 vs. 83.2 ng/mL), and Brazilian blowout (181.4 vs. 134.6 ng/mL). Hairdressers who provided 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). While larger studies are needed, this dissertation provides new data on PCP use and phthalate exposure among Black children and hairdressers.

EXAMINING CONSUMER PRODUCT USE AND PHTHALATE EXPOSURE AMONG VULNERABLE POPULATIONS

by

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Dedication

For my family, who never stopped believing in me.

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List of Abbreviations

Abbreviation	Name
ACT	Asthma control test
aOR	Adjusted odds ratio
BP	Butyl paraben
BBzP	Butyl benzyl phthalate
BMI	Body mass index
BPA	Bisphenol A
CDC	Centers for Disease Control and Prevention
CI	Confidence interval
DBP	Dibutyl phthalate
DEA	Diethanolamine
DEHP	Di(2-ethylhexyl) phthalate
DEP	Diethyl phthalate
DiBP	Di-isobutyl phthalate
DiNP	Diisononyl phthalate
DnBP	Di-n-butyl phthalate
DnOP	Di-n-octyl phthalate
DOP	Di-octyl phthalate
ED	Emergency department
EDC	Endocrine disrupting chemical
EU	European Union
FD&C	Federal Food, Drug, and Cosmetics Act
FeNO	Forced exhaled nitric oxide
FEV_1	Forced expiratory volume in the first second
FP&L	Fair Packaging and Labeling Act
FVC	Forced vital capacity
GLI	Global Lung Function Initiative
GM	Geometric mean
HEPA	High-efficiency particulate air
IL	Interleukin
Ig	Immunoglobulin
LOD	Limit of detection
LOQ	Limit of quantification
MP	Methyl paraben
NH	Non-Hispanic
MBP	Monobutyl phthalate
MBzP	Butyl benzyl phthalate
MCPP	Mono-3-carboxypropyl phthalate
MEA	Monoethanolamine
MECPP	Mono(2-ethyl-5-carboxypentyl) phthalate
MEHP	Mono(2-ethylhexyl) phthalate
MEHHP	Mono(2-ethyl-5-hydroxyhexyl) phthalate

Abbreviation	Name
MEHHTP	Mono-2-ethyl-5-hydroxyhexyl terephthalate
MEOHP	Mono(2-ethyl-5-oxohexyl) phthalate (MEOHP)
MEP	Monoethyl phthalate
MiBP	Monoisobutyl phthalate (MiBP)
MnBP	Monobutyl phthalate
MSD	Maximal symptom days
PCP	Personal care product
PM	Particulate matter
PP	Propyl paraben
PPE	Personal protective equipment
QA	Quality assurance
QC	Quality control
SD	Standard deviation
SES	Socioeconomic status
TEA	Triethanolamine
Th	T helper
U.S.	United States
FDA	Food and Drug Administration
VOC	Volatile organic compound

Chapter 1: Background

Approximately 1 in 13 (25.7 million) Americans have asthma, and higher rates have been reported for women and non-Hispanic (NH) Black children.[1] This chronic respiratory disease causes recurrent episodes of wheezing, chest tightness, and breathlessness,[2] and is also one of the most common chronic childhood diseases.[2,3] In the U.S., this disease results in a significant public health and economic burden with asthma-related costs, including those associated with healthcare costs, missed days of work/school, and deaths, is estimated to exceed $80 billion per year.[4] While asthma may be controlled, the lack of appropriate treatment can lead to death.

There are several recognized risk factors that contribute to the development and exacerbation of asthma, including air pollution and tobacco smoke exposure;[5–9] however, emerging research suggests that chemicals commonly used in personal care and consumer products may also play a role.[5,10–16]

Personal care and consumer product use

Many of the chemicals present in personal care and consumer products (e.g., phthalates, parabens) are endocrine-disrupting compounds that have been associated with increased risk of a myriad of health outcomes, including reproductive effects,[17–

[24] obesity,[25–28] metabolic syndrome,[29] diabetes,[30–32] and asthma.[13,15,33–35] These chemicals are used as preservatives, solvents and fixatives for fragrance in personal care products.[16,36–39] Some are also used as plasticizers in consumer goods and building materials (e.g., vinyl flooring, food packaging, etc.). [40,41] Recurrent exposure to these chemicals may occur through daily application of personal care products, routine use of consumer goods, airborne exposures indoors, and consumption of contaminated foods and drinks.[37,40,42–46]

While exposure to chemicals commonly found in personal care and consumer products is ubiquitous in the general population,[45–49] gender and racial/ethnic disparities are documented.[45,47,50] For example, in studies of the U.S. general population, NH Black participants had higher urinary monoethyl phthalate (MEP) and methyl paraben (MP) concentrations compared to NH-White participants, and females had higher urinary MEP, butyl benzyl phthalate (MBzP), MP, and propyl paraben (PP) concentrations compared to males.[45,47] Some of these differences in exposures may be explained in part by use patterns of consumer and personal care products. [51–60] In studies among majority White populations, adults reported using an average of 8-13 personal care products each day; while young children (<8 years) reported using ~4 products per day, and women reported using more products than men.[51–53] The type of products used varies by race/ethnicity. Adolescent and adult Latinas report frequently using cosmetic products (i.e., make-up),[53–56] while Black women report frequent use of feminine hygiene[53,57] and hair care products, especially hair oil, root stimulator, and no-lye perms and relaxers.[53,55,58–60] An individual product

can contain up to 22 chemicals of concern,[16] and it is estimated that the average adult is exposed daily to more than 85 unique chemicals through the use of personal care products.[61] Limited studies report that chemicals found in PCPs like phthalates, parabens, glycol ethers, ethanolamines, and fragrances[16,37–39] have been linked to asthma prevalence and morbidity.[13,62–67] Information about these chemicals of concern, including how they are used in PCPs and a summary of the federal regulations that provide oversight for personal care and consumer products are outlined in the sections below.

Phthalates

Phthalates are a class of synthetic compounds used as plasticizers in consumer goods such as vinyl flooring, plastic goods, medical devices, food packaging, industrial solvents, as medication excipients, and as additives and preservatives in food and cosmetic products.[40,41] These diesters of 1,2-benzenedicarboxylic acids (phthalic acid) have specific characteristics based on the length of their dialkyl or alkyl/aryl side chain.[40,41] High molecular weight (long-branched) phthalates such as di(2-ethylhexyl) phthalate (DEHP), di-isobutyl phthalate (DiNP), and di-n-octyl phthalate (DOP) are most often used to add flexibility to vinyl products, while low molecular weight (short-branched) phthalates such as diethyl phthalate (DEP), dibutyl phthalate (DBP), and butyl benzyl phthalate (BBzP) are commonly used in personal care products as fragrance carriers and solvents (**Table A.1**).[40]

The main routes of exposure to phthalates are ingestion, inhalation, and dermal absorption.[37,40,42–44] Ingestion may occur through contaminated foods, medications taken orally, and non-dietary ingestion of contaminated dust.[42,68–71] While phthalates have low volatility, they have been found in indoor air and dust samples indicating their ability to leach from products.[72,73] Studies have also reported significant positive correlations between phthalate indoor air concentrations and urinary metabolites for low molecular weight phthalates, suggesting inhalation may be a significant route of exposure.[74] Following exposure and absorption, phthalates are rapidly metabolized and excreted in urine within 24 hours.[75] Phthalate metabolites have been measured in several biological matrices, including serum, amniotic fluid, breast milk, saliva, semen, and meconium.[41,76] However, urine is the most commonly used exposure matrix.

Phthalates are commonly found in personal care products worldwide, with DEHP and DEP as the most frequently detected.[37,44,77,78] In a U.S.-based study that measured 9 phthalates in 170 personal care products, DEHP was the most frequently detected phthalate, followed by DiBP and DEP in rinse-off products and DEP, DBP, and DiBP in leave-on products. All perfumes/fragrances and 90% of skin toners contained DEP and 67% of fragrances and 90% of nail polishes contained DBP. While DEHP was frequently detected, the concentration was relatively low, which may indicate leaching from the plastic packaging of the products.[37] However, one study that measured chemicals in personal care products used by women of color reported that DEHP was measured at 1019 ug/g in leave-on hair styling products used by Black

women.[79] In addition, DEP has been measured in feminine hygiene cleansing cloths/wipes[79] and hair styling products, including root stimulator, hair lotion, and relaxers commonly used by Black women.[38,79] Notably, both prenatal and childhood exposure to phthalates has been associated with asthma development and morbidity.[14,62,80–83]

Parabens

Parabens are a group of alkyl esters of p-hydroxybenzoic acid commonly used in personal care and consumer products as preservatives.[16,37,39,84,85] The main routes of exposure are dermal absorption and ingestion.[86] Parabens have been measured in serum, human milk, placenta, and breast tumor tissues, but are most commonly measured in urine.[84] Parabens have been frequently measured in a variety of personal care products, including body lotions, skincare products, haircare products, and cosmetics.[16,37,38] Methyl paraben (MP) and propyl paraben (PP) are the most frequently detected parabens and have been measured in concentrations ranging from <1 ug/g to 8200 ug/g (measured in body washes).[16,37,38,79] Exposure to parabens among boys (<18 years) with asthma in the U.S. general population has been associated with an increase in asthma-related emergency department (ED) visits, indicating a possible role in asthma morbidity.[13]

Glycol ethers

Glycol ethers are a class of chemicals that includes more than 200 compounds (based on a search for “glycol ether” in the European Commission Cosmetics Ingredients

(CosIng) database).[85] Glycol ethers are often categorized as ethylene oxide-based glycol ethers (e-series) which are used in consumer products and propylene oxide-based glycol ethers (p-series) which are used in personal care products as a binder, stabilizer, humectant, solvent, plasticizer, and to increase or decrease viscosity.[85,87,88] The main routes of exposure are through dermal absorption and inhalation.[89] They are often listed on ingredient labels,[39] but, due to the number of compounds, are not frequently measured in products.[16] For example, in a study that measured endocrine disrupting and asthma-associated chemicals in more than 200 personal care and consumer products, glycol ethers were found in face lotion, sunscreen, and shaving cream. However, only 8 glycol ether compounds were measured.[16] Glycol ethers are not typically measured in biomonitoring studies in the U.S.; however, several glycol ether metabolites were detected in pregnant women (20-59 years)[90] and 6-year old children in France.[91,92] Interestingly, among pregnant women, the use of cosmetics in the prior 24 hours was associated with higher urinary metabolites of several glycol ethers.[90] In a case-control study among pre-school children, authors reported that increased concentrations of airborne propylene glycol and glycol ethers were associated with asthma among pre-school children.[67]

Ethanolamines

Ethanolamines are a group of amino alcohols – including triethanolamine (TEA), diethanolamine (DEA), and monoethanolamine (MEA) – that are added to personal care products as a surfactant, humectant, conditioner, buffer, or for viscosity.[85,93,94] For example, they may be used in hair products to enhance the appearance or

suppleness of hair.[95] Ethanolamines have been reported on the ingredient labels of lotions/moisturizers as well as a variety of hair products, including shampoo, conditioner, hair color, and styling products,[39] and have been measured in concentrations >1000 ug/g in shampoos.[16] The main routes of exposure are through dermal application.[96,97] In general, ethanolamines are not measured in biomonitoring studies, so there is a lack of data on the extent of exposure to these chemicals. However, several case studies reported occupational asthma caused by ethanolamine-containing products.[63,64]

Fragrances

Fragrances are mixtures of volatile organic compounds (VOCs) and other chemicals, such as DEP (a phthalate used as a fragrance carrier), that are added to products to "impart a scent to a product, mask the odor of other materials, or alter the mood."[98] The most common route of exposure to fragrances is through dermal application and inhalation.[99] Fragrances can be synthetic or natural compounds, but the individual chemical components of fragrance are often unknown and are exempt from labeling requirements because they are considered proprietary or trade secrets.[100] There are estimated to be hundreds of chemicals included in a fragrance. Both synthetic and natural fragrance compounds (e.g., limonene, linalool, musks) are frequently measured in personal care products[16,38,79] and are often correlated with DEP.[16] Some fragrance ingredients can interact with indoor air and dust to create secondary byproducts that could be more hazardous than the individual ingredient. For example, terpenes (e.g., limonene) can interact with indoor air to form formaldehyde.[101,102] In a

perfume challenge study, adults with asthma showed significant declines in lung function and asthma symptoms (e.g., chest tightness, wheezing) following inhalation of perfume.[65] In addition, population-based studies among adults with asthma have reported asthma attacks and other respiratory issues from exposure to fragranced products.[103]

Federal regulations of chemicals in personal care products

Most cosmetics and personal care products used for "cleansing, beautifying, promoting attractiveness, or altering the appearance without affecting the body's structure or functions" are regulated by the U.S. Food and Drug Administration (FDA) under the Federal Food, Drug, and Cosmetics (FD&C) Act and the Fair Packaging and Labeling (FP&L) Acts.[104] The definition of "cosmetic" under FD&C generally includes face, body, and hair products. However, therapeutic products are considered a drug rather than a cosmetic, and some products, for example, soap, may be regulated by the FDA or the Consumer Product Safety Commission, depending on the type of soap.[105] With the exception of color additives, the FD&C does not require products or ingredients to be approved by the FDA before being released for consumer use; instead the manufacturers and cosmetic companies are legally responsible for ensuring the safety of their own products.[104] In general, any ingredient is allowed under the FD&C as long as the product is appropriately labeled, deemed to be safe under the labeled instructions, and has not been adulterated or misbranded.

Ingredient labels are required by the FD&C on products designed for retail sale. The law indicates that the label should include all ingredients in the product listed in order of predominance (greatest to least). However, there are exceptions. Fragrance ingredients may be listed as “fragrance” or can be listed individually, ingredients at concentration <1% can be listed in any order (following ingredients >1%), and ingredients considered incidental or trade secrets do not have to be listed. Fragrance ingredients are often considered trade secrets and are listed as “fragrance” or “parfum” on products.[106] If a consumer is trying to minimize their exposure to a certain chemical ingredient, these labeling exceptions can make it difficult to determine all the chemicals in the personal care products they use.

In addition to the FDA’s oversight of personal care and consumer products, the Occupational Safety and Health Administration (OSHA) provides some additional regulations to protect workers from hair products that may contain formaldehyde, such as hair straightening products.[107,108] To protect hairdressers, OSHA’s formaldehyde standard (29 CFR. 1910.1048) requires that salon owners avoid products that contain formaldehyde, if possible. However, if these products cannot be avoided, salons should monitor formaldehyde in the air, ensure adequate ventilation, provide hairdressers with personal protective equipment, and ensure that all hairdressers are trained on the hazards associated with formaldehyde.[108,109]

Vulnerable populations

Children and occupationally exposed populations, such as hairdressers, may be at risk of increased exposure to the chemicals commonly found in personal care products due, in part, to distinct product use patterns. In addition, Black children and hairdressers serving ethnically diverse clientele may be at even greater risk due to use of products specifically formulated for ethnic populations, which may have high concentrations of chemicals of concern (e.g., phthalates, parabens).[38,79,110] However, there is currently a lack of data on product use patterns and chemical exposures among these populations. Understanding the extent of exposure among children and occupationally exposure women, and the potential role that personal care product use may play in asthma morbidity among children is an important step on the path to reducing disparities and protecting the health of vulnerable populations.

Children

Children begin using personal care products at a young age. A study among majority White children 8 years and younger reported that children used an average of 4 products a day, which included toothpaste (98%), liquid soap (86-88%), and shampoo (34-37%) as the most frequently used products.[52] Few studies have reported personal care product use patterns among Black and African American children.[111,112] However, a study that retrospectively assessed hair care product use during childhood and adolescence among Black women indicated that several hair products, including

chemical relaxers and texturizers were used as young as 5 years, and another study among 201 African American females ages 1 to 15 years reported use of chemical products at 4 years.[111,112] This is of potential concern as hair care products marketed to Black and African American communities have been reported to have high concentrations endocrine disrupting chemicals (EDCs) linked to adverse health effects. For example, a study that measured chemicals in hair products reported that hair relaxers frequently contained DEP, parabens, and 5-8 targeted fragrance ingredients. Of note, two no-lye hair relaxing products marketed for children contained high concentrations of DEHP, nonylphenol, BPA, and diethanolamine, which are prohibited under the European Union (EU) Cosmetics Directive [113], and o-phenylphenol, which is regulated under California's Proposition 65.[38,114] The EU Cosmetics Directive and Prop 65 identify chemicals to be prohibited or regulated based on their potential to be carcinogenic, mutagenic, and reproductive or developmental toxicants.[113,114]

During critical periods of development, children are potentially more susceptible to environmental contaminants, such as EDCs,[115–117] which can mimic or alter endocrine and metabolic functions.[118] Increased susceptibility in children can be attributed to their immature body systems and rapid growth, but it is also influenced by other factors, including genetics and epigenetics, nutrition, sociodemographic factors, and other co-morbidities.[119] The most critical periods of development are *in utero* and early childhood; however, continued growth and development throughout middle/late childhood and adolescence, make these periods also more susceptible to chemical

exposures.[115,118] For example, while lung development begins *in utero*, it continues throughout childhood to approximately 18-20 years of age.[115,120] Exposures to EDCs during these critical periods may play a role in the later development of conditions during childhood and into adulthood.[116,117]

Because children are potentially more susceptible to the chemicals commonly found in personal care products, including EDCs, it is important that we understand the extent of exposure and the potential role that exposure may play in disease, especially among Black and African American children who may be differentially exposed to chemicals through their use of personal care products and who are disproportionately suffering from asthma.

Occupational groups

Approximately 650,000 women work as hairdressers in the U.S. and are exposed to numerous chemicals, including phthalates, formaldehyde, and VOCs,[107,121–126] through their work. Women who work as hairdressers may experience elevated exposures to chemicals in these products due to personal and occupational use potentially increasing their risk of health effects associated with the chemicals contained in or formed from the use of these products. Several studies have examined the air quality in hair salons, including the measurement of chemicals commonly found in personal care products.[73,122,127,128] Phthalates measured in air samples collected from Taipei hair salons were below occupational exposure limits, however, they were higher than concentrations reported in residential environments.[122]

Similarly, Subedi et al measured phthalates in dust samples in several U.S. hair salons, homes, and child care facilities and estimated that occupational intake of phthalates from exposure to dust in hair salons was ~3 times higher than residential exposures.[73] Working in a hair salon has been associated with both reproductive[129–132] and respiratory symptoms and conditions, including asthma.[127,133–140] Chemicals in hair and other personal care products may be a contributing factor to adverse health effects reported among hairdressers; however, few biomonitoring studies have examined the body burden among hairdressers. To date, only two studies conducted in Slovakia have measured urinary phthalate metabolites among hairdressing apprentices.[123,124] Phthalate metabolites were detected in >85% of the first-morning urine samples.[123] Compared to controls, hairdressing apprentices had higher geometric mean (GM) and median concentrations of di(2-ethyhexyl) phthalate (DEHP) metabolites, including mono(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP), mono(2-ethyl-5-oxohexyl) phthalate (MEOHP), mono(2-ethylhexyl) phthalate (MEHP), molar sum of DEHP metabolites, monoisobutyl phthalate (MiBP), and monobutyl phthalate (MnBP). However, only MiBP was statistically significantly higher.[123,124] Hairdressers of color and hairdressers serving an ethnically diverse population may be exposed to higher levels of chemicals due to the type of products used and services provided,[141] yet to date, no studies have examined exposure in this potentially vulnerable occupational group.

Asthma pathophysiology

Asthma is a chronic, inflammatory condition characterized by a narrowing of the airways that causes breathing difficulties. While we do not completely understand the etiology, both genetic predisposition and environmental factors are posited to play a role in this disease.[142] There are two main types of asthma: atopic (allergic) asthma and non-atopic (non-allergic). Atopic or allergic asthma is the most common type of asthma and is triggered by an allergen. This allergen then interacts with T helper (Th)2 cells to produce the Th2 cytokines, interleukin (IL)-4, IL-5, and IL-13. Then, IL-4 stimulates plasma cells to produce immunoglobulin (Ig)E antibodies which bind onto mast cells. This triggers degranulation of the mast cell and leads to the production of histamines and leukotrienes. IL-5 activates eosinophils, which releases leukotrienes and proteases. IL-13 increases airway hyperresponsiveness.[143,144] Non-atopic asthma is not as well understood but is generally characterized by the absence of IgE antibodies.[143]

Asthma can be controlled when triggers are removed, or when it is appropriately treated. However, in chronic asthma cases, fibrosis and remodeling of tissue can occur leading to permanent and irreversible tissue damage.[145]

Chemicals in personal care products and asthma

While several cross-sectional epidemiological studies among children and adults in the U.S. general population report associations between chemicals in consumer and personal care products and asthma prevalence and morbidity;[13,14] only one study to

date has examined the association between personal care product use and lung function using spirometry.[10] The study, by Dales et al, reported that personal care product use was associated with significant reductions in lung function.[10] While this was a large cross-sectional study with 5604 participants aged 6-79 years, it consisted of majority white participants (>80%). In addition, the study was conducted in Canada, where personal care product use patterns may differ from those in the U.S.

The specific mechanisms for how chemicals in personal care products may contribute to asthma is an evolving and growing area of research. Some experimental studies indicate that phthalates and other chemicals commonly found in personal care products may impact both immune and allergic responses.[146–148] For example, phthalates may directly and indirectly contribute to airway sensitization, inflammation, and remodeling, which are key characteristics of asthma.[146,149,150] A*n in vitro* study found that human epithelial cells treated with several phthalates, including DEP which is commonly found in personal care products, increased the proliferation and migration of bronchial smooth muscle cells, which may indicate remodeling.[150] Other *in vitro* and *in vivo* studies indicate that phthalates may have indirect effects by acting as an adjuvant to increase the production of Th2 cytokines, including IL-4 and IL-5 and production of IgE antibodies.[147,148,151,152] In addition, phthalates may induce oxidative stress and Th2 induced airway inflammation.[151]

Given the health concerns associated with chemicals commonly used in personal care products, the disparities in chemical exposures, and potential role in the development

and exacerbation of asthma, it is necessary that we further explore personal care product use patterns, chemical exposures, and their potential role on respiratory health among vulnerable populations.

Dissertation goal and aims

The overarching goal of this dissertation is to characterize personal care product use and phthalate exposure among understudied, underrepresented vulnerable populations that may be experiencing disparate exposures, through three aims to: 1) characterize personal care and consumer product use that could impact chemical exposures among African American children with asthma; 2) evaluate the association between personal care product use and asthma morbidity among African American children; and 3) characterize exposure and evaluate workplace factors associated with phthalates in a pilot sample of hairdressers serving ethnically diverse clientele.

Chapter 2: Personal Care and Consumer Product Use Among Children with Asthma Living in Baltimore City

Abstract

Over 4 million children in the U.S. have asthma with higher rates reported among Black children. Accumulating evidence suggests that chemicals in personal care and other consumer products may play a role in asthma development and control; however, consumer product use patterns and behaviors among children with asthma remain sparse. In the present study, we characterized personal care and consumer product use among 110 children with asthma, ages 8-17 years, living in Baltimore City using an interviewer-administered survey. The survey queried participants on their use of personal care products, hair services, feminine hygiene products, and household products in the prior 12 months, prior 7 days, and general use. Fisher's Exact and Mann-Whitney tests were used to assess product use by age (8-11 vs. 12-17 years) and sex. Participants were majority Black (87%), aged 8-11 years (66%), and 56% were male. Participants reported using an average of 17 personal care products (range: 5-33), including 13 face and body products (range: 4-23) and 5 hair products (range: 0-10) in the prior 12 months. Adolescents (12-17 years) and females reported more frequent use of hair products (hair gel, conditioner), hair services (press and curl, weaves, braids), face products (cleanser, moisturizer), and body

products (body wash, perfume) compared to younger children (8-11 years) and males, respectively. Similar use patterns were reported in the prior 7 days. In addition, participants reported using chemical treatments on their hair as young as 4 years and females aged 11-16 years reported regular use of feminine wipes, feminine spray, and regular deodorant in the genital area. Adolescents and females may be at increased risk of chemical exposures through more frequent use of personal care products. In addition, use of chemical hair products among males and females at a young age could have implications for both chemical exposures and health. Future research should examine this further to understand the potential impact of product use and chemical exposures on children's health.

Introduction

Approximately 1 in 17 (4.7 million) U.S. children have asthma and higher rates have been reported among non-Hispanic (NH) Black children (12.3%), adolescents 11-21 years (9.0%), and boys (5.7%).[153] Accumulating evidence indicates that chemicals commonly found in personal care and consumer products, such as phthalates, parabens, and phenols, may play a role in the development and exacerbation of asthma.[5,10–16,154] In addition, studies have reported that some of these chemicals in consumer products may impart sexually dimorphic effects among children. For example, in a representative pediatric sample of the U.S. general population, methyl paraben (MP) and propyl paraben (PP) were associated with increased prevalence odds of asthma-related emergency department (ED) visits among boys with asthma[13]

while another study reported that urinary monoethyl phthalate (MEP) concentrations were associated with current asthma in boys (6-17 years).[14]

Chemicals are frequently used in personal care and consumer products as preservatives, solvents and fixatives for fragrances.[36,155,156] Exposure to these chemicals may occur through the daily use and application of personal care products and household products like cleaners.[37,40,42–46] In studies among majority White populations, adults report using an average of 8-13 personal care products each day, while women typically use more products than men, and young children (< 8 years) use the fewest number of products.[51,52] It is estimated that the average adult is exposed to more than 85 chemicals daily through the use of personal care products.[61] While exposure to chemicals commonly found in personal care and consumer products is ubiquitous in the U.S. general population,[45–49] sex and racial/ethnic disparities have been reported.[45,47,50] For example, biomonitoring studies have reported that females have higher urinary MEP, butyl benzyl phthalate (MBzP), MP, and PP concentrations compared to males, while NH Black participants have higher urinary MEP and MP concentrations compared to NH-White participants.[45,47] These exposure differences are posited to be due, in part, to use patterns of personal care and consumer products.

While several studies have characterized personal care product use among children,[52,54,112,157,158] few studies have examined product use among Black children[112] and no studies have included children with asthma. In a retrospective

study, Black women reported using hair oil, hair lotion, root stimulator, leave-in conditioners, and perms and relaxers during childhood and adolescence;[111,159] and use of some of these products, such as relaxers may begin at a young age (4-5 years).[111,112] The frequent use of hair care products reported by Black women during childhood and adolescence as well as the use of chemical hair products at a young age is of concern due to the potentially high concentrations of chemicals measured in products targeted toward ethnic populations.[38,58] For example, a survey of hair product ingredient labels found most hair products frequently used by Black women contained hormone disruptors like parabens and placenta, while another study measured high concentrations of diethyl phthalate (DEP) in 78% of ethnic hair products studied.[38,58] Given the potential for disparately high chemical exposures during vulnerable periods of susceptibility and development in children, the high asthma burden reported among Black children,[1] and emerging evidence suggesting that chemicals in personal care and consumer products may impact respiratory health,[12] it is critical that we examine product use patterns to help identify products and chemicals of concern for further investigation.

To begin addressing these data gaps, we sought to characterize and assess age and sex differences in personal care and consumer product use among children 8-17 years with asthma living in Baltimore City, Maryland.

Methods

Study design and population

We used data collected from the AIRWEIGHS study, a randomized control trial of 198 children, 8-17 years with persistent asthma. The overarching goal of the study was to assess whether a high-efficiency particulate air (HEPA) filters could improve respiratory health of inner-city children with asthma. The study was conducted between 2017 and 2020 (prior to the Covid-19 pandemic shutdown). To be eligible, participants had to: 1) meet the criteria for persistent asthma based on frequency and severity of symptoms as defined by the National Asthma Education and Prevention Program,[160 161,162] 2) experienced an asthma exacerbation (i.e., an episode that caused the airways to become swollen and inflamed) [163] in the previous 12 months, 3) be a non-smoker as confirmed with a urine cotinine test, and 4) reside in a primary home four or more nights during the week with no plans to move during the study period. Participants were excluded if they had significant pulmonary or cardiac disease, had a home that was in disrepair, were enrolled in another environmental asthma study in the previous 12 months, or were pregnant.

Data collection

The parent study required participants to complete up to three clinic visits every four weeks over a 16-week period. The first clinic visit included a baseline demographic interviewer-administered survey that captured information on participant characteristics including sex, age, race/ethnicity, anthropometric measurements (height and weight) and collection of baseline clinical data. The follow-up visits

(clinic visit 2 and clinic visit 3) included collection of additional clinical data, completion of the personal care and consumer product use survey, and provision of biospecimens. For the present study, we used data acquired from the personal care and consumer product survey administered at clinic visit 2 which covered use of products in the prior 12 months, recent use, and general consumer product use frequency and demographic data from a baseline questionnaire conducted at clinic visit 1. Caregivers provided informed consent and study participants provided assent. All study protocols were reviewed and approved by the Johns Hopkins University Institutional Review Board and written informed consent and assent was obtained from all participants prior to data collection.

Personal care and consumer products survey

The personal care and consumer product use survey was developed based on an extensive literature review which identified types of products and to inform frequency and intensity of use. The types of products, professional services, and response options in the survey were revised based on feedback received by 10 Black mothers. We then pilot tested the survey for comprehension and survey fatigue among 25 participants in AIRWEIGHS and revised it accordingly.

The interviewer-administered comprehensive personal care and consumer product survey was completed by the primary caregiver for children under 14 years of age or the both the caregiver and participant if the child was 14 years of age or older. The survey included additional demographic information not already collected at clinic visit 1 (e.g., school grade and jobs), and queried participants on their use of personal

care products, hair services, feminine hygiene products, and use of other household consumer products in the home (e.g., scented products, household cleaners, pesticides) and other consumer behaviors (e.g., consumption of food or drinks from plastic containers, metal cans, etc.) that could be linked to chemical exposures.

Personal care product use surveys included 13 hair products (e.g., shampoo, conditioner, hair gel) and 33 face and body products (e.g., face cleanser, body soap, sunscreen). Frequency of personal care product use was queried in several ways: use in the past 12 months (yes/no), use in the past 7 days (used in the past 24 hours, 2 days ago, 3-7 days ago), and use in general (more than 5 times per week, 1-5 times per week, 1-3 times per month, less than once a month). Based on frequency of responses, we recoded use in the previous 7 days as yes/no and general use was recoded as rarely/never, monthly (1-3 times/month), and weekly (>once/week).

Frequency of several hair services was assessed, including chemical texturizing, straightening/relaxing hair, hair coloring, braids/sister locs/twists, Brazilian blowout, press and curl, and weave extensions. A description of each hair service is summarized in the Appendix (**Table A.2**). Frequency for hair services were assessed as past 12 months and recent use. Recent use was assessed as last 24 hours; last 7 days; more than 7 days ago, but within the last 30 days; and more than 1 month ago. Participants were also queried on whether they ever used a chemical texturizer or hair relaxer and their age of first use for these services.

The frequency for feminine hygiene products, including pads and tampons was assessed as use in general (i.e., daily, 3-7 days each month, other) and last use (i.e., last 1-3 days, over the last 7 days, more than 7 days ago). Questions related to products normally used during the menstrual cycle were asked among girls who reported starting their menses, while all female participants were asked about their use of other feminine hygiene products to address concerns with odor, such as feminine wipes, feminine spray, feminine wash or douche, and regular deodorant used in the genital area. Use was assessed with the following question, "Do you regularly use any of the following products during the year?"

Other consumer products included questions on the regular use of 10 household products (e.g., incense, scented candles, air fresheners, scented cleaning products, scented carpet powder, scented laundry detergent, scented dryer sheets, scented fabric softener, antibacterial soap, and pesticides).

Statistical analysis

We calculated descriptive statistics, including frequencies, means, medians, range, and standard deviations (SD) to summarize demographic characteristics and personal care and consumer product use. Differences in personal care and consumer product use patterns were assessed by age and sex. Age was categorized as 8-11 years (children) and 12-17 years (adolescents), and binary sex was categorized as male and female. The age categories were selected based on CDC life stages.[164]

Chi-square and Fisher's exact for cell frequencies <5 were used to assess differences in product use by age (8-11 vs. 12-17 years) and sex. For categorical variables (i.e., use in general [rarely/never, monthly, weekly]), logistic regression was used to identify which categories were significantly different. Mann-Whitney tests were used to assess age and sex differences for continuous variables (i.e., number of products used). Statistical significance was assessed at $p<0.05$ and all analyses were conducted in Stata SE 17.0 for Mac (StataCorp, College Station, TX).

Results

Participant characteristics

A total of 175 children participated in clinic visit 2, and of those, 110 children ages 8-17 years (overall [mean: 10.8; SD: 2.5 years]; males [mean: 10.9; SD: 2.6 years]; females [mean: 10.7; SD: 2.2 years]) completed the personal care and consumer product use survey (**Figure A.*1*)**. More than half of the participants were male (56.4%), predominantly Black (87.2%), and had public insurance (82.7%). Nearly 40% of caregivers had a high school education and 65.4% reported a household income of less than $50,000 (**Table 1**). There were no significant differences between demographic characteristics among participants included in this analysis and participants excluded due to incomplete data.

Table 1. AIRWEIGHS study participant characteristics[a]

Characteristic	Study Participants, n=110 n (%)	Participants Excluded, n=65 n (%)
Age (years)[b]		
8-11	72 (65.5)	37 (56.9)
12-17	38 (34.6)	28 (43.1)
Gender		
Male	63 (57.3)	41 (63.1)
Female	47 (42.7)	24 (36.9)
Race[c]		
Black	95 (86.4)	51 (78.5)
Other	15 (13.6)	14 (21.5)
Caregiver Education		
High school graduate or lower	62 (56.4)	35 (53.9)
Some college or more	48 (43.6)	30 (46.2)
Household Income		
Less than $15,000	26 (23.6)	20 (30.8)
$15,000-$34,999	33 (30.0)	26 (40.0)
$35,000-$49,999	14 (12.7)	7 (10.8)
$50,000 or greater	16 (14.6)	7 (10.8)
Refused/Don't know	21 (19.1)	5 (7.7)
Health Insurance		
Private	17 (15.5)	9 (13.9)
Public	91 (82.7)	56 (86.2)
Don't know	2 (1.8)	0 (0.0)
Caregiver Current Smoker	29 (26.6)	18 (27.7)

[a.] Differences between participants included vs. excluded were assessed using Chi-square or Fisher's Exact test; no statistically significant differences were observed. [b.] The average age is 10.7 years with standard deviation of 2.5 years. [c.] The other race category includes participants who identify as white and as multi-racial.

Number of personal care products used

Overall, participants reported using an average of 17 personal care products (range: 5-33), which included 13 face and body products (range: 4-23) and 5 hair products (range: 0-10) in the past 12 months. Adolescents (12-17 years) reported using more personal care products ($p=0.020$) and face and body products ($p=0.005$) compared to children (8-11 years). Females reported using more personal care products ($p<0.001$), hair products ($p<0.001$), and face and body products ($p<0.001$) compared to males. (**Figure 1**) Similar results were observed for the number of products used in the past

7 days by age; however, we did not observe any differences in hair product use between females and males in the past 7 days (**Figure 2**).

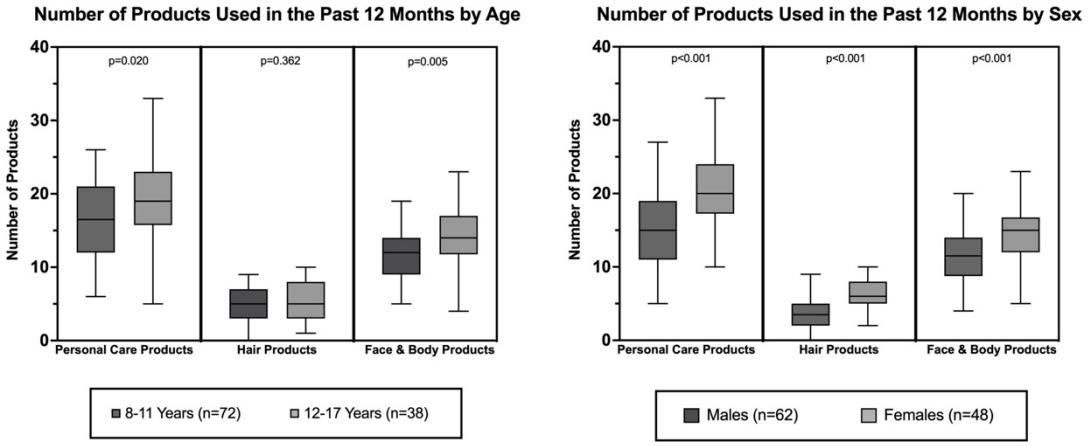


Figure 1. Number of products used in the past 12 months by age and sex[a,b]

[a.] The personal care products category represents the total number of hair and face and body products used in the past 12 months. [b.] Mann-Whitney tests were used to assess differences in product use by age and sex; significance was determined as $p<0.05$.

Figure 2. Number of products used in the past 7 days by age and sex[a,b]

[a.] The personal care products category represents the total number of hair and face and body products used in the past 7 days. [b.] Mann-Whitney tests were used to assess differences in product use by age and sex; significance was determined as $p<0.05$.

Hair products

Of the 13 hair products, the most commonly used products in the past 12 months included liquid shampoo (97.3%), hair oil (70.9%), washout conditioner (70.0%), and leave-in conditioner (52.7%). We did not observe any differences in hair product use by age in the past 12 months. However, females were more likely to report using leave-in conditioner (females: 79.2% vs. males: 32.3%, $p<0.01$), washout conditioner (females: 93.8% vs. males: 51.6%, $p<0.01$), heat protector (females: 27.1% vs. males: 1.6%, $p<0.01$), hair gel (females: 79.2% vs. males: 11.3%, $p<0.01$), hair lotion (females: 62.5% vs. males: 37.1%, $p<0.01$), hair oil (females: 81.3% vs. males: 62.9%, $p=0.03$), and coconut oil (females: 47.9 vs. males: 25.8%, $p=0.01$) compared to males. (**Figure 3**) Similarly, in the past 7 days, there were no observed differences in most hair product use by age, except for coconut oil, which was more frequently used by adolescents (adolescents: 31.6% vs. children: 13.9%, $p=0.03$). There were noted differences in hair product use by sex in the past 7 days. For example, males were more likely to report using liquid shampoo (males: 71.0% vs. females: 41.7%, $p<0.01$), and females were more likely to report using heat protector (females: 8.3% vs. males: 0.0%, $p=0.03$), hair gel (females: 47.9% vs. males: 3.2%, $p<0.01$), and coconut oil (females: 29.2% vs. males: 12.9%, $p=0.03$). (**Table 2**).

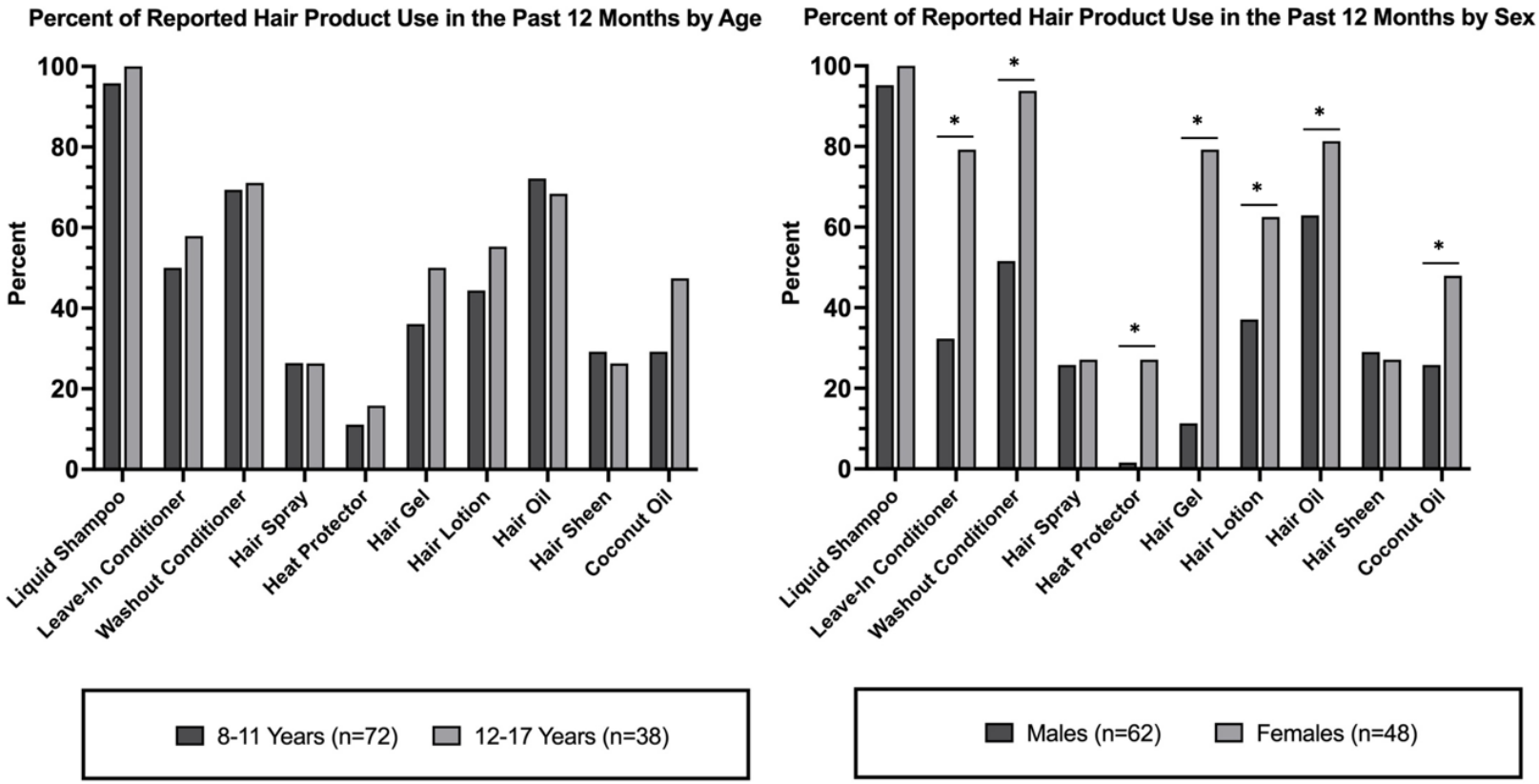


Figure 3. Percent of reported hair product use in the past 12 months by age and sex[a]

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

Table 2. Hair product use in the past 7 days by age and sex

Hair Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value[a]	Males (n=62)	Females (n=48)	p-value[a]
Dry Shampoo	1 (0.91)	1 (1.4)	0 (0.1)	0.66	1 (1.6)	0 (0.0)	0.56
Liquid Shampoo	64 (58.2)	39 (54.2)	25 (65.8)	0.17	44 (71.0)	20 (41.7)	<0.01*
Leave-in Conditioner	25 (22.7)	13 (18.1)	12 (31.6)	0.09	13 (21.0)	12 (25.0)	0.39
Washout Conditioner	33 (30.0)	20 (27.8)	13 (34.2)	0.31	16 (25.8)	17 (35.4)	0.19
Aerosol Hairspray	11 (10.0)	6 (8.3)	5 (13.2)	0.31	6 (9.7)	5 (10.4)	0.57
Non-aerosol Hairspray	2 (1.8)	1 (1.4)	1 (2.6)	0.57	0 (0.0)	2 (4.2)	0.19
Heat Protector	4 (3.6)	1 (1.4)	3 (7.9)	0.12	0 (0.0)	4 (8.3)	0.03*
Hair Gel	25 (22.7)	13 (18.1)	12 (31.6)	0.09	2 (3.2)	23 (47.9)	<0.01*
Hair Lotion	25 (22.7)	14 (19.4)	11 (29.0)	0.19	10 (16.1)	15 (31.3)	0.05*
Hair Oil	57 (51.8)	36 (50.0)	21 (55.3)	0.37	30 (48.4)	27 (56.3)	0.27
Hair Sheen	12 (10.9)	9 (12.5)	3 (7.9)	0.35	7 (11.3)	5 (10.4)	0.57
Root Stimulator	1 (0.91)	0 (0.0)	1 (2.6)	0.35	0 (0.0)	1 (2.1)	0.44
Coconut Oil for Hair	22 (20.0)	10 (13.9)	12 (31.6)	0.03*	8 (12.9)	14 (29.2)	0.03*

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

In general, hair oil (37.3%), liquid shampoo (32.7%), hair lotion (19.1%), and hair gel (18.2%) were reported to be used at least once a week. There were no differences in general use of hair products by age. Males reported using liquid shampoo weekly (males: 48.4% vs., females: 12.5%, $p<0.01$), while females reported weekly use of hair gel (females: 39.6% vs. males: 1.6%, $p<0.01$) and monthly use of washout conditioner (females: 66.7% vs. males: 30.7%, $p<0.01$) and leave-in conditioner (females: 45.8% vs. males: 14.5%, $p<0.01$). (**Figure 4**)

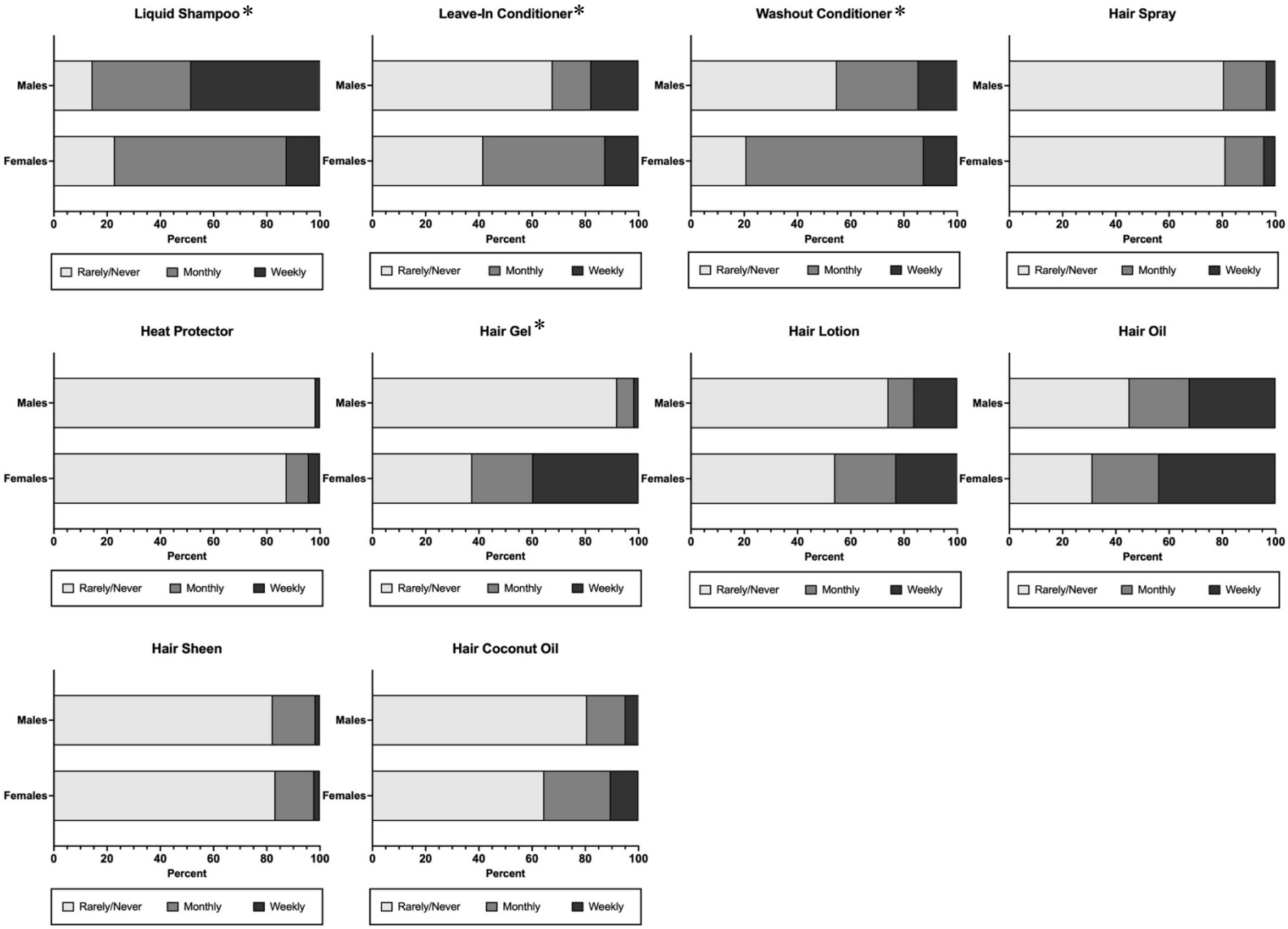


Figure 4. General frequency of hair product use by sex[a]

[a.] Differences in product use by age and sex were assessed using Fisher's Exact; Logistic regression was used to assess which frequency category was significantly different (reference category was never/rarely); significance was determined as $p<0.05$ and noted with an asterisk (*).

Hair salon services

We assessed 7 hair salon services received in the past 12 months. Salon services reported included braids, sister locs, or twists (36.4%), press and curl (25.5%), hair straightening or relaxing (8.2%), weave extensions (8.2%), and hair coloring (5.5%). Adolescents were more likely to report press and curl (adolescents: 36.8% vs. children: 19.4%, p=0.04) and weave extensions (adolescents: 15.8% vs. children: 4.2%, p=0.04) compared to younger children. Females were more likely than males to receive braids, sister locs, or twists (females: 81.3% vs. males: 1.6%, p<0.01), press and curl (females: 56.3% vs. males: 1.6%, p<0.01), to straighten or relax their hair (females: 18.8% vs. males: 0.0%, p<0.01), and to get weave extensions (females: 18.8% vs. males: 0.0%, p<0.01) (**Table A.3**Error! Reference source not found.).

Nearly 20% of participants (n=21) reported ever chemically relaxing their hair and 7.3%(n=8) reported chemically texturizing their hair. All participants who reported ever chemically relaxing their hair were females, while 37.5% (n=3) of participants who reported ever chemically texturizing their hair were male. Participants reported chemically relaxing or texturizing their hair as early as 4 years (mean: 9 years; range: 4-14 years) (**Figure 5**). Females began chemically relaxing or texturizing their hair at a younger age than males (females mean age: 8.6 years; males mean age: 12.7 years).

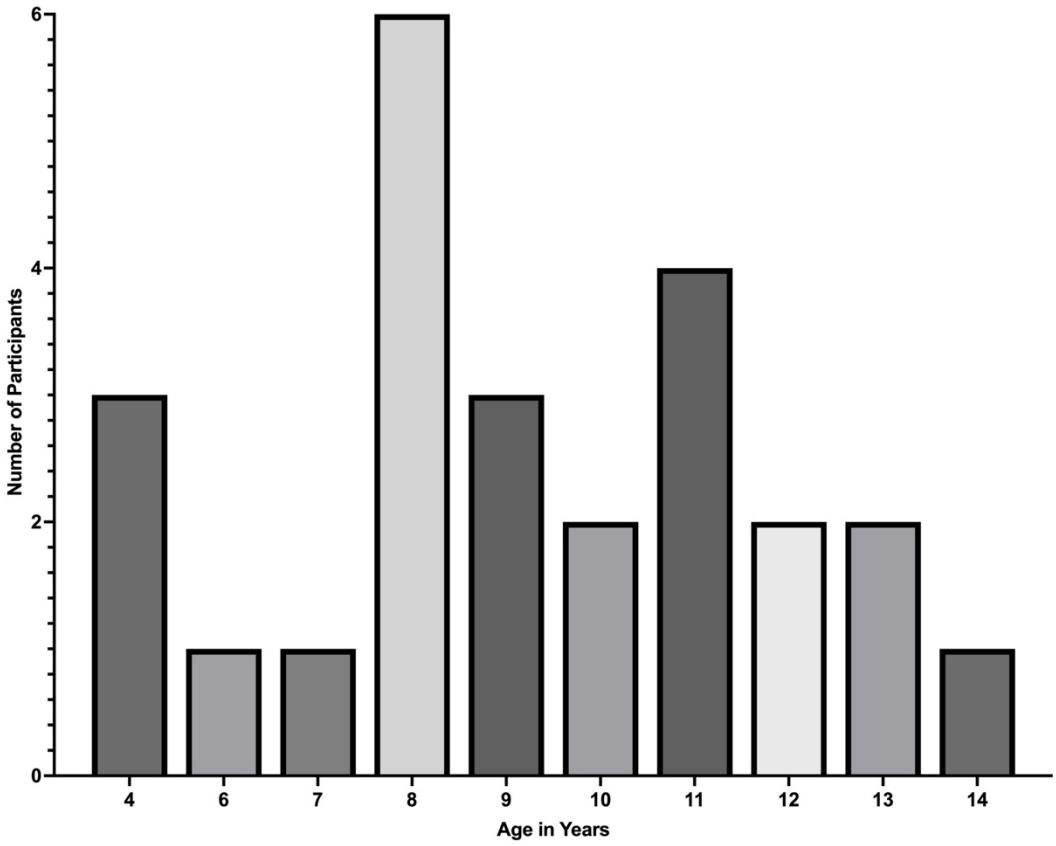


Figure 5. Age of starting chemically relaxing or texturizing hair, n=25

Face and body products

Among all participants, the most commonly reported products used in the past 12 months were toothpaste (100.0%), bar soap (91.8%), liquid hand soap (86.4%), deodorant (84.6%), mouthwash (83.6%), body wash (81.8%), body lotion (81.8%), hand sanitizer (78.2%), hand lotion (74.6%), chapstick/lipbalm (74.6%), and spray/pump perfume (60.9%). (**Table A.4**Error! Reference source not found.) Compared to children, adolescents were more likely to report using products for their face [face cleanser (adolescents: 42.1% vs. children: 2.8%, $p<0.01$), face mask (adolescents: 39.5% vs. children: 5.6%, $p<0.01$), facial moisturizer (adolescents:

21.1% vs. children: 6.9%, p=0.03), and acne cream (adolescents: 23.7% vs. children: 2.8%, p<0.01)], fragrances [spray/pump perfume (adolescents: 79.0% vs. children: 51.4%, p<0.01), liquid/roll-on perfume (adolescents: 31.6% vs. children: 12.5%, p=0.02)], and body wash (adolescents: 94.7% vs. children: 75.0%, p=0.01); while younger children were more likely to report use of bar soap (adolescents: 81.6% vs. children: 91.8%, p=0.01). Females were more likely to report using face masks (females: 29.2% vs. males: 8.1%, p<0.01), chapstick/lipbalm (females: 87.5% vs. males: 64.5%, p<0.01), nail polish (females: 85.4% vs. males: 1.6%, p<0.01), and nail polish remover (females: 70.8% vs. males: 1.6%, p<0.01) compared to males.(**Figure 6**) In general, similar results were observed for use in the past 7 days, though there were a few differences (**Table A.5**). For example, children were more likely to report use of liquid hand soap (children: 88.9% vs. adolescents: 73.7%, p=0.04) and adolescents were more likely to report use of mouthwash (adolescents: 79.0% vs. children: 48.6%, p<0.01). In addition, females were likely to report use of bar soap (females: 91.7% vs. males: 75.8%, p=0.03), deodorant (females: 89.6% vs. males: 74.2%, p=0.03), and spray/pump perfume (females: 56.3% vs. 33.9%, p=0.02) compared to males in the past 7 days.

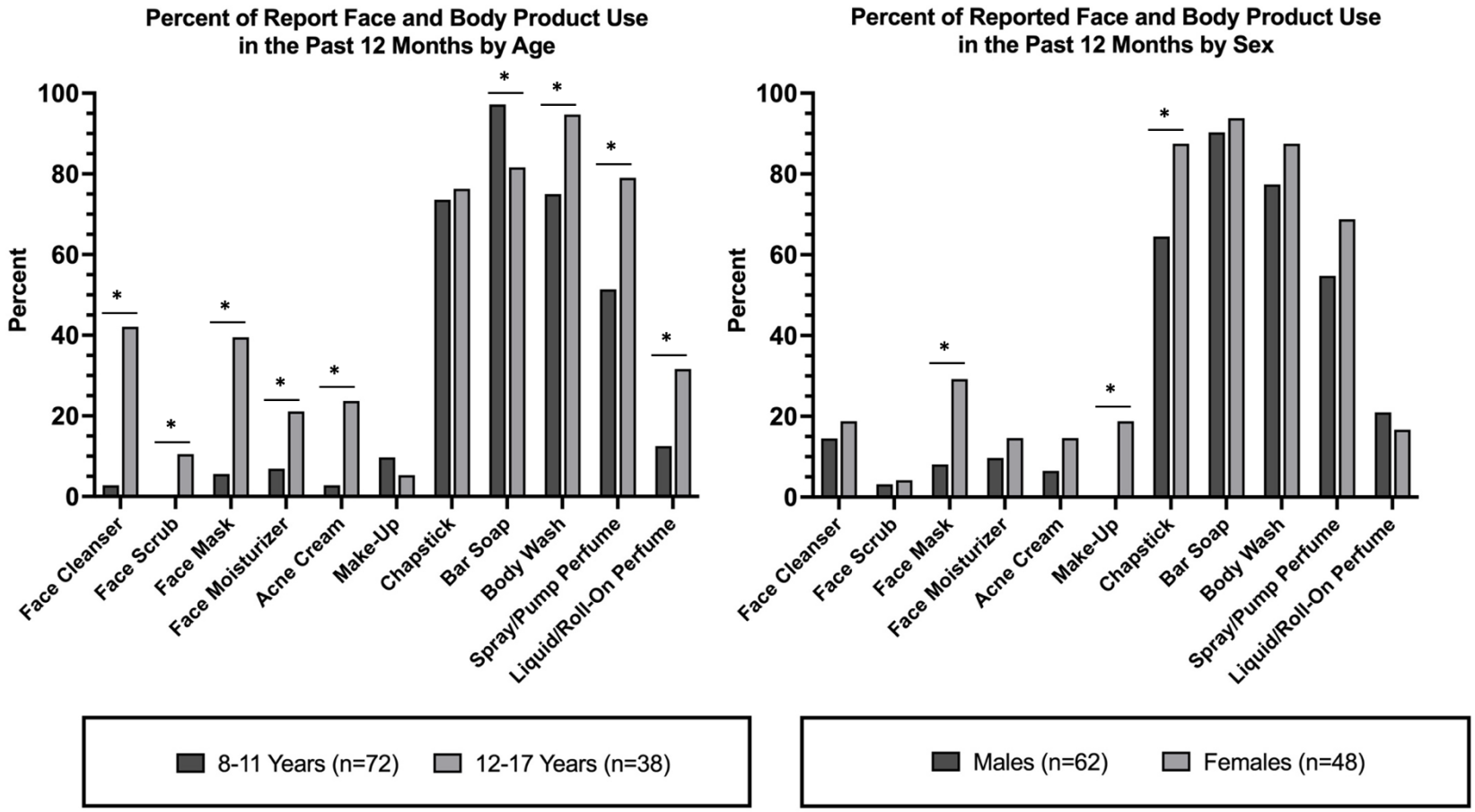


Figure 6. Percent of reported face and body product use in the past 12 months by age and sex[a]

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

In general, adolescents were more likely to report weekly use of face cleanser (adolescents: 21.1% vs. children: 1.4%, $p<0.01$), acne cream (adolescents: 10.5% vs. children: 7.9%, $p=0.01$), body wash (adolescents: 76.3% vs. children: 52.8%, $p=0.02$), spray/pump perfume (adolescents: 68.4% vs. children: 23.6%, $p<0.01$) and liquid/roll-on perfume (adolescents: 23.7% vs. children: 5.6%, $p=0.01$). Children were more likely to report weekly use of bar soap (children: 91.7% vs. adolescents: 71.1%, $p=0.02$). (**Figure 7**) Compared to males, females were more likely to report weekly use of chapstick/lipbalm (females: 75.0% vs. males: 41.9%, $p<0.01$) and monthly use of nail polish (females: 35.4% vs. males: 1.6%, $p<0.01$) and nail polish remover (females: 37.5% vs. males: 1.6%, $p<0.01$).

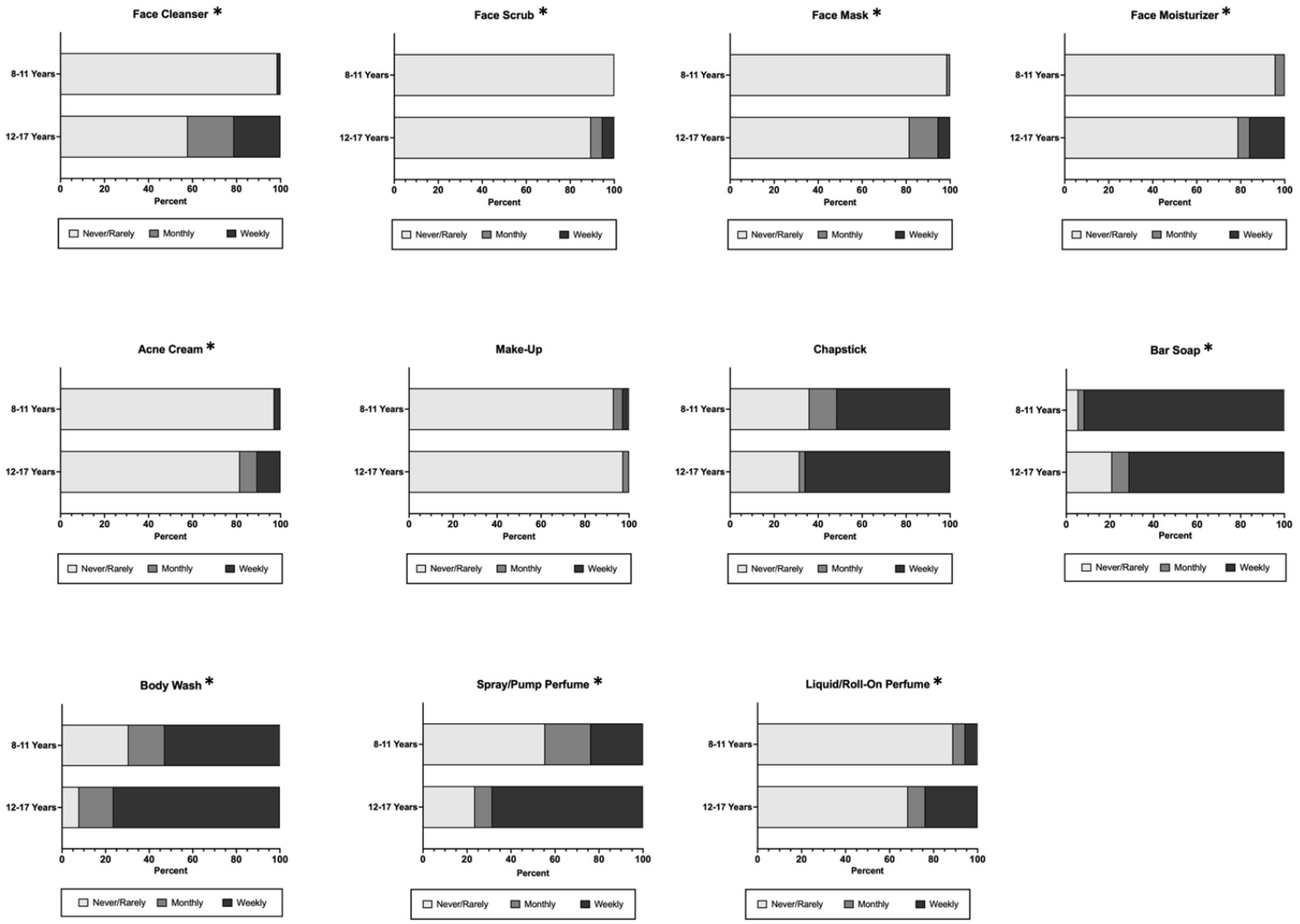


Figure 7. General frequency of face and body product use by age[a]

[a.] Differences in product use by age and sex were assessed using Fisher's Exact; Logistic regression was used to assess which frequency category was significantly different (reference category was never/rarely); significance was determined as $p<0.05$ and noted with an asterisk (*).

Feminine hygiene products

Of the 48 females in our study, 22 (43.8%) reported starting their menses between the ages of 9 to 13 years (**Figure A.2**). All females who started their menses (100.0%) reported using pads 3-7 days per month, 36.4% of females 12-16 years reported using feminine wipes and 13.6% of females 12-13 years reported use of feminine spray in the past 12 months. Interestingly, two females (9.1%) both aged 11 years reported using regular deodorant in the genital area (**Table 3**).

Table 3. Feminine hygiene product use in past 12 months among females who started their menses, n=22

Product	n (%)	Mean Age (Range)
Maxi pads	22 (100.0)	12.4 (9,16)
Tampons	2 (9.1)	14 (12,16)
Feminine wipes	8 (36.4)	13.1 (12,16)
Feminine spray	3 (13.6)	12.7 (12,13)
Regular Deodorant[a]	2 (9.1)	11 (11,11)
Douche	0 (0.0)	--

[a.]Regular deodorant in the genital area

Household consumer products

Most participants reported regular use of scented products at home, including household cleaning products (84.6%), laundry detergent (86.4%), air fresheners (81.8%), dryer sheets (73.6%), and fabric softener (56.5%). There were no differences in household product use among participants by age or sex. (**Table 4**)

Table 4. Frequency of regular household consumer product use among study participants, n=110[a]

Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Incense	21 (19.1)	13 (18.1)	8 (21.1)	0.44	9 (14.5)	12 (25.0)	0.13
Scented candles	40 (36.4)	24 (33.3)	16 (42.1)	0.24	20 (32.3)	20 (41.7)	0.21
Air fresheners	90 (81.8)	57 (79.2)	33 (86.8)	0.24	50 (80.7)	40 (83.3)	0.46
Scented household cleaning products	93 (84.6)	62 (86.1)	31 (81.6)	0.36	54 (87.1)	39 (81.3)	0.28
Scented carpet powder	35 (31.8)	20 (27.8)	15 (39.5)	0.15	17 (27.4)	18 (37.5)	0.18
Scented laundry detergent	95 (86.4)	61 (84.7)	34 (89.5)	0.35	52 (83.9)	43 (89.6)	0.28
Scented dryer sheets	81 (73.6)	53 (73.6)	28 (73.7)	0.59	45 (72.6)	36 (75.0)	0.48
Scented fabric softener	72 (56.5)	47 (65.3)	25 (65.8)	0.57	38 (61.3)	34 (70.8)	0.20
Antibacterial soap for handwashing	87 (79.1)	56 (77.8)	31 (81.6)	0.42	45 (72.6)	42 (87.5)	0.05
Pesticides	30 (27.3)	21 (29.2)	9 (23.7)	0.35	19 (30.7)	11 (22.9)	0.25

[a.] Regular use was assessed by a question that asked, "Are any of the following products regularly used at home?" [b.] Fisher's Exact tests were used to assess differences in product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

Discussion

In the present study among a sample of predominantly Black children with asthma, we found that adolescents (12-17 years) and females reported more frequent use of hair, face, and perfume compared to children (8-11 years) and males, respectively. Interestingly, participants reported using chemical intensive treatments like texturizing and relaxing their hair as young as 4 years and females aged 11-16 years reported regular use of feminine wipes, spray, and regular deodorant in the genital area. In addition, use of scented household products was reported among all participants.

Black female adolescents aged 12-17 years in our study used an average of 21 (range: 10-33) personal care products in the past 12 months and an average of 14 products (range: 5-24) in the past 7 days. The number of products used by participants in our study was similar to the number of products used by college-aged females (aged 18-22 years; 80.4% White) from South Carolina, who reported using 4 to 26 products in the prior week.[165] Use of a high number of products at a young age is concerning due to the potential for increased exposure to chemicals, including endocrine disrupting and asthma-associated compounds, such as phthalates, parabens, glycol ethers, ethanolamines, and fragrance ingredients, which have been frequently measured in personal care and consumer products. [16,37–39]

The number of personal care products used has been associated with increased urinary metabolites of both phthalates and parabens.[52,54,166] For example, previous

research reported that the number of personal care products used in the past 24 hours is associated with increased urinary metabolite concentrations of MEP[54] and PP.[166] While another study among adult-child pairs in California reported higher average urinary metabolite concentrations of MP, PP, and butyl paraben (BP) among adults (≥18 years) who used 7-15 products in the past 24 hours compared to those who used <7 products.[52] However, the number of products used among children <8 years was not associated with urinary metabolites.[52]

Few studies, to date, have characterized personal care product use among children.[52,112,157–159] Moreover, these studies included retrospective assessment of product use during childhood and adolescence only among Black women or included children < 8 years. In general, hair product use reported by children in our study was higher than hair product use reported during childhood and adolescence in retrospective studies among Black women.[111,159] For example, a larger proportion of children in our study reported ever using chemical relaxer and straighteners than 1,555 African American women aged 23-34 years during childhood (35.7% vs. 9%) and adolescence (55.0% vs. 34.0%) [111] and 248 multi-ethnic women during childhood (35.7% vs. 6.1%).[159] Differences across studies such as age differences (children vs. adults), racial/ethnic distribution, and the method used to assess hair product use (i.e., retrospective surveys administered among adults on product use in childhood and adolescence) may explain the differences observed. For example, the majority (91.7%) of our female participants identified as Black, while the study among multi-ethnic women included 24.2% Hispanic, 49.6% non-Hispanic (NH) Black, and 26.2%

NH-white women.[159] In addition, the retrospective assessment of hair product use in prior studies[111,159] could have led to either under- or over-reporting of hair products due to recall bias. Frequent use of hair care products among Black/African American children is of concern due to the potentially higher concentrations of chemicals that have been measured in products marketed toward ethnic populations.[38,58] Of note, participants in our study reported using chemical relaxers and texturizers as young as 4 years, which is similar to initial use of chemical products reported previously in a study among 201 African American females ages 1 to 15 years.[112] In addition, 37.5% of participants who reported ever chemically texturizing their hair were male. To our knowledge, no studies, have reported chemical texturizer use among males. Using chemical relaxers and texturizers at an early age may have implications for exposures to endocrine disrupting chemicals (EDCs) during critical windows of exposure could contribute the development of disease later in childhood and adulthood.[117] For example, chemical relaxer/straightener use during childhood and adolescence has been associated with increased odds of premenopausal breast cancer.[59] In a study that measured chemical hair products commonly used by Black women, hair relaxers frequently contained DEP, parabens, and several targeted fragrance ingredients.[38] Authors also found that two no-lye hair relaxing products marketed for children contained high concentrations of several ingredients that are prohibited by the European Union (EU) Cosmetics Directive (DEHP, nonylphenol, BPA, and diethanolamine) or regulated under California's Proposition 65 (o-phenylphenol).[38] DEHP, nonylphenol, and BPA are prohibited because they are reproductive toxicants and endocrine disruptors, and diethanolamine is a reproductive toxicant and suspected

carcinogen.[113] O-phenylphenol is regulated under California's Proposition 65 due to carcinogenicity.[114]

Similar to prior studies among women, adolescents in our study also reported regular use of perfume and other potentially fragranced products including hand sanitizer, body wash, and body lotion.[53] In addition, more than 75% of participants reported using hand sanitizer in the previous 12 months. This study was conducted pre-COVID, therefore it is likely that hand sanitizer use is now higher among this population, which could increase exposure to chemicals including fragrances and phthalates.[167] Fragrance ingredients are trade secrets or proprietary combinations of several chemicals, [98] which are exempt from ingredient labeling requirements and are instead listed as "fragrance."[38,98,156] In addition to several individual fragrance chemicals, studies have also measured high concentrations of DEP,[16,37] an endocrine disruptor that is used as a fixative in fragranced products.[168] Increased use of perfume has been associated with higher concentrations of several phthalate metabolites, including MEP,[166] a biomarker for DEP. Exposure to phthalates has been associated with numerous adverse health effects, including reproductive[169–171] and respiratory effects.[14,172] Frequent use of fragranced products in our sample of children with asthma is concerning due to the potential for triggering asthma exacerbations.[65,101,103]

Among the 22 females in our study who reported beginning their menses, up to 36% reported using feminine products including feminine spray, wipes, or regular deodorant in the genital area. Similar reports of feminine spray were observed in our

study (13.6%) compared to Black women >18 years (13.8-16.0%),[55,57] and Latina adolescents 14-18 years old (14.0%) and women >18 years (16.9%);[54,55] while a smaller proportion of White women >18 years report less use (3%).[55,57] Cultural and structural level factors could explain increased use of feminine hygiene products among Black and Latina women, including stigma associated with vaginal odors especially during menstruation.[110,173] Increased use of feminine hygiene products is of concern due to the potential exposure to chemicals, including volatile organic compounds (VOCs) and other endocrine disrupting chemicals, which have been measured in a variety of feminine hygiene products sold in the U.S.[174,175] For example, a recent study found chloroform, benzene, 1,4-dioxane, and naphthalene in the majority of feminine washes;[174] while another study detected phthalates and parabens in maxi pads and tampons.[175] The use of regular deodorant in the genital region is another potential concern as it has been reported to contain high concentrations of DEP, fragrances, and glycol ethers[16] and is not formulated for the sensitive genital region, where the thinner skin may provide less protection against chemical exposures.[176]

While our findings increase our understanding of the type and frequency of products that Black children with asthma use, the results should be interpreted in light of study limitations. First, personal care and consumer product use was self-reported during an interviewer-administered survey, which could have led to the potential for interviewer bias. This was minimized using a standardized survey and by ensuring that interviewers were adequately trained in data collection. In addition, participants may

have experienced survey fatigue and may have had recall issues with personal care and consumer product use. However, the survey included questions about use of products in the past 12 months as well as more detailed exposure questions focused on recent use (past 7 days) which may have simplified recall. We also observed similar results for use in the prior 12 months and in the prior 7 days at the time the survey was administered. Half of the surveys were completed by the participant's caregiver, which could have also contributed to underreporting of personal care product use, due to the caregiver not knowing all the products used by the participant. Results may not be generalizable to other demographic groups or rural populations based on our focus on a sample of majority Black children with asthma in Baltimore, MD. For example, children with asthma may limit their use of certain products that may exacerbate their asthma symptoms. In addition, urban populations may have access to different types of products than persons living in more rural or isolated areas. Personal care product use served as a proxy for chemical exposure so we were not able to identify which chemical(s) or combination of chemicals participants may have been exposed to; however, we were able to identify use patterns among an understudied population that could be used to further evaluate exposure. Finally, we had a small sample size with 110 total participants. Larger studies are needed to verify our findings.

To our knowledge, this is the first study to characterize personal care and consumer product use among majority Black children with asthma. Through an extensive survey, we were able to examine frequency of personal care product use several

different ways (prior 12 months, prior 7 days, and in general) and observed consistent differences in product use by age and sex.

These findings increase our understanding and highlight age and sex differences in personal care and consumer product use among Black children with asthma. Comparisons of our results with other studies indicate that product use among Black children may be similar to use patterns reported among Black women and many of the products used that are targeted toward ethnic populations may contain high concentrations of chemicals of concern. Future research should further examine the relationship between product use, chemicals exposures, and health outcomes in disparately exposed populations, especially given the increased use of chemical hair products (i.e., relaxer) and feminine hygiene products at a young age. Understanding these relationships, especially among children with asthma, may inform interventions designed to reduce chemical exposures through personal care and consumer products.

Chapter 3: Personal Care Product Use and Asthma Morbidity Among Children with Asthma

Abstract

Over 4 million (5.8%) U.S. children <18 years suffer from asthma, a chronic inflammatory condition that affects the airways and leads to breathing difficulty. It is a complex disease so the etiology and contributing factors to both prevalence and morbidity is an evolving and growing area of research. There is emerging evidence that chemicals in personal care products (PCP) may play a role in asthma development and control, but research remains sparse. Generalized linear regression models and linear regression models were used to assess associations between self-reported PCP use and pulmonary function, inflammation, and measures of asthma symptoms in the prior two weeks among 110 children 8-17 years with asthma living in Baltimore City. Product use included individual products and the number of products used in the prior 7 days by type of application (i.e., aerosol, wash-off, leave-on hair products, leave-on face and body products). Models were adjusted for age, sex, race, insurance status, season, and having a caregiver who is a current smoker. Participants were majority Black (87%), male (56%), and 8-11 years (66%). In the prior 7 days, participants used an average of 7 PCPs (range: 3-23). Use of aerosol products, shampoo, hair sheen, and nail polish were associated with increased odds of maximal symptom days [number of aerosol products (adjusted odds ratio (aOR): 1.36; 95% confidence interval (CI): 1.17, 1.59), hairspray (aOR: 1.63; CI: 1.14, 2.33),

perfume (aOR: 1.40; CI: 1.11, 1.77); liquid shampoo (aOR: 1.34; CI: 1.05, 1.73), hair sheen (aOR: 1.41; CI: 1.00, 2.00), and nail polish (aOR: 2.42; CI: 1.72, 3.41)]. Hair products were positively associated with exercise-related symptoms [hair coconut oil (aOR: 1.40; CI: 1.01, 1.95), hair gel (aOR: 1.85; CI: 1.26, 2.70), hair oil (aOR: 1.17; CI: 0.88, 1.55) and hair sheen (aOR: 2.10; CI: 1.44, 3.06)]. In general, we did not observe associations between product use and lung function or inflammation. Our findings indicate that some PCPs may contribute to asthma morbidity, but larger studies are needed to confirm our findings and to identify chemicals of concern.

Introduction

Asthma is one of the most common chronic childhood diseases in the U.S.[2,3] It is a complex disease characterized by chronic airway inflammation and causes recurrent episodes of wheezing, chest tightness, and breathlessness.[2] As of 2020, 4.7 million (5.8%) U.S. children (<18 years) had current asthma.[153] Higher rates of current asthma have been reported among adolescents 11-21 years (9.0%), boys (5.7%), non-Hispanic (NH) Black children (12.3%), and individuals living below the poverty threshold (11.0%).[153] Asthma-related costs, including healthcare costs, missed days of work/school, and deaths, are estimated to exceed $80 billion per year.[4] There are many factors that contribute to the development and exacerbation of asthma, such as individual factors (i.e., body mass index, stress/depression), household factors (i.e., mold, pests, secondhand smoke), and neighborhood-level factors (i.e., air pollution, stress caused by violence, racial segregation, etc.).[5] While much of the prior research has focused on household and neighborhood-level factors,[6–9] recent data indicate that

chemicals in consumer and personal care products may play a role in lung health.[5,10–16]

A wide range of chemicals have been measured in personal care products (PCPs), including a number of endocrine-disrupting and asthma-associated chemicals.[16,38] For example, phthalates, parabens, glycol ethers, and ethanolamines have frequently been measured in a variety of personal care products, including perfumes, nail polish, lipstick, body lotions, shampoos, and hair styling products.[16,37,38] Exposure to chemicals in PCPs occurs mainly through dermal application and inhalation.[37] Previous studies have reported the average adult uses 9-13 products per day[51–53] and children <8 years used a median of 4 products.[52] In our previous study, Black children and adolescents reported using a median of 7 products in the prior 24 hours (unpublished data). The use of multiple products can result in exposure to large mixtures of chemicals.[16,37,38] In a study of more than 200 consumer and personal care products, Dodson et al, measured up to 22 chemicals in a single product[16] and the Environmental Working Group estimates that an average adult is exposed to over 85 different chemicals through their daily use of personal care products.[61,177]

Exposure to chemicals commonly found in personal care products is ubiquitous,[45–49] and racial/ethnic and gender disparities for chemicals commonly found in these products are documented.[45,47,50] For example, in the U.S. general population, females are reported to have higher urinary biomarker concentrations for several phthalates and parabens compared to males, while NH-Black participants are reported to have

higher urinary concentrations compared to NH-White participants.[45,47] It is postulated that personal care and consumer product use patterns may contribute to these exposure disparities and may also play a role in asthma disparities.

The specific mechanisms by which chemicals in personal care products may contribute to asthma is an evolving and growing area of research. However, *in vitro* and *in vivo* studies suggest that phthalates and other chemicals commonly found in personal care products may impact both immune and allergic responses.[146–148] For example, phthalates may directly and indirectly contribute to airway sensitization, inflammation, and remodeling, which are key characteristics of asthma.[146–152]

Numerous studies have indicated that prenatal exposures to chemicals commonly found in personal care products may contribute to asthma development.[178–180] Several cross-sectional epidemiological studies in the U.S. general population, for example, report that phthalates and parabens may be associated with both asthma prevalence and morbidity.[13,14,62] Odebeatu et al, reported that mono-benzyl phthalate (MBzP) was associated with self-reported asthma among children (6-17 years) and that monoethyl phthalate (MEP) was associated with current asthma in boys (6-17 years) and males (>18 years).[14] Similarly, Quiros-Alcala et al reported that methyl and propyl paraben were associated with increased prevalence odds of asthma-related emergency department (ED) visits among boys with asthma.[13] In another study in a sample of children with asthma, the molar sum of DEHP metabolites (MEHP, MEHHP, MEOHP, MECPP), MBzP, and mono-2-ethyl-5-hydroxyhexyl terephthalate

(MEHHTP) were associated with increased odds of asthma symptoms.[62] As a proxy for the complex chemical mixtures in personal care products, a study among healthy children and adults in Canada used survey-based methods to examine the relationship between personal care product use and lung function.[10] They reported that hairstyle products (e.g., hair spray, gel, mousse, etc.) were associated with significant reductions in FEV_1 and FEV_1/FVC among both men and women. Among women, use of eye make-up, scented body products, fragrance (e.g., perfumes, colognes, and aftershaves) and lipstick were associated with reductions in lung function.[10]

Understanding the relationship between potential environmental triggers, including personal care products, and asthma morbidity remains an important area of study given asthma has no cure. To our knowledge, no studies have examined the role of personal product use on asthma morbidity among children with asthma. To begin addressing this gap, we sought to examine associations between self-reported personal care product use and measures of asthma symptoms, and lung function and inflammation among children ages 8-17 years with asthma living in Baltimore City, Maryland. We hypothesized that personal care product use would be associated with worse asthma symptoms, reduced lung function, and increased lung inflammation.

Methods

Study design and population

We used data collected from the AIRWEIGHS study, a randomized control trial of 198 children, 8-17 years with persistent asthma conducted between 2017 and 2020. The study aimed to assess whether a high-efficiency particulate air (HEPA) filters could improve respiratory health of inner-city children with asthma. To be eligible, participants had to: 1) meet the criteria for persistent asthma based on the frequency and severity of symptoms as defined by the National Asthma Education and Prevention Program,[160] 2) experienced an asthma exacerbation (i.e., an episode that caused the airways to become swollen and inflamed) in the previous 12 months, 3) be a non-smoker as confirmed with a urine cotinine test, and 4) reside in a primary home four or more nights during the week with no plans to move during the study period. Participants were excluded if they had significant pulmonary or cardiac disease, had a home that was in disrepair, were enrolled in another environmental asthma study in the previous 12 months, or were pregnant. Participants were recruited from Johns Hopkins outpatient clinics and pediatric emergency department, recruitment flyers, and through a registry of previous study participants. The Johns Hopkins School of Medicine Institutional Review Board Study approved all study protocols. Eligibility and informed consent/assent were obtained during the initial clinic visit.

Study procedures and clinical assessment

The parent study took place over 16 weeks and included three clinic visits occurring every 4 weeks, three home visits, and one sleep visit. During each clinic visit, pulmonary function (pre- and post-bronchodilator spirometry), lung inflammation (exhaled nitric oxide), height/weight, and questionnaires on demographics (baseline visit only), asthma symptoms, control, and severity were completed. Height and weight were used to calculate body mass index (BMI). BMI was classified by age and sex-specific percentiles, based on Centers for Disease Control and Prevention (CDC) BMI growth charts.[181] Demographics included participant age, race, gender, caregiver education, household income, insurance, and caregiver smoking status. Asthma control was measured using the Asthma Control Test (ACT), a validated 5-item questionnaire that includes questions on asthma symptoms and medication use.[182] Asthma severity was assessed during the first clinic visit using the National Asthma Education and Prevention Program guidelines (e.g., number of days and nights with symptoms, albuterol use, and forced expiratory volume in the first second (FEV1) and was classified as intermittent, mild, moderate, and severe.[160] In addition, indoor particulate matter ($PM_{2.5}$) was measured in the participant's bedroom over a one-week time period that occurred within 2-4 weeks of the 2nd clinic visit.

Respiratory outcomes

Number of asthma symptoms in the prior two weeks (0-14 days) was captured via standardized and validated questionnaires previously used in asthma cohort studies[183–185] and included: 1) cough, wheeze, or chest tightness, 2) cough without a cold, 3) exercise-related symptoms (cough or chest tightness when running or going

upstairs), 4) slowed activity due to asthma (having to slow down or stop activity due to asthma), 5) slowed speech due to asthma (unable to speak), and 6) nighttime wakening with symptoms. Number of days with cough, wheeze, or chest tightness, slowed activity due to asthma, and nighttime wakening with asthma symptoms were combined to create a variable for maximal symptom days (MSD).[186] Questionnaires were completed by the primary caregiver of children or both participant and caregiver.

Pre- and post-bronchodilator pulmonary function measures, including FEV1 and forced vital capacity (FVC), were collected using a PiKO spirometer (nSpire Health, Longmont, CO, USA). The Global Lung Function Initiative (GLI) was used to estimate ethnic, age-specific percent predicted values.[187,188] Lung inflammation was measured via forced exhaled nitric oxide (FeNO) according to the American Thoracic Society Guidelines using a handheld, FDA-approved analyzer (NIOX TM System, Aerocrine, Sweden).

Exposure assessment of personal care product use

The interviewer-administered comprehensive personal care and consumer product survey was used as a proxy for chemical exposures that could potentially impact lung health. The survey included questions on use of 13 hair products (e.g., shampoo, conditioner, hair gel) and 33 face and body products (e.g., face cleanser, body soap, sunscreen). Frequency of use was assessed as *recent* use in the prior 7 days (used in the prior 24 hours, 2 days ago, 3-7 days ago) and *in general* (more than 5 times per week, 1-5 times per week, 1-3 times per month, less than once a month). Similar to

other studies on personal care products,[37,189] we grouped products into distinct categories (i.e., aerosolized products, wash-off products, leave-on hair products, and leave-on face and body products) based on how the product was used and type of exposure (i.e., inhalation, dermal absorption) and then summed the total number of products used in the prior 7 days in each category to create composite variables for recent use. "Aerosol products," which are products that could be a source of inhalation, included use of hairspray, perfume, liquid perfume, body powder, and dry shampoo. "Wash-off products," which are products that are applied to the skin or hair and then washed off, included bar soap, body wash, hand soap, liquid shampoo, washout conditioner, face cleanser, face mask, face scrub, and shaving cream. "Leave-on hair products," which are products that are applied to the hair and are not washed off, included hair coconut oil, hair gel, hair lotion, hair sheen, heat protector, leave-in conditioner, and hair stimulator. "Leave-on face and body products," which are products that are applied to the skin and are not washed off, included acne cream, baby oil, body lotion, chapstick, coconut oil, deodorant, face moisturizer, hand sanitizer, hand lotion, nail polish, petroleum jelly, and sunscreen. Individual products with reported frequency <10% were included in the calculation of the composite variables but were not included in the analysis as individual products.

For the present analyses, we used data collected during clinic visit 1 (demographic data only) and clinic visit 2 for 110 participants with complete survey data on asthma outcomes and personal care product use (**Figure A.*1***). An intervention as part of the

parent study occurred between clinic visits 2 and 3, therefore, data from clinic visit 3 was not included in this analysis.

Statistical analysis

We calculated descriptive statistics, including frequencies, means, medians, range, and standard deviations (SD) to summarize demographic characteristics, personal care product use, and asthma outcomes. To assess the association between personal care products and asthma morbidity, multivariable linear regression models were used for continuous measures of pulmonary function and inflammation (i.e., FEV1, FEV1/FVC, FeNO) and generalized linear regression models with binomial distribution were used for asthma symptoms in prior two weeks. Potential confounders were selected *a priori* based on our review of the literature and a directed acyclic graph (DAG). Confounders included continuous age (years), gender (male vs. female), race (other vs. Black), health insurance status (public, private, don't know), having a caregiver who is a current smoker (no vs. yes), and season of clinic visit (fall, winter, spring, summer). Inclusion of income and caregiver education as alternatives to insurance status in models did not alter our results; therefore, health insurance status was included as a proxy for socioeconomic status (SES) to maintain power and retain our sample size as information was missing on some participants for the other SES measures.

We additionally conducted secondary analyses to determine whether the interpretation of our findings remained when accounting for other recognized risk factors of adverse respiratory effects - poor indoor air quality[185,190] and obesity.[191,192]

Separate models were run that included the variables in the main model (i.e., age, sex, gender, race, season, and caregiver who is a current smoker) plus $PM_{2.5}$ and BMI. Statistical significance was set at $p<0.05$ and all analyses were conducted in Stata SE 17.0 for Mac (StataCorp, College Station, TX).

Results

Participant characteristics

There were 175 children who participated in clinic visit 2, and of those, 110 children ages 8-17 years (mean: 10.8; SD: 2.5 years) completed both the clinical assessment and the personal care product use survey (**Figure A.*1***). More than half of the participants for the present analyses were male (57.3%), predominantly Black (86.4%), had public insurance (82.7%), and 66.3% reported a household income of less than $50,000. Approximately one-quarter (26.6%) of participant caregivers reported smoking and nearly half (48.2%) of participants were obese (**Table 5**). The majority of participants had well controlled (60.9%), mild or moderate asthma (77.3%), and reported an average of 4.5 (SD: 4.7) maximal symptom days, 2.9 (SD: 3.5) cough without a cold, 2.8 (SD: 4.1) exercise-related symptoms, and 0.3 (SD: 0.8) inability to speak due to asthma in the prior two weeks (**Table 6**). There were no statistically significant differences in demographic or clinical characteristics between study participants with complete clinical and exposure data (n=110) compared to children who did not have complete outcome and exposure data (n=65).

Table 5. AIRWEIGHS study participant characteristics[a]

Characteristic	Study Participants, n=110	Excluded Participants, n=65
Age (years), mean (sd)	10.7 (2.5)	11.3 (2.5)
Age (years), n (%)		
8-11	72 (65.5)	37 (56.9)
12-17	38 (34.6)	28 (43.1)
Gender, n (%)		
Male	63 (57.3)	41 (63.1)
Female	47 (42.7)	24 (36.9)
Race, n (%)[b]		
Black	95 (86.4)	51 (78.5)
Other	15 (13.6)	14 (21.5)
Caregiver Education, n (%)		
High school graduate or lower	62 (56.4)	35 (53.9)
Some college or more	48 (43.6)	30 (46.2)
Household Income, n (%)		
Less than $15,000	26 (23.6)	20 (30.8)
$15,000-$34,999	33 (30.0)	26 (40.0)
$35,000-$49,999	14 (12.7)	7 (10.8)
$50,000 or greater	16 (14.6)	7 (10.8)
Refused/Don't know	21 (19.1)	5 (7.7)
Health Insurance, n (%)		
Private	17 (15.5)	9 (13.9)
Public	91 (82.7)	56 (86.2)
Don't know	2 (1.8)	0 (0.0)
Season, n (%)[c]		
Winter	30 (27.3)	6 (11.8)
Spring	19 (17.3)	13 (25.5)
Summer	28 (25.5)	14 (27.5)
Fall	33 (30.0)	18 (35.3)
Caregiver Current Smoker, n (%)	29 (26.6)	18 (27.7)
Body Mass Index, n (%)		
Underweight	1 (0.9)	1 (1.9)
Normal weight	39 (35.5)	20 (37.7)
Overweight	17 (15.5)	8 (15.1)
Obese	53 (48.2)	24 (45.3)

[a.] Differences between participants included vs. excluded were assessed using Chi-square or Fisher's Exact test; no statistically significant differences were observed.[b.] The other race category includes participants who identify as white and as multi-racial. [c.] Season is based on the time period that the participant completed the personal care product survey and respiratory morbidity data was collected.

Table 6. Asthma outcomes among AIRWEIGHS participants, n=110

Asthma Outcomes	**Study Participants n=110**
Number of days with asthma symptoms in prior two weeks, mean (sd)	
Maximal symptom days	4.5 (4.7)
Coughing, wheezing, or chest tightness	3.1 (3.7)
Slowed activity due to asthma	2.6 (4.0)
Nighttime symptoms	1.9 (3.0)
Cough without a cold	2.9 (3.5)
Exercise-related symptoms	2.8 (4.1)
Lung function and inflammation, mean (sd)	
Pre-FEV1 (% predicted)	88.5 (16.4)
Post-FEV1 (% predicted)	96.8 (15.9)
Pre-FEV1/FVC (% predicted)	91.1 (9.9)
Post-FEV1/FVC (% predicted)	95.8 (9.0)
FeNO (ppb)	29.6 (26.9)
Number of times inhaler was use in prior two weeks, mean (sd)	
Daytime use	3.0 (3.8)
Nighttime use	0.9 (1.8)
Asthma severity (NAEPP classification), n (%)	
Intermittent	6 (5.5)
Mild	44 (40.0)
Moderate	41 (37.3)
Severe	19 (17.3)
Asthma control, mean (sd)[a]	19.8 (3.8)
Asthma control score categorized, n (%)	
>19 (Well controlled)	67 (60.9)
$\leq$19 (Not controlled)	43 (39.1)
$PM_{2.5}$ (ug/m^3), mean (sd)	26.0 (28.0)

[a.] Asthma control was assessed by the Asthma Control Test (ACT), a validated 5-item questionnaire that includes questions on asthma symptoms and medication use.[182]

Personal care product use

Overall, participants reported using an average of 0.7 (range: 0-3) aerosol products, 3.3 (range: 1-7) wash-off products, 1.6 (range: 0-6) leave-on hair products, and 4.4 leave-on face and body products (range: 0-8) in the prior 7 days (**Table 7**). The five most frequently used products in the prior 7 days included hand soap (83.6%), bar soap (82.7%), deodorant (80.9%), body lotion (74.6%), and body wash (65.5%). In general, participants with severe asthma reported using less products than participants with mild or intermittent asthma (e.g., body wash: 36.8% vs. 68.0%, p=0.01).

Associations between aerosol products and asthma symptoms in the prior two weeks

In general, we observed positive associations between recent personal care product use and asthma symptoms in the prior two weeks (

Figure *8*). We observed a general positive trend for total number of aerosol products used in the prior 7 days and several symptoms, including maximal symptom days (adjusted odds ratio (aOR): 1.36; 95% CI: 1.17, 1.59) and exercise-related symptoms (aOR: 1.46; 95% CI: 1.22, 1.75). Use of aerosol hairspray was positively associated with maximal symptom days (aOR: 1.63; 95% CI: 1.14, 2.33) and exercise-related symptoms (aOR: 1.86; 95% CI: 1.25, 2.77); a general positive trend was observed for perfume use and all symptoms; (e.g., maximal symptom days [aOR: 1.40; 95% CI: 1.11, 1.77]).

Table 7. Personal care product use in the prior 7 days by asthma severity among AIRWEIGHS participants, n=110[a]

Product	Overall n=110	Intermittent/Mild n=50	Moderate n=41	Severe n=19
Number of aerosol products, Mean (SD)	0.7 (0.8)	0.6 (0.7)	0.7 (0.8)	0.7 (0.9)
Aerosol hairspray	11 (10.0)	3 (6.0)	5 (12.2)	3 (15.8)
Non-aerosol hairspray	2 (1.8)	0 (0.0)	1 (2.4)	1 (5.3)
Body powder	1 (0.91)	1 (2.0)	0 (0.0)	0 (0.0)
Dry shampoo	1 (0.91)	1 (2.0)	0 (0.0)	0 (0.0)
Perfume	48 (43.6)	24 (48.0)	16 (39.0)	8 (42.1)
Liquid perfume	10 (9.1)	3 (6.0)	5 (12.2)	2 (10.5)
Number of wash-off products, Mean (SD)	3.3 (1.2)	3.4 (1.1)	3.4 (1.2)	2.9 (1.2)
Bar soap	91 (82.7)	37 (74.0)	36 (87.8)	18 (94.7)
Body wash*	72 (65.5)	34 (68.0)	31 (75.6)	7 (36.8)
Face cleanser	10 (9.1)	4 (8.0)	5 (12.2)	1 (5.3)
Face mask	3 (2.7)	2 (4.0)	1 (2.4)	0 (0.0)
Face scrub	2 (1.8)	1 (2.0)	1 (2.4)	0 (0.0)
Shaving cream	1 (0.9)	1 (2.0)	0 (0.0)	0 (0.0)
Hand soap	92 (83.6)	44 (88.0)	34 (82.9)	14 (73.7)
Liquid shampoo	64 (58.2)	33 (66.0)	22 (53.7)	9 (47.4)
Washout conditioner	33 (30.0)	16 (32.0)	10 (24.4)	7 (36.8)
Number of leave-on hair products, Mean (SD)	1.6 (1.5)	1.3 (1.4)	1.8 (1.6)	1.6 (1.8)
Hair coconut oil	22 (20.0)	9 (18.0)	10 (24.4)	3 (15.8)
Hair gel	25 (22.7)	8 (16.0)	11 (26.8)	6 (31.6)
Hair lotion	25 (22.7)	8 (16.0)	13 (31.2)	4 (21.1)
Hair oil	57 (51.8)	25 (50.0)	22 (53.7)	10 (52.6)
Hair sheen	12 (10.9)	5 (10.0)	4 (9.8)	3 (15.8)
Heat protector	4 (3.6)	1 (2.0)	1 (2.4)	2 (10.5)
Leave-in conditioner	25 (22.7)	10 (20.0)	12 (29.3)	3 (15.8)
Stimulator	1 (0.9)	1 (2.0)	0 (0.0)	0 (0.0)

Product	Overall n=110	Intermittent/Mild n=50	Moderate n=41	Severe n=19
Number of leave-on face & body products, Mean (SD)	4.4 (1.7)	4.3 (1.7)	4.8 (1.6)	3.8 (1.9)
Acne	6 (5.5)	3 (6.0)	2 (4.9)	1 (5.3)
Baby oil	9 (8.2)	4 (8.0)	4 (9.8)	1 (5.3)
Body lotion	82 (74.6)	38 (76.0)	31 (75.6)	13 (68.4)
Chapstick	64 (58.2)	28 (56.0)	27 (65.9)	9 (47.4)
Coconut oil	18 (16.4)	8 (16.0)	8 (19.5)	2 (10.5)
Deodorant	89 (80.9)	41 (82.0)	34 (82.9)	14 (73.7)
Face moisturizer	10 (9.1)	7 (14.0)	2 (4.9)	1 (5.3)
Hand lotion	72 (65.5)	30 (60.0)	29 (70.7)	13 (68.4)
Hand sanitizer	72 (65.5)	33 (66.0)	27 (65.9)	12 (63.2)
Nail polish	16 (14.6)	6 (12.0)	6 (14.6)	4 (21.1)
Petroleum jelly*	42 (38.2)	16 (32.0)	23 (56.1)	3 (15.8)
Sunscreen	4 (3.6)	1 (2.0)	3 (7.3)	0 (0.0)

[a.] Fisher's Exact and Kruskal-Wallis were used to assess differences in product use by asthma severity; statistical significance was determined as p-value<0.05 and indicated by an asterisk (*)

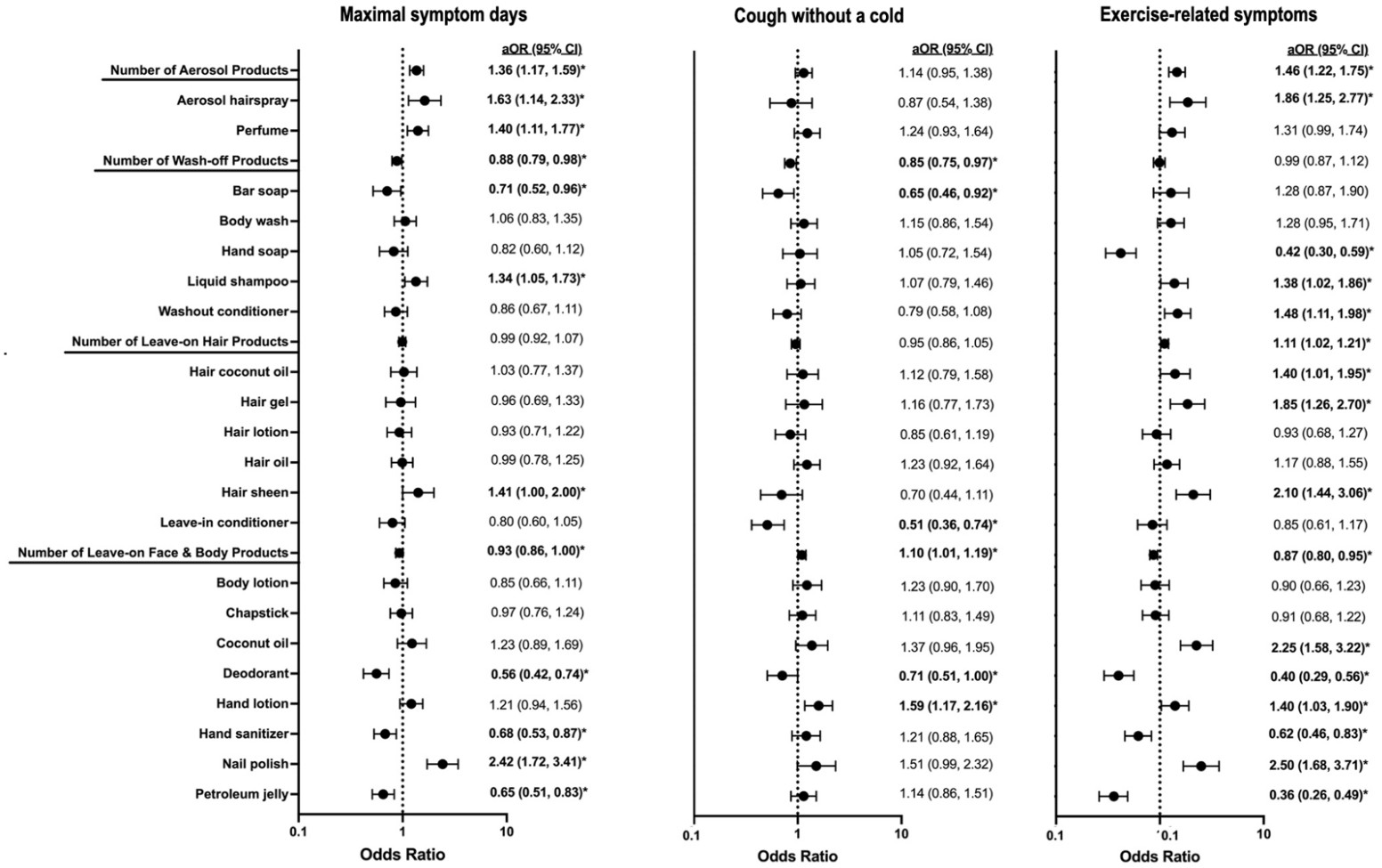


Figure 8. Association between recent personal care product use and asthma symptoms in the prior two weeks[a,b,c]

[a.] Number of products is the sum of individual products for each category in the past 7 days and individual products indicate use in the past 7 days; individual products used by less than 10% of participants were excluded from analysis. [b.] Generalized linear models with binomial distribution were used to estimate odds ratios and 95% confidence intervals. [c.] Models were adjusted for age, sex, race, caregiver smokers, insurance status, and season, statistical significance was determined as $p<0.05$ and indicated by an asterisk (*).

Associations between wash-off products and asthma symptoms in the prior two weeks

In general, wash-off products were inversely associated with asthma symptoms. For example, the number of wash-off products used in the prior 7 days was inversely associated with maximal symptom days (aOR: 0.88; 95% CI: 0.79, 0.98) and cough without a cold (aOR: 0.85; 95% CI: 0.75, 0.97). In addition, use of bar soap was inversely associated with maximal symptom days (aOR: 0.71; 95% CI: 0.52, 0.96) and cough without a cold (aOR: 0.65; 95% CI: 0.46, 0.92), and hand soap was inversely associated with exercise-related symptoms (aOR: 0.42; 95% CI: 0.30, 0.59). On the contrary, body wash and liquid shampoo were, in general, positively associated with all asthma symptoms (body wash: maximal symptom days [aOR: 1.06; 95% CI: 0.83, 1.35], liquid shampoo: maximal symptom days [aOR: 1.34; 95% CI: 1.05, 1.73]).

Associations between leave-on hair products and asthma symptoms in the prior two weeks

The number of leave-on hair products was positively associated with exercise-related symptoms (aOR: 1.11; 95% CI: 1.02, 1.21). In general, several hair products were positively associated with exercise-related symptoms (hair coconut oil [aOR: 1.40; 95% CI: 1.01, 1.95], hair gel [aOR: 1.85; 95% CI: 1.26, 2.70], hair oil [aOR: 1.17; 95% CI: 0.88, 1.55] and hair sheen [aOR: 2.10; 95% CI: 1.44, 3.06]).

Associations between leave-on face & body products and asthma symptoms in the prior two weeks

In general, leave-on face and body products, including coconut oil, hand lotion, and nail polish were positively associated with asthma morbidity (e.g., nail polish: maximal symptom days [aOR: 2.42; 95% CI: 1.72, 3.41]; cough without a cold [aOR: 1.51; 95% CI: 0.99, 2.32]; exercise-related symptoms [aOR: 2.50; 95% CI: 1.68, 3.71]). While inverse associations were observed for deodorant (maximal symptom days [aOR: 0.56; 95% CI: 0.42, 0.74]; cough without a cold [aOR: 0.71; 95% CI: 0.51, 1.00]; exercise-related symptoms [aOR: 0.40; 95% CI: 0.29, 0.56]), hand sanitizer (maximal symptom days [aOR: 0.68; 95% CI: 0.53, 0.87]; exercise-related symptoms [aOR: 0.62; 95% CI: 0.46, 0.83]), and petroleum jelly (maximal symptom days [aOR: 0.65; 95% CI: 0.51, 0.83]; exercise-related symptoms [aOR: 0.36; 95% CI: 0.26, 0.49]).

Inclusion of continuous BMI z-score or $PM_{2.5}$ as model covariates in our secondary analyses, did not change the overall interpretation of our results though in some cases it strengthened associations observed.

Associations between recent personal care products use and pulmonary function and inflammation

In general, we did not observe statistically significant associations between personal care product use and GLI percent predicted pulmonary function measures (FEV_1, FEV_1/FVC) or lung inflammation (FeNO). While not statistically significant, several leave-on hair products were associated with decreases in FEV_1 (hair oil, hair sheen,

leave-in conditioner) and increases in FeNO (hair coconut oil, hair gel, hair lotion, hair oil). In addition, deodorant was associated with decreases in both FEV_1 and FEV_1/FVC, and aerosol hairspray, body wash, body lotion, and nail polish were associated with increases in FeNO (**Table A.6, Table A.7, Table A.8**)

Discussion

In the present study, we observed positive associations between use of several personal care products, including aerosol products and hair products, and asthma symptoms among children with asthma. However, we did not observe associations between product use and lung function or inflammation.

To date, one other study has examined associations between personal care product use and lung function using spirometry.[10] The study reported that personal care product use was associated with significant reductions in lung function.[10] While this was a large population level study with 5,604 participants aged 6-79 years, it consisted of majority white participants (>80%) and asthma prevalence among participants could not be corroborated. In our study, we did not observe consistent reductions in lung function or increased lung inflammation. Additionally, since the participants in our study already have asthma, it is possible that personal care products may trigger symptoms but may not lead to significant reductions in lung function. Studies on phthalates and lung function among children with asthma have reported mixed results. For example, a U.S.-based study reported no associations between phthalates and lung function,[62] while a Korean study reported a lagged effect

where one phthalate metabolite (MEHHP) was associated with significant reductions in FEV_1.[80] One potential reason for the differences in these studies may be that the U.S. study used GLI equations to calculate ethnic, age-specific percent predicted lung function measures, while the Korean study did not. In addition, specific products used may be different in the U.S. vs. Korea.

Endocrine-disrupting and asthma-associated chemicals have been identified on the ingredient labels of >10,000 personal care products[39] and measured in >200 consumer and personal care products, including 18 hair products specifically targeted to Black women.[16,37,38] Across all product types, the most frequently measured chemicals were phthalates, parabens, and cyclosiloxanes.[16,38] In our study, we observed positive associations between asthma symptoms and perfume, nail polish, hand lotion, shampoo, washout conditioner, and several hair styling products. Interestingly, these products have been reported to contain a number of chemicals potentially associated with asthma, including phthalates, parabens, glycol ethers, ethanolamines, and fragrances.[16,37–39] Perfume and nail polish may contain several phthalates, including the highest concentrations of DEP (perfume) and DiBP, DBP, and DEHP (nail polish).[16,37] In addition, perfume contains high concentrations of fragrance ingredients. The strong associations we observed between asthma symptoms and perfume and nail polish could be due, in part, to the high concentration of phthalates, such as DEP, reported in these products. Still, studies that examined associations between asthma and phthalate metabolites have reported inconsistent associations with the DEP biomarker, MEP.[14,15,62,80] Notably, there are many chemical ingredients

included as part of a fragrance and it is possible that other fragrance ingredients (which may not typically be measured in biomonitoring studies) could be driving some of these associations.[16] For example, liquid shampoo is reported to contain high concentrations of ethanolamines. Ethanolamines are used as emulsifiers[16] in shampoo to increase hair body, suppleness, or sheen[95] and have been associated with asthma in occupational studies.[63,64,66] In addition, the phthalate, DEHP, has been associated with both asthma prevalence[33] and asthma morbidity.[62] DEHP has been detected in 76% of rinse-off products and 66% of leave-on products in low concentrations,[37] which may indicate leaching from the packaging.[37,149]

We observed inverse associations between bar soap, hand soap, leave-in conditioner, deodorant, hand sanitizer, and petroleum jelly. These inverse associations could be due to several potential factors. First, these products may be less likely to include endocrine-disrupting and asthma-associated chemicals. In a study of ingredient labels, target chemicals were reported to be in 20% or less of these products. For example, bar soap included MP, BP, and some fragrances as ingredients on 0-10% of products, while hair styling products listed MP and fragrances as ingredients on 10-20% and 30-40% of products, respectively.[39] While ingredient labels may not be indicative of all chemicals in a product, Helm et al reported that chemicals detected at higher concentrations were more likely to be included on the ingredient label than chemicals detected in low concentrations.[38,39] Personal care products are regulated under the Food, Drug, and Cosmetics Act, which does not require that incidental ingredients to be included on the ingredient label (i.e., ingredients that have no function in the

product or present at insignificant levels).[193] Another potential explanation for inverse associations could be the variability in the number and concentration of chemicals within product categories. For example, Dodson et al reported that the chemicals detected in sunscreens ranged from 4-7 chemical compounds in some products, and could go up to 24 chemicals in some sunscreens.[16] We also observed that study participants with more severe asthma may have lower income (**Table A.9**), which could limit access to a wide variety of products. In our study, body wash, which could be more expensive than bar soap, was more frequently reported by children with intermittent/mild asthma compared to children with severe asthma. There may also be other differences that we are unable to account for, such as exposure to other indoor contaminants (i.e., pests, mold, etc.). Finally, we cannot rule out that this may be a spurious finding.

Asthma is a chronic lung disease that can be characterized by airway obstruction, inflammation, and hyperresponsiveness.[194] The mechanism through which chemicals in personal care products impact asthma is not entirely clear due in part to the complexity of asthma. A growing body of research indicates that several chemicals may play a role in asthma prevalence and morbidity.[5,12,13,62] However, the complex chemical co-exposures through regular use of personal care products could have additive or interacting effects, which complicates our ability to identify specific chemicals that may be contributing to an effect.[16] In addition, products created during the application or use of personal care products could be another contributing factor. For example, hair straightening products often contain formaldehyde, which volatilize

when heat is applied to the hair. Occupational cases studies among hairdressers have reported associations between hair straightener, flat iron use, and asthma.[195]

Our results should be interpreted in light of several limitations. First, an interviewer-administered survey was used to assess personal care product use potentially leading to recall bias, underreporting based on respondent and reliance on time period evaluated in the survey. The comprehensive survey queried participants on their use of a wide range of products in the prior 12 months, prior 7 days, and in general. While we queried about use in the prior 7 days which may have been easier to recall than product use in the prior 12 months, recall bias cannot be completely discarded as product use for a different time frame not captured in our study may still be relevant. Additionally, caregivers completed the survey for approximately half of the participants, which could have led to under-reporting of product use due to them not being fully aware of all the products their child is using regularly, especially among older children. Also, product use in the prior 7 days did not align with the report of asthma symptoms which were assessed in the prior two weeks; therefore, we assumed that product use was relatively consistent. For example, it is possible that a product triggered asthma was used in the prior two weeks, but not in the prior 7 days. Since we did not ask about product use in the prior two weeks, we may have missed this product.

Product use as a proxy for chemical exposure is an imperfect measure of exposure. There is wide variation in the number and concentration of chemical ingredients both

between- and within-product categories; therefore, use of a particular product (i.e., shampoo) may not be a precise marker for chemical exposures that could trigger respiratory symptoms. For example, products may be scented/unscented, phthalate-free/paraben-free, and differences in brand formulation may impact chemical composition of the product and subsequent exposure.[16] Still, given the complexity and our limited ability to measure the hundreds of chemicals found in personal care products, survey-based methods can serve as a beneficial tool to capture product use overall and may be able to highlight certain products and chemicals that require further investigation.

Our small sample size (n=110) also limited our power to conduct age and sex stratified analyses as gender disparities in both product use and asthma have been documented.[13,14] We were also not able to determine temporality between personal care product use and asthma morbidity. Lastly, the study was conducted among majority Black children with asthma from Baltimore City, MD. Our results may be representative of urban children with asthma but may not be generalizable to other race and ethnic groups or rural populations due to potential differences in product use and exposure to other contributors to asthma, such as air quality. For example, children with asthma may use less products than children without asthma and children living in urban centers may have access to a wider variety of products than children in rural settings.

Despite the limitations noted, this study has several strengths. The results provide important data in a vulnerable population of children with asthma that can help inform future epidemiological studies. While generalizability of our results may be limited due to our focus on a predominantly Black cohort of children, Black children in the U.S. suffer a high asthma burden and our study highlights the potential role that personal care product use may play in asthma morbidity. To our knowledge, this is the first paper to examine the association between personal care product use and asthma morbidity. In addition, we controlled for important confounders, including age, sex, race, insurance, having a caregiver smoker, and season and, in sensitivity analysis, we assessed the role of recognized risk factors for asthma (e.g., $PM_{2.5}$, BMI), and use of rescue medications.

Conclusions

In this study, we generally observed positive associations between personal care product use and asthma symptoms. Given the complex mix of chemicals found in personal care products, larger epidemiological studies are needed to further investigate the role of personal care product use and the association with respiratory outcomes – including asthma morbidity – among vulnerable populations. Future studies may want to consider the collection of detailed personal care product use histories, including the amount of product used, and expanding biological measurements of chemicals to include target fragrance ingredients, as well as glycol ethers and ethanolamines.

Chapter 4: Occupational Exposures to Phthalates Among Black and Latina U.S. Hairdressers Serving an Ethnically Diverse Clientele: A Pilot Study

Reprinted with permission from Boyle MD, Kavi LK, Louis LM, et al. Occupational exposures to phthalates among black and Latina U.S. Hairdressers serving an ethnically diverse clientele: A pilot study. Environ Sci Technol. 2021;55(12):8128-8138. Doi:10.1021/acs.est.1c00427.

Abstract

Hairdressers may be differentially exposed to phthalates through hair salon services provided and products used, yet few studies have investigated these exposures in this population. We characterized concentrations and exposure determinants to nine phthalate metabolites in post-shift urine samples among 23 female hairdressers working across three Black and three Dominican salons, and 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 ng/mL 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.

Introduction

Phthalates are a class of chemicals commonly found in consumer products, including food packaging and cosmetics.[40,41] High molecular weight phthalates, such as di(2-ethylhexyl) phthalate (DEHP), di-isobutyl 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 (PCP) in the form of fragrance, including in cosmetics and personal hygiene products (e.g., skin creams and lotions, shampoos, oils, perfume/fragranced products, and other hair styling products like hair sprays).[40,156,196] The main routes of phthalate exposures are ingestion, inhalation, and dermal absorption.[37,40,42–44] 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.[154,197–199] For example, there is mounting evidence which suggests that phthalates impact male and female fertility.[200] Prenatal exposure to some phthalates, including to DEP which is heavily used in personal care products, has been linked to a higher odds of preterm birth[200–202], decreased anogenital distance among male infants,[203] and pregnancy complications including risk factors for gestational diabetes,[204] anemia[205,206] and preeclampsia.[207] Although phthalate exposure is ubiquitous in the general population,[47–49] gender and racial/ethnic disparities are reported.[47,50] 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.[38,58,60,208]

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.[209] Disparate phthalate exposure is a concern among racially and ethnically diverse female hairdressers who primarily serve women of color as personal and occupational use of products containing these chemicals could be elevated in this population. Occupational exposure to phthalates could occur through several pathways including dermal absorption, ingestion, and inhalation. Phthalates are semi-volatile and have

been detected in the air and dust collected from hair salons in the U.S. and other countries.[73,122,128] Despite the potential for disproportionate exposures, to our knowledge only two studies to date measured phthalates among hairdressers via biomonitoring conducted in Slovakia.[123,124] Authors reported higher urinary phthalate metabolite concentrations among apprentice hairdressers compared to controls in Slovakia.[123] Notably, no U.S. studies have assessed phthalate exposures among women working in hair salons.

Given rising public health concerns of phthalate exposures, the exposure disparities reported among women of color thought to arise partly due to PCP use,[110] 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, hairdressers working at these salons will be referred to 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, though 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 $\geq$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 one year prior to study enrollment to ensure hairdressers were experienced with a high volume of clientele and who provided a wide array of hair services and products. 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 providing any data or biospecimens.

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, smoking status), health information (e.g., respiratory and reproductive health), as well as personal and workplace behaviors (e.g., cosmetics, hair products used, and other PCP use in the previous 24-48 hours, 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 hours. 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, Brazilian blowout), products used (e.g., shampoo, gel, bleach, hair dye) and PPE (e.g., gloves, apron, mask) used at work. Hairdressers also self-reported the hair salon services they provided and the hair salon products used. A post-shift questionnaire on the day of biospecimen collection obtained 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 behaviors

such as use of PPE. A description of hair salon services provided by participating hairdressers is available in the Appendix, **Table A.2**.

Exposure assessment of phthalates

Urine samples were obtained at the end of the workday (post-shift) from all study participants. 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 post-shift 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 hour, where they were aliquoted into 2mL cryovials and stored at -80C until laboratory analyses for phthalate metabolites. Specific gravity was measured using an ATAGO 3741 Refractometer Pen (ATAGO™3741, 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.[210] Nine phthalate metabolites were measured, representing exposure to six parent compounds (**Table 8**). 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 di-isobutyl 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 non-specific 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). The LODs ranged between 0.063 and 0.542 ng/mL.

Table 8. Phthalate parent compounds, metabolites, and general sources of exposure.[211–215]

Parent Compound	Metabolite	Metabolite Abbreviation	General Sources of Exposure	Approximate Human Biological Half-life (hours)
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, 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, industrial solvents	<24 hours*

* 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 hours.

We evaluated concentrations of individual phthalate metabolites as well as the molar sum of the di(2-ethylhexyl) phthalate (Σ DEHP)-devolving metabolites (MEHP, MEHHP, MEOHP, MECPP) using the following formula as reported previously[48,216,217]: $\Sigma\ DEHP\ (\mu mol/L) = C_{MEHP}\ (ng/mL) * (1/MW_{MEHP}) + C_{MEHHP}\ (ng/mL) * (1/MW_{MEHHP}) + C_{MEOHP}\ (ng/mL) * (1/MW_{MEOHP}) + C_{MECPP}\ (ng/mL) * (1/MW_{MECPP})$, where C_{MEHP} (ng/mL), for example, is the individual's urinary concentration of MEHP in ng/mL, 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 Σ DEHP (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.[48,216,217]

To account for urinary dilution, we used specific gravity corrected phthalate metabolite concentrations using the following formula: C_{sg}=[(C * 1.019-1) / (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.[218]

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 vs. Dominican salons using Chi-square, Fisher's exact, and Student's t-tests.

We determined detection frequency (DF), geometric means (GM), percentiles (p25, p50, p75), and range for phthalate metabolite concentrations. Phthalate metabolite concentrations were right-skewed, so concentrations were log_2-transformed. We used Shapiro-Wilk test to assess normality. Five of the nine phthalates were not log-normally distributed; therefore, we used the non-parametric 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 vs. 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 personal protective equipment (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 post-shift surveys. Geometric mean 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 demographics

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 non-smokers (82.6%) (**Table 9**). 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; range: 21-56 years) than hairdressers (mean age: 40.2; 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 similar between hairdressers [cosmetics: 3.4 (range: 0-9); hair products: 2.1 (range: 0-4); PCPs: 10.5 (range: 0-26)] and office workers [cosmetics: 2.5 (range: 0-5); hair products: 1.5 (range: 0-3); 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 15.0 (range: 3-40) years and working 44.3 (range: 9-91) hours per week. However, hairdressers were more likely to receive $\geq$2 hair salon services in the past 12 months compared to office workers (43.5% vs. 11.8%). Hairdressers from Dominican salons reported serving more clients per week (mean: 32.7; range: 7-50 clients/week) than hairdressers from Black salons (mean: 18.7; range: 7-37 clients/week; $p<0.05$). (**Table 9**)

Both hairdressers and office workers reported infrequent use of hair products on themselves in the past 24-48 hours. 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.[219]

Table 9. Study participant characteristics (n=40, 2018-2019)

Characteristic	Hairdressers			Office Workers (n=17)
	All (n=23)	Black Salons (n=11)	Dominican Salons (n=12)	
	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 (0.00)	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 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 past 24-48 hours				
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[d]	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, Asian, and Other. [b] $p<0.05$ for comparisons between hairdressers from Black and Dominican salons using Fisher's exact test for categorical variables and 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 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 blowout/keratin treatments, and hair color. [e] Personal care products included a total of 31 non-cosmetic and non-hair products, such as soap, body wash, shaving cream, deodorant, body lotion, and perfume.

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 10**). Geometric mean concentrations were significantly higher among hairdressers than office workers for five phthalates and Σ DEHP (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; Σ DEHP: 22.0 ng/mL vs. 5.9 ng/mL; $p<0.05$). 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 A.10**).

We found that urinary phthalate metabolite concentrations were higher among hairdressers compared to women who worked in an office setting. In particular, GM MEP levels were more than 10 times higher in hairdressers compared to office workers. Notably, we found concentrations for three DEHP-devolving metabolites and the ΣDEHP 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, though they may also result from exposure to other sources like 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)[220] (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%),[221] while they were 5 times lower than those reported in another study in a group of 17 Vietnamese nail salon workers, the majority of whom were female (88%).[222] Compared to two other studies among non-pregnant women of reproductive age, hairdressers in our study had 2.3 to 40.5 times higher uncorrected median MEP concentrations (122.7 ng/mL).[24,223] 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 ug/L among 173 women with premature ovarian failure and 246 control women, respectively;[24] and Hauser et al. reported a median MEP concentration of 52.2 ug/L among 256 US women undergoing in vitro fertilization.[223] Similarly, compared to studies that reported GM values among women of reproductive age, we observed higher GM MEP concentrations among hairdressers in our study.[23,210,222] For example, specific gravity-corrected GM MEP concentrations were 7 times higher among hairdressers compared to a sample of Latino adults, the majority of which were female.[210]

Notably, MEP is a metabolite of DEP which is a low molecular phthalate commonly used in personal care products,[156] including hair products,[38] which may explain the higher MEP concentrations observed among hairdressers. A 2018 study measured EDCs in hair products typically used by Black women (e.g., hair oils, root stimulators, hair lotion, relaxers) and detected DEP in 78% of all the products tested.[38]

We did not observe any statistically significant differences in phthalate metabolite concentrations between hairdressers from Black vs. Dominican salons, although we cannot dismiss the possibility that our small sample size could have limited these comparisons (**Table A.11**). 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.[123,124] 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.[123] 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.[124] Differences between these studies may be due to different product regulations and formulations in Europe vs. 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, [54,166] 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 7 products in the previous 24 hours, while Berger et al. reported that 71% of adolescent Latinas 14-18 years used 9-19 products in the previous 48 hours.[54,166] Frequent PCP use has also been positively associated with phthalate metabolite concentrations among women, specifically MEP, MiBP, and MnBP.[54,166] 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.[38]

Table 10. Specific gravity-corrected summary statistics for phthalate metabolite concentrations in ng/mL among study participants (n=40, 2018-2019)

Metabolite	LOD	Hairdressers (n=23) Specific gravity-corrected				Office workers (n=17) Specific gravity-corrected				p-value[b]
		DF %	GM	p50 (p25, p75)	Range	DF %	GM	p50 (p25, p75)	Range	
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
Σ DEHP[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.] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, MECPP metabolites. [b.] P-values from 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; MBzP: Monobenzyl phthalate

General workplace behaviors and phthalate metabolite concentrations among hairdressers

We observed higher phthalate metabolite concentrations for several hair salon services provided (**Table 11**), products used (**Table 12**), and PPE used while performing chemical services (**Table 13**).

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 (82.6%) 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 11**). 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. Geometric mean 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; MEHP: 1.1 ng/mL vs. 0.5 ng/mL), bleaching (MCPP: 0.6 ng/mL vs. 0.1 ng/mL; MEHP: 1.3 ng/mL vs. 0.1 ng/mL), and permanent hair coloring (MCPP: 0.5 ng/mL vs. 0.1 ng/mL; 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 Σ DEHP were higher among hairdressers who reported providing haircuts compared to those who did not provide this service (**Table 11**).

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 11**). To our knowledge, this is the first study to report that several natural hairstyles were associated with lower phthalate metabolite concentrations. 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 chemicals ingredients of potential concern in these products.[224]

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 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 providing an array of services making it difficult to parse the impact of each individual service on phthalate metabolite concentrations.

Hairdressers reported generally using an array of products while providing hair salon services for their clients. For example, more than 75% of hairdressers reported using 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 of 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 Σ DEHP (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 those products.

Table 11. 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	Σ DEHP[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
Semi-permanent 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

Services Provided	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[a]
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.] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, 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; MBzP: Monobenzyl phthalate

Table 12. 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	Σ DEHP[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

Products Used	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[a]
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.] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, 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; MBzP: Monobenzyl phthalate

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 13**). 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.

Table 13. Specific gravity-corrected geometric mean phthalate metabolite concentrations (ng/mL) based on personal protective equipment used in general (n=23, 2018-2019)

Personal protective equipment used while performing chemical services	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[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.] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, 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; MBzP: Monobenzyl phthalate

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 A.12**). 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; MnBP: 20.6 ng/mL vs. 8.0 ng/mL) and permanent hair color (MEP: 295.6 ng/mL vs. 136.4 ng/mL; 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 semi-permanent 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 A.12**). These results suggest that use of gloves was 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 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 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.[56] For example, policy-level interventions could include elimination of these chemicals from hair products or to 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 women working in hair salons. However, hairdressers may face pressure to not wear PPE in front of their clients, which could impact compliance. Of note, 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 sample collected at the end of the shift. While phthalates are rapidly metabolized and reported to be mostly excreted in less than 24 hours, [213,214] 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 all other studies among non-pregnant 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 PCP use is an increasing concern and may reflect an additional facet of environmental justice.[110] 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 comprised 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.

Chapter 5: Conclusions

Summary of results

This dissertation provides foundational exposure and epidemiologic data that aims to improve our understanding of the factors associated with chemical exposures through personal care and consumer products among Black children and occupationally exposed hairdressers, as well as the association between product use and asthma morbidity among Black children with asthma.

In Chapter 2, we examined personal care product use patterns among Black children with asthma and found that adolescents (12-17 years) and females reported more frequent use of hair, face, and perfume compared to children (8-11 years) and males, respectively. In addition, children reported using chemical intensive processes on their hair, such as texturizing and relaxing, as young as 4 years old and participants as young as 11 years reported use of scented feminine hygiene products, such as wipes, spray, and regular deodorant in the genital area. In previous studies, Black women have reported using chemical relaxers/texturizers during childhood and adolescence. To our knowledge, no studies to date have reported use of chemical texturizers among males or use of regular deodorant in the genital area. Furthermore, our results indicate that Black children may have similar use patterns to those reported by Black women and many of the products used that are targeted toward ethnic populations may

contain high concentrations of chemicals of concern. Exposure to chemicals in personal care products during critical periods of development, including childhood and adolescence, may have implications for the development and severity of disease, such as asthma. The results of this study contribute new data that can help inform larger, future studies to further understand chemical exposures through the use of personal care products among Black children.

In Chapter 3, we examined the association between personal care product use and asthma morbidity among Black children with asthma. In general, we observed positive associations between several personal care products and asthma symptoms. Though not always statistically significant, there were positive associations between aerosol products, such as hairspray and perfume and measures of asthma morbidity (i.e., maximal symptom days) and lung inflammation. Identifying products that may trigger or increase risk of asthma symptoms can inform more targeted biomonitoring studies and the development of interventions to improve asthma morbidity.

In Chapter 4, we measured urinary phthalate metabolite concentrations among female hairdressers who serve an ethnically diverse clientele and found that, in general, phthalate metabolite concentrations were higher among hairdressers compared to both office workers and women in the U.S. general population. Specifically, hairdressers had MEP concentrations that were more than 10 times higher than office workers and median concentrations were 41 times higher than women experiencing premature ovarian failure. In addition, we found that hairdressers who reported performing

chemical-based hair salon services in general (i.e., permanent waves/texturizing, relaxing, bleaching, permanent hair color, and Brazilian blowouts) had higher MEP concentrations compared to hairdressers who did not perform the services. While hairdressers who reported performing low/no chemical-intensive services (i.e., twists, sister locs/locs, and afros) had lower MEP concentrations than hairdressers who did not perform these services. Phthalate exposure may play a role in reproductive and respiratory health, therefore, reducing chemical exposures among hairdressers of reproductive age is imperative not only for the health of the hairdresser, but also to protect the health of their future children.

Complexity of assessing chemical exposures through personal care products

Assessing chemical exposures through the use of personal care and consumer products is not a trivial task. Due to exemptions in cosmetic labeling requirements, it is unclear which chemicals are included in each product and how much of that chemical is included in any given product. For example, ingredients deemed to be trade secrets, such as fragrance or ingredients that mask odor can be listed under the umbrella term "fragrance."[100] Neither chemical ingredients nor the final product require approval before entering the consumer marketplace. Instead, the cosmetic industry is self-regulated and is responsible for ensuring product safety.[104] An additional complexity in exposure assessment arises when assessing product use in broad categories (i.e., shampoo, body lotion, etc.), since we may be unable to capture the within- and between-product chemical variability. Due to the number of chemicals being used in personal care products, it is cost and time prohibitive to

measure every chemical in a product or in biomonitoring studies. There are also complex co-mixtures of chemicals in products that may have additive effects. While a concentration of a chemical considered safe may be used in an individual product, the use of multiple products in a day may increase the exposure of these chemicals and exposure to other chemicals that could be of potential concern in these products is unavoidable. Finally, secondary products, that are potentially more harmful than the original ingredient listed on the product label, may be created or formed through application of heat.

Future research

Larger epidemiological studies are needed to further examine the relationship between product use, chemicals exposures, and health outcomes in disparately exposed populations. Future research should consider the collection of detailed personal care product use histories to capture the amount of product used and/or the number of times per day a product is used, collection of multiple urine samples to account for variability of non-persistent chemicals, and measurement of other chemicals of concern (i.e., targeted fragrance ingredients, glycol ethers, ethanolamines).

In addition, future studies may consider developing and testing targeted personal and workplace interventions designed to reduce chemical exposures. For example, workplace interventions with hairdressers may include examining the role of administrative controls on chemical-intensive services, such as varying scheduling

(e.g., only one chemical service at a time) and/or location (e.g., near open door/window or ventilation), or adding/improving ventilation systems, if feasible. While individual-level interventions may target cultural norms and behaviors that may contribute to increased exposures (e.g., use of scented feminine hygiene products, use of chemical relaxers/texturizers).

Protecting consumers

A growing body of research indicates that chemicals in personal care products may be of source of public health concern, especially among vulnerable populations who may be disparately exposed. Individual-level interventions are a necessary step toward protecting human health, however, policy-level changes that remove the onus from the individual are critical and should be prioritized. This could include stricter consumer protection laws that eliminate chemicals of concern from personal care and consumer products or improving product labeling to help consumers and hairdressers select products without key chemicals. In order to protect the health of current and future generations precautionary approaches should be considered by taking action now through scientific advocacy and increased regulation of chemicals before they are used in consumer products.

Appendices

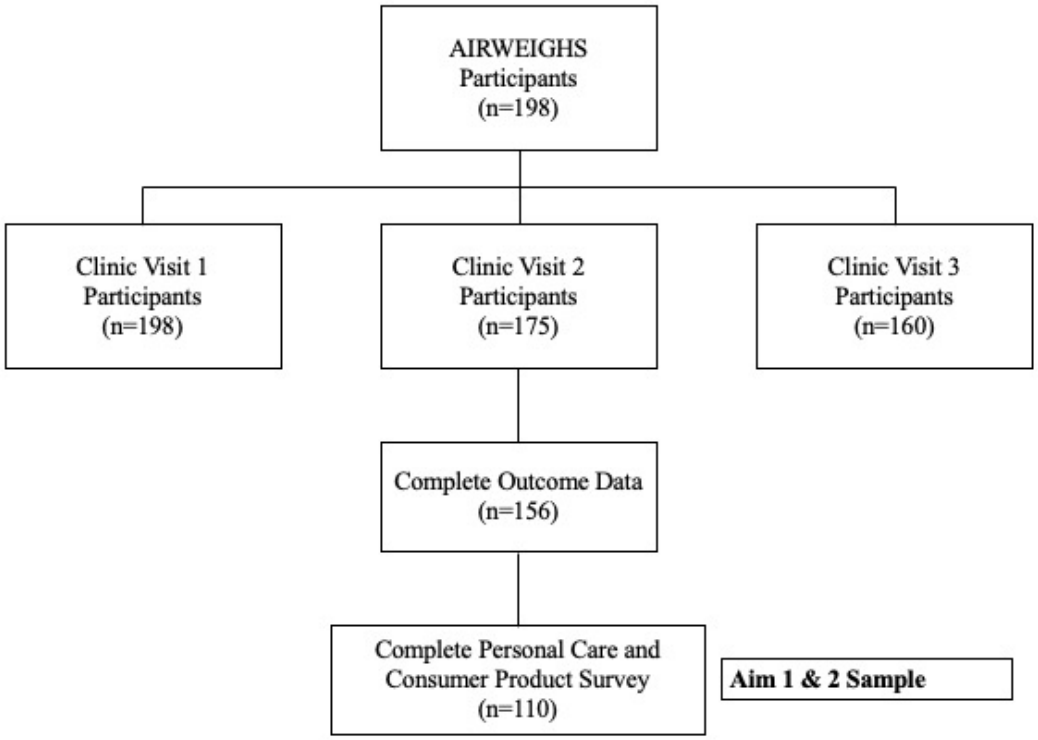


Figure A.1. AIRWEIGHS sample size

Table A.1. Select phthalate compounds, metabolites, and chemical structures[212]

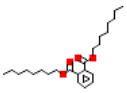
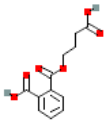
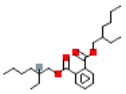
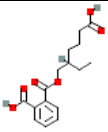
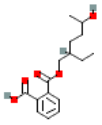
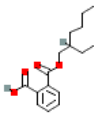
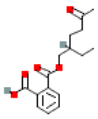
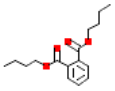
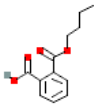
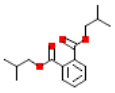
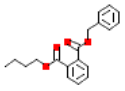
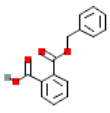
Parent compound	Chemical structure	Metabolite	Chemical structure
Diethyl phthalate		Monoethyl phthalate	
Di-*n*-octyl phthalate		Mono-3-carboxypropyl phthalate	
Di(2-ethylhexyl) phthalate		Mono(2-ethyl-5-carboxypentyl) phthalate	
		Mono(2-ethyl-5-hydroxyhexyl) phthalate	
		Mono(2-ethylhexyl) phthalate	
		Mono(2-ethyl-5-oxohexyl) phthalate	
Di-*n*-butyl phthalate		Monobutyl phthalate	
Diisobutyl phthalate		Monoisobutyl phthalate	
Butyl benzyl phthalate		Monobenzyl phthalate	

Table A.2. Description of hair salon services[141,225,226]

Name of Process	Description of Style	Description of Hair Care Process
Permanent waves or texturizing	Process that creates permanent curls or waves in hair	Using hands or a brush, a permanent waving solution is applied to the hair. The solution breaks down existing disulfide bonds within the hair, enabling it to be molded into curls or waves. After a set amount of time, the solution is rinsed off and a neutralizing solution is used to restore normal hair pH. The waves or curls last until new hair grows which needs to then be permed.
Chemical straightening or relaxing	Process that permanently straightens hair	Using hands or a brush, relaxer cream is applied to the hair. The solution breaks down existing disulfide bonds within the hair. Once the cream is applied, the hair is smoothed section by section in order to straighten it. After a set amount of time, the cream is rinsed off and a neutralizing shampoo is used to restore normal hair pH. The straightening lasts until new hair grows which needs to then be relaxed.
Hair dye	Process that dyes hair a different color	Using hands or a brush, hair dye is added to the hair. After a set amount of time, the dye is rinsed off. Permanent hair dye will last until new hair grows out. Semi-permanent hair dye will last for about 4 or 6 weeks, at which point it can be washed out.
Braids/sister locs/twists	A hairstyle formed by intertwining three or more strands of hair, twisting hair into medium or small strands, or intertwining two strands of hair	Hair is divided into even sections of two or more. The hair is then braided or twisted together. Hair extensions can be added to the elongate the hair.

Name of Process	Description of Style	Description of Hair Care Process
Brazilian blowout or keratin treatment	Process that semi-permanently straightening hair	Keratin, a sealing liquid, and a preservative solution is applied to the hair. The hair is then straightened with a flat iron. This style lasts several months and is then reapplied.
Press and curl	Process that creates curls in hair with curling iron or straightens hair with flat iron	Hair is straightened with a flat iron or styled with a curling iron.
Weave extensions (with or without glue)	Process that attaches synthetic or artificial hair to existing hair for the purpose of increasing hair length or volume. This process can be done with or without the use of chemicals.	Hair extensions are attached to existing hair or afixed to head using glue or other chemicals (chemicals), or with clips, braids, sewing or other methods (without chemicals). Extensions will last days or month depending on style, condition and maintenance.

Table A.3. Hair services received in the past 12 months by age and sex[a]

Hair Service	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Chemical texturizer	2 (1.8)	1 (1.4)	1 (2.6)	0.57	0 (0.0)	2 (4.2)	0.19
Straightener/relaxer	9 (8.2)	4 (5.6)	5 (13.2)	0.15	0 (0.0)	9 (18.8)	**<0.01***
Hair coloring (permanent and semi-permanent)	6 (5.5)	2 (2.8)	4 (10.5)	0.11	3 (4.8)	3 (6.3)	0.53
Braids/sister locks/twists	40 (36.4)	23 (31.9)	17 (44.7)	0.13	1 (1.6)	39 (81.3)	**<0.01***
Brazilian blowout/keratin treatment	3 (2.7)	3 (4.2)	0 (0.0)	0.28	0 (0.0)	3 (6.3)	0.08
Press and curl	28 (25.5)	14 (19.4)	14 (36.8)	**0.04***	1 (1.6)	27 (56.3)	**<0.01***
Weave extensions	9 (8.2)	3 (4.2)	6 (15.8)	**0.04***	0 (0.0)	9 (18.8)	**<0.01***

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

Table A.4. Face and body products used in the past 12 months by age and sex[a]

Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Facial Moisturizer	13 (11.8)	5 (6.9)	8 (21.1)	**0.03***	6 (9.7)	7 (14.6)	0.31
Face Cleanser	18 (16.4)	2 (2.8)	16 (42.1)	**<0.01***	9 (14.5)	9 (18.8)	0.37
Face Scrub	4 (3.6)	0 (0.0)	4 (10.5)	**0.01***	2 (3.2)	2 (4.2)	0.59
Face Mask	19 (17.3)	4 (5.6)	15 (39.5)	**<0.01***	5 (8.1)	14 (29.2)	**<0.01***
Chapstick/Lipbalm	82 (74.6)	53 (73.6)	29 (76.3)	0.47	40 (64.5)	42 (87.5)	**0.01***
Makeup	9 (8.2)	7 (9.7)	2 (5.3)	0.34	0 (0.0)	9 (18.8)	**<0.01***
Shaving Cream	3 (2.7)	1 (1.4)	2 (5.3)	0.27	3 (4.8)	0 (0.0)	0.18
Toner	2 (1.8)	2 (2.8)	0 (0.0)	0.43	1 (1.6)	1 (2.1)	0.69
Acne Cream	11 (10.0)	2 (2.8)	9 (23.7)	**<0.01***	4 (6.5)	7 (14.6)	0.14
Liquid Hand Soap	95 (86.4)	65 (90.3)	30 (79.0)	0.09	54 (87.1)	41 (85.4)	0.51
Bar Soap	101 (91.8)	70 (97.2)	31 (81.6)	**0.01***	56 (90.3)	45 (93.8)	0.39
Body Wash	90 (81.8)	54 (75.0)	36 (94.7)	**0.01***	48 (77.4)	42 (87.5)	0.13
Hand Sanitizer	86 (78.2)	57 (79.2)	29 (76.3)	0.45	48 (77.4)	38 (79.2)	0.51
Nail Polish	42 (38.2)	24 (33.3)	18 (47.4)	0.11	1 (1.6)	41 (85.4)	**<0.01***
Nail Polish Remover	35 (31.8)	19 (26.4)	16 (42.1)	0.07	1 (1.6)	34 (70.8)	**<0.01***
Deodorant	93 (84.6)	59 (81.9)	34 (89.5)	0.23	50 (80.6)	43 (89.6)	0.15
Spray/Pump Perfume	67 (60.9)	37 (51.4)	30 (79.0)	**<0.01***	34 (54.8)	33 (68.8)	0.10
Liquid/Roll-On Perfume	21 (19.1)	9 (12.5)	12 (31.6)	**0.02***	13 (21.0)	8 (16.7)	0.38
Sunscreen	33 (30.0)	23 (31.9)	10 (26.3)	0.35	22 (35.5)	11 (22.9)	0.11
Baby Oil	22 (20.0)	14 (19.4)	8 (21.1)	0.51	9 (14.5)	13 (27.1)	0.08
Coconut Oil	27 (24.6)	17 (23.6)	10 (26.3)	0.46	13 (21.0)	14 (29.2)	0.22

Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Petroleum Jelly	60 (54.6)	38 (52.8)	22 (57.9)	0.379	35 (56.5)	25 (52.1)	0.396
Hand Lotion	82 (74.6)	51 (70.8)	31 (81.6)	0.159	44 (70.9)	38 (79.2)	0.225
Body Lotion	90 (81.8)	58 (80.6)	32 (84.2)	0.423	50 (80.6)	40 (83.3)	0.458
Body Powder	13 (11.8)	7 (9.7)	6 (15.8)	0.261	7 (11.3)	6 (12.5)	0.537
Floss	59 (53.6)	41 (56.9)	18 (47.4)	0.225	32 (51.6)	27 (56.3)	0.386
Mouthwash	92 (83.6)	58 (80.6)	34 (89.5)	0.177	51 (82.3)	41 (85.4)	0.43
Tooth Whitener	5 (4.6)	2 (2.8)	3 (7.9)	0.224	3 (4.8)	2 (4.2)	0.62
Toothpaste	110 (100.0)	72 (100.0)	38 (100.0)	--	62 (100.0)	48 (100.0)	--

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

Table A.5. Face and body products used in the past 7 days by age and sex[a]

Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Facial Moisturizer	10 (9.1)	3 (4.2)	7 (18.4)	**0.02***	5 (8.1)	5 (10.4)	0.46
Face Cleanser	10 (9.1)	1 (1.4)	9 (23.7)	**<0.01***	6 (9.7)	4 (8.3)	0.54
Face Scrub	2 (1.8)	0 (0.0)	2 (5.3)	0.12	2 (3.2)	0 (0.0)	0.32
Face Mask	3 (2.7)	0 (0.0)	3 (7.9)	**0.04***	0 (0.0)	3 (7.9)	**0.04***
Chapstick	64 (58.2)	40 (55.6)	24 (63.2)	0.29	25 (40.3)	39 (81.3)	**<0.01***
Makeup	4 (3.6)	3 (4.2)	1 (2.6)	0.57	0 (0.0)	4 (8.3)	**0.03***
Shaving Cream	1 (0.9)	0 (0.0)	1 (2.6)	0.35	1 (1.6)	0 (0.0)	0.56
Toner	0 (0.0)	0 (0.0)	0 (0.0)	--	0 (0.0)	0 (0.0)	--
Acne Cream	6 (5.5)	1 (1.4)	5 (13.2)	**0.02***	4 (6.5)	2 (4.2)	0.47
Liquid Hand Soap	92 (93.6)	64 (88.9)	28 (73.7)	**0.04***	52 (83.9)	40 (83.3)	0.57
Bar Soap	91 (82.7)	62 (86.1)	29 (76.3)	0.15	47 (75.8)	44 (91.7)	**0.03***
Body Wash	72 (65.5)	41 (56.9)	31 (81.6)	**0.01***	41 (66.1)	31 (64.6)	0.51
Sanitizer	72 (64.5)	49 (68.1)	23 (60.5)	0.28	38 (61.3)	34 (70.8)	0.20
Nail Polish	16 (14.6)	11 (15.3)	5 (13.2)	0.50	1 (1.6)	15 (31.3)	**<0.01***
Nail Polish Remover	7 (6.4)	3 (4.2)	4 (10.5)	0.19	1 (1.6)	6 (12.5)	**0.03***
Deodorant	89 (80.9)	55 (76.4)	34 (89.5)	0.08	46 (74.2)	43 (89.6)	**0.03***
Spray/Pump Perfume	48 (43.6)	24 (33.3)	24 (63.2)	**<0.01***	21 (33.9)	27 (56.3)	**0.02***
Liquid/Roll-On Perfume	10 (9.1)	3 (4.2)	7 (18.4)	**0.02***	3 (4.8)	7 (14.6)	0.08
Sunscreen	4 (3.6)	3 (4.2)	1 (2.6)	0.57	2 (3.2)	2 (4.2)	0.59
Baby Oil	9 (8.2)	6 (8.3)	3 (7.9)	0.62	4 (6.5)	5 (10.4)	0.34
Coconut Oil	18 (16.4)	10 (13.9)	8 (21.1)	0.24	8 (12.9)	10 (20.8)	0.20

Product	n (%)	Age			Sex		
		8-11 Years (n=72)	12-17 Years (n=38)	p-value	Males (n=62)	Females (n=48)	p-value
Petroleum Jelly	42 (38.2)	23 (31.9)	19 (50.0)	0.05	26 (41.9)	16 (33.3)	0.24
Hand Lotion	72 (64.5)	43 (59.7)	29 (76.3)	0.06	38 (61.3)	34 (70.8)	0.20
Body Lotion	82 (74.6)	51 (70.8)	31 (81.6)	0.16	46 (74.2)	36 (75.0)	0.55
Body Powder	1 (0.9)	1 (1.4)	0 (0.0)	0.66	1 (1.6)	0 (0.0)	0.56
Floss	40 (36.4)	27 (37.5)	13 (34.2)	0.45	21 (33.9)	19 (39.6)	0.34
Mouthwash	65 (59.1)	35 (48.6)	30 (79.0)	**<0.01***	37 (60.0)	28 (58.3)	0.52
Tooth Whitener	0 (0.0)	0 (0.0)	0 (0.0)	--	0 (0.0)	0 (0.0)	--
Toothpaste	109 (99.1)	71 (98.6)	38 (100.0)	0.66	61 (98.4)	48 (100.0)	0.56

[a.] Fisher's Exact tests were used to assess differences in hair product use by age and sex; significance was determined as $p<0.05$ and noted with an asterisk (*).

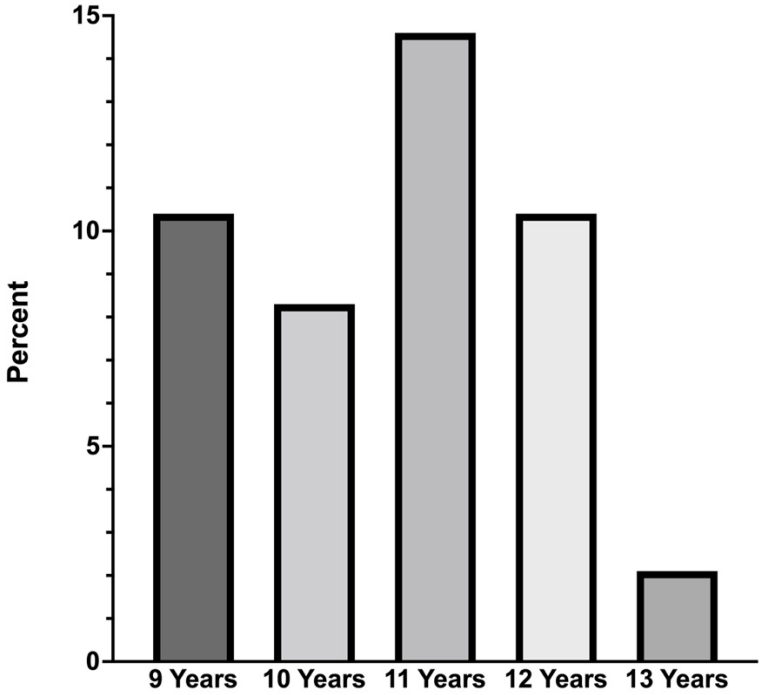


Figure A.2. Age at menarche, n=22

Table A.6. Associations between recent personal care product use and FEV_1[a,b,c]

Personal Care Products[c]	**Pre-FEV_1 %**		**Post-FEV_1 %**	
	Crude OR (95% CI)	**Adjusted OR (95% CI)**	**Crude OR (95% CI)**	**Adjusted OR (95% CI)**
Number of aerosol products	0.34 (-4.55, 5.23)	0.07 (-4.81, 4.95)	0.84 (-3.90, 5.57)	0.20 (-4.67, 5.08)
Aerosol hairspray	-1.73 (-12.12, 8.66)	-1.09 (-10.95, 8.76)	-1.39 (-11.47, 8.68)	-0.63 (-10.48, 9.22)
Perfume	2.00 (-4.30, 8.30)	1.51 (-4.89, 7.91)	2.04 (-4.06, 8.14)	0.83 (-5.57, 7.22)
Number of wash-off products	2.05 (-0.64, 4.73)	0.88 (-1.91, 3.66)	1.64 (-0.97, 4.26)	0.60 (-2.19, 3.38)
Bar soap	0.41 (-7.84, 8.67)	-0.73 (-8.97, 7.51)	2.83 (-5.15, 10.81)	1.48 (-6.75, 9.70)
Body wash	**6.71 (0.26, 13.15)***	6.30 (-0.07, 12.66)	3.83 (-2.50, 10.16)	2.92 (-3.53, 9.38)
Hand soap	-1.39 (-10.02, 7.23)	-2.19 (-10.96, 6.58)	-0.44 (-8.81, 7.92)	-1.92 (-10.68, 6.85)
Liquid shampoo	2.06 (-4.29, 8.41)	-0.15 (-7.00, 6.69)	0.77 (-5.39, 6.93)	-0.20 (-7.03, 6.64)
Washout conditioner	2.80 (-4.00, 9.59)	-1.60 (-8.44, 5.24)	1.07 (-5.53, 7.68)	-2.69 (-9.50, 4.13)
Number of leave-on hair products	-0.58 (-2.78, 1.63)	-0.78 (-3.00, 1.45)	-0.63 (-2.77, 1.51)	-1.06 (-3.27, 1.16)
Hair coconut oil	5.39 (-2.35, 13.12)	4.46 (-3.29, 12.21)	5.54 (-1.94, 13.03)	4.16 (-3.59, 11.90)
Hair gel	0.08 (-7.37, 7.53)	-4.56 (-13.21, 4.08)	2.09 (-5.11, 9.30)	-2.76 (-11.42, 5.91)
Hair lotion	0.58 (-6.87, 8.03)	0.12 (-7.04, 7.28)	0.24 (-6.98, 7.46)	-0.84 (-7.99, 6.31)
Hair oil	-5.53 (-11.71, 0.65)	-3.80 (-10.17, 2.58)	**-6.87 (-12.80, -0.94)***	-5.34 (-11.66, 0.99)
Hair sheen	-6.90 (-16.81, 3.02)	-4.88 (-14.52, 4.77)	-8.63 (-18.19, 0.92)	-6.74 (-16.33, 2.85)
Leave-in conditioner	-0.52 (-7.97, 6.92)	-1.43 (-8.57, 5.71)	-0.08 (-7.30, 7.14)	-1.37 (-8.50, 5.76)
Number of leave-on face & body products	0.72 (-1.19, 2.62)	0.75 (-1.26, 2.75)	0.71 (-1.14, 2.55)	0.49 (-1.51, 2.50)
Baby oil	2.67 (-8.70, 14.04)	1.09 (-9.81, 11.99)	0.12 (-10.90, 11.15)	-1.27 (-12.15, 9.62)
Body lotion	-4.38 (-11.58, 2.83)	-0.97 (-8.20, 6.26)	-4.41 (-11.39, 2.57)	-1.80 (-9.02, 5.41)
Chapstick	**6.44 (0.20, 12.68)***	5.65 (-0.99, 12.30)	**7.05 (1.03, 13.06)***	6.06 (-0.57, 12.68)
Coconut oil	4.78 (-3.60, 13.17)	2.30 (-6.14, 10.75)	4.39 (-3.74, 12.52)	2.82 (-5.60, 11.25)
Deodorant	-5.12 (-13.00, 2.76)	-3.35 (-11.51, 4.81)	-4.92 (-12.56, 2.72)	-4.87 (-12.99, 3.25)
Hand lotion	-2.59 (-9.19, 4.00)	-0.59 (-7.40, 6.22)	-2.90 (-9.28, 3.48)	-2.26 (-9.05, 4.53)
Hand sanitizer	0.98 (-5.64, 7.59)	-3.28 (-10.18, 3.63)	0.22 (-6.19, 6.63)	-3.84 (-10.72, 3.05)
Nail polish	3.99 (-4.83, 12.80)	2.14 (-7.17, 11.46)	5.64 (-2.87, 14.15)	3.50 (-5.79, 12.78)
Petroleum jelly	1.88 (-4.55, 8.30)	2.61 (-3.83, 9.05)	1.87 (-4.35, 8.10)	3.13 (-3.29, 9.55)

[a.] Number of products is the sum of individual products for each category in the past 7 days and individual products indicate use in the past 7 days. [b.]Models were adjusted for age, sex, race, caregivers who smoke, insurance status, and season, statistical significance was determined as $p<0.05$ and indicated by an asterisk (*). [c.] Personal care products used by less than 10% of participants were excluded from analysis.

Table A.7. Associations between recent personal care product use and FEV_1/FVC[a,b,c]

Personal Care Products[c]	**Pre-FEV_1/FVC**		**Post-FEV_1/FVC**	
	Crude OR (95% CI)	**Adjusted OR (95% CI)**	**Crude OR (95% CI)**	**Adjusted OR (95% CI)**
Number of aerosol products	0.74 (-2.21, 3.70)	0.40 (-2.76, 3.56)	0.63 (-2.04, 3.31)	-0.10 (-2.98, 2.77)
Aerosol hairspray	3.44 (-2.81, 9.69)	3.47 (-2.88, 9.83)	2.32 (-3.34, 7.99)	2.50 (-3.28, 8.28)
Perfume	0.90 (-2.91, 4.71)	0.44 (-3.71, 4.60)	0.54 (-2.91, 3.99)	-0.67 (-4.44, 3.09)
Number of wash-off products	1.00 (-0.63, 2.63)	0.90 (-0.90, 2.70)	0.79 (-0.69, 2.26)	0.65 (-0.99, 2.29)
Bar soap	1.41 (-3.57, 6.40)	0.84 (-4.50, 6.18)	1.53 (-2.98, 6.03)	0.18 (-4.67, 5.04)
Body wash	**5.14 (1.29, 8.99)***	**5.46 (1.39, 9.52)***	**3.82 (0.30, 7.34)***	**4.03 (0.30, 7.76)***
Hand soap	-2.70 (-7.89, 2.49)	-1.85 (-7.53, 3.83)	-0.99 (-5.70, 3.73)	0.13 (-5.04, 5.30)
Liquid shampoo	1.14 (-2.70, 4.98)	0.48 (-3.95, 4.92)	0.61 (-2.87, 4.08)	0.74 (-3.28, 4.77)
Washout conditioner	1.51 (-2.60, 5.62)	0.81 (-3.62, 5.25)	0.65 (-3.08, 4.37)	-0.32 (-4.35, 3.71)
Number of leave-on hair products	0.63 (-0.70, 1.96)	0.62 (-0.82, 2.06)	0.34 (-0.87, 1.54)	-0.02 (-1.33, 1.30)
Hair coconut oil	-0.41 (-5.13, 4.30)	-1.05 (-6.10, 4.00)	-1.11 (-5.37, 3.15)	-2.42 (-6.99, 2.14)
Hair gel	1.98 (-2.50, 6.47)	3.12 (-2.49, 8.72)	2.98 (-1.05, 7.01)	2.34 (-2.76, 7.44)
Hair lotion	0.42 (-4.09, 4.92)	0.44 (-4.20, 5.08)	0.97 (-3.09, 5.04)	0.38 (-3.83, 4.60)
Hair oil	0.62 (-3.17, 4.41)	-0.63 (-4.79, 3.53)	-0.30 (-3.73, 3.13)	-1.65 (-5.41, 2.12)
Hair sheen	3.65 (-2.36, 9.66)	5.01 (-1.19, 11.21)	-0.98 (-6.44, 4.49)	0.25 (-5.45, 5.96)
Leave-in conditioner	2.25 (-2.23, 6.73)	2.78 (-1.82, 7.38)	1.86 (-2.19, 5.92)	1.80 (-2.38, 5.99)
Number of leave-on face & body products	0.71 (-0.43, 1.86)	0.81 (-0.48, 2.10)	0.81 (-0.22, 1.85)	0.73 (-0.45, 1.90)
Baby oil	6.32 (-0.45, 13.10)	5.34 (-1.64, 12.33)	6.06 (-0.06, 12.17)	5.52 (-0.80, 11.84)
Body lotion	-0.15 (-4.53, 4.24)	0.67 (-4.01, 5.36)	0.24 (-3.73, 4.20)	0.34 (-3.92, 4.60)
Chapstick	2.14 (-1.68, 5.96)	2.87 (-1.47, 7.20)	**3.47 (0.05, 6.88)***	3.22 (-0.70, 7.13)
Coconut oil	3.03 (-2.03, 8.10)	1.57 (-3.90, 7.04)	2.05 (-2.55, 6.64)	1.28 (-3.69, 6.25)
Deodorant	-0.76 (-5.56, 4.04)	-1.57 (-6.87, 3.73)	-0.43 (-4.77, 3.91)	-2.09 (-6.90, 2.71)
Hand lotion	1.99 (-1.99, 5.97)	2.60 (-1.79, 6.98)	2.32 (-1.27, 5.90)	2.04 (-1.95, 6.02)
Hand sanitizer	-1.27 (-5.26, 2.72)	-1.04 (-5.53, 3.45)	-2.65 (-6.23, 0.93)	-2.04 (-6.10, 2.03)
Nail polish	-0.10 (-5.45, 5.25)	0.26 (-5.79, 6.30)	-0.03 (-4.87, 4.81)	-1.39 (-6.87, 4.09)
Petroleum jelly	1.46 (-2.42, 5.34)	1.29 (-2.89, 5.48)	2.53 (-0.95, 6.02)	3.39 (-0.35, 7.13)

[a.] Number of products is the sum of individual products for each category in the past 7 days and individual products indicate use in the past 7 days. [b.]Models were adjusted for age, sex, race, caregiver smokers, insurance status, and season, statistical significance was determined as $p<0.05$ and indicated by an asterisk (*). [c.] Personal care products used by less than 10% of participants were excluded from analysis.

Table A.8. Associations between recent personal care product use and lung inflammation[a,b,c]

Personal Care Products[c]	**Crude OR (95% CI)**	**Adjusted OR (95% CI)**
Number of aerosol products	-1.57 (-9.80, 6.66)	-1.54 (-9.86, 6.78)
Aerosol hairspray	7.25 (-10.53, 25.02)	7.30 (-9.77, 24.38)
Perfume	-4.18 (-14.63, 6.28)	-5.41 (-16.17, 5.35)
Number of wash-off products	-0.90 (-5.36, 3.57)	-2.31 (-7.00, 2.38)
Bar soap	-4.22 (-18.07, 9.63)	-3.56 (-17.80, 10.68)
Body wash	5.14 (-5.73, 16.00)	7.65 (-3.32, 18.61)
Hand soap	**-17.14 (-30.61, -3.67)***	-10.45 (-24.71, 3.81)
Liquid shampoo	5.04 (-5.43, 15.51)	0.53 (-11.16, 12.22)
Washout conditioner	-3.21 (-14.43, 8.01)	-7.27 (-18.73, 4.19)
Number of leave-on hair products	2.47 (-1.24, 6.17)	2.64 (-1.13, 6.42)
Hair coconut oil	10.77 (-2.13, 23.67)	11.02 (-2.03, 24.06)
Hair gel	6.41 (-5.97, 18.79)	7.90 (-6.79, 22.58)
Hair lotion	6.12 (-6.46, 18.70)	6.24 (-5.99, 18.47)
Hair oil	1.80 (-8.58, 12.19)	3.27 (-7.56, 14.10)
Hair sheen	0.60 (-15.84, 17.05)	1.83 (-14.39, 18.06)
Leave-in conditioner	2.41 (-10.22, 15.03)	1.08 (-11.37, 13.53)
Number of leave-on face & body products	-0.51 (-3.72, 2.71)	-1.05 (-4.50, 2.40)
Baby oil	-1.42 (-20.11, 17.28)	3.42 (-14.85, 21.68)
Body lotion	3.00 (-8.94, 14.93)	1.33 (-10.90, 13.56)
Chapstick	1.03 (-9.48, 11.54)	-1.95 (-13.25, 9.36)
Coconut oil	-0.82 (-15.02, 13.38)	5.63 (-8.89, 20.15)
Deodorant	-5.77 (-19.04, 7.49)	-6.34 (-20.45, 7.77)
Hand lotion	-3.54 (-14.43, 7.35)	-9.69 (-21.16, 1.79)
Hand sanitizer	-1.58 (-12.48, 9.33)	0.47 (-11.12, 12.06)
Nail polish	7.02 (-7.87, 21.91)	2.46 (-13.54, 18.46)
Petroleum jelly	-1.96 (-12.58, 8.66)	-1.93 (-12.75, 8.90)

[a.] Number of products is the sum of individual products for each category in the past 7 days and individual products indicate use in the past 7 days. [b.]Models were adjusted for age, sex, race, caregiver smokers, insurance status, and season, statistical significance was determined as $p<0.05$ and indicated by an asterisk (*). [c.] Personal care products used by less than 10% of participants were excluded from analysis.

Table A.9. Asthma severity by income among AIRWEIGHS participants, n=110

Income	Asthma Severity		
	Intermittent/Mild n=50	**Moderate n=41**	**Severe n=19**
Less than $15,000	12 (24.0)	8 (19.5)	6 (31.6)
$15,000 to $35,000	14 (28.0)	13 (31.7)	6 (31.6)
$35,000 to $50,000	7 (14.0)	5 (12.2)	2 (10.5)
$50,000 or more	10 (20.0)	5 (12.2)	1 (5.3)
Refused/Don’t know	7 (14.0)	10 (24.4)	4 (21.1)

Table A.10. Summary statistics for uncorrected phthalate metabolite concentrations in ng/mL among study participants (n=40, 2018-2019)

Metabolite	LOD	Hairdressers (n=23)				Office Controls (n=17)				p-value[b]
		DF %	GM	P50 (P25, P75)	Range	DF %	GM	P50 (P25, P75)	Range	
MEP	0.237	100	143.9	122.7 (60.8, 320.2)	17.5-1193.3	100	12.1	20.4 (2.8, 24.9)	1.5-220.1	**<0.001**
MCPP	0.187	60.9	0.5	0.3 (0.1, 1.2)	0-5.6	35.3	0.2	0.1 (0.1, 0.3)	0.1 -2.1	**--**
MECPP	0.156	100	6.7	5.3 (3.1, 21.5)	1.3-63.4	100	1.6	1.6 (0.8, 2.5)	0.3-9.5	**<0.001**
MEHHP	0.197	100	6.4	5.7 (2.7, 12.4)	1.3-109.0	100	1.7	1.2 (1.2, 2.4)	0.4-5.6	**<0.001**
MEHP	0.291	52.2	0.8	1.4 (0.1, 4.2)	0.1-11.9	23.5	0.2	0.1 (0.1, 0.1)	0.1-1.2	**--**
MEOHP	0.089	100	3.7	3.6 (1.6, 7.3)	0.8-23.8	94.1	0.9	0.9 (0.6, 1.9)	0.04-4.7	**<0.001**
MnBP	0.246	100	8.4	11.8 (2.8, 18.6)	0.8-111.9	100	3.0	3.7 (1.2, 6.5)	0.6-10.0	**0.004**
MiBP	0.542	91.3	3.0	3.1 (1.3, 9.0)	0.3-26.8	47.1	0.6	0.3 (0.3, 1.2)	0.3-3.7	**--**
MBzP	0.063	91.3	0.8	1.2 (0.4, 2.6)	0.3-6.8	94.1	0.7	1.1 (0.2, 1.7)	0.03-4.6	0.753
Σ DEHP[a]	--	--	19.6	16.8 (9.0, 43.0)	3.6-173.5	--	4.7	4.1 (3.1, 6.3)	0.9-15.7	**<0.001**

[a.] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, MECPP metabolites (ng/mL). [b.] P-values from Wilcoxon rank sum test comparing phthalate biomarker concentrations between hairdressers and office controls; 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; MBzP: Monobenzyl phthalate

Table A.11. Summary statistics for phthalate metabolite concentrations in ng/mL among hairdressers stratified by type of salon (n=23, 2018-2019)[a]

Metabolite	LOD	Hairdressers from Black Salons (n=11) Uncorrected / Specific gravity-corrected				Hairdressers from Dominican Salons (n=12) Uncorrected / Specific gravity-corrected				p-value[c]
		DF %	GM	P50 (P25, P75)	Range	DF %	GM	P50 (P25, P75)	Range	
MEP	0.237	100	130.9	98.2 (51.3, 317.8)	31.4-763.1	100	156.8	183.4 (61.0, 183.4)	17.5-1193.3	0.460
			136.4	103.7 (53.0, 475.2)	34.4-582.2		188.3	187.1 (68.5, 500.0)	36.5-897.1	
MCPP	0.187	72.7	0.7	0.5 0.1, 2.4)	0-5.6	50.0	0.3	0.1 (0.1, 0.9)	0-1.7	--
			0.6	0.5 (0.1, 2.1)	0-3.9		0.3	0.2 (0.1, 0.8)	0-1.2	
MECPP	0.156	100	8.2	5.6 (4.0, 21.8)	1.8-63.4	100	5.5	4.5 (2.6, 15.9)	1.3-31.5	0.538
			8.6	5.3 (3.6, 23.8)	3.1-52.2		6.7	7.2 (3.1, 17.2)	1.2-22.6	
MEHHP	0.197	100	8.6	6.6 (4.8, 13.2)	2.5-109.0	100	4.9	4.4 (2.2, 9.5)	1.3-43.9	0.623
			8.9	6.8 (3.5, 16.2)	2.8-89.8		5.9	6.8 (2.7, 12.9)	1.4-31.5	
MEHP	0.291	45.5	0.7	0.1 (0.1, 4.2)	0.1-11.9	58.3	0.9	1.7 0.1, 4.7)	0.1-8.1	--
			0.8	0.2 (0.1, 6.4)	0.1-30.7		1.1	2.0 0.1, 5.5)	0.1-11.1	
MEOHP	0.089	100	4.6	4.6 (3.1, 7.5)	1.5-15.8	100	3.1	2.8 (1.4, 5.9)	0.8-23.8	0.538
			4.8	4.8 (2.5, 6.7)	1.8-20.1		3.7	3.8 (2.0, 7.2)	0.9-17.1	
MnBP	0.246	100	13.6	15.2 (8.7, 20.2)	2.8-46.3	100	5.4	5.7 (1.9, 13.3)	0.8-111.9	0.124
			14.2	12.8 (9.0, 37.5)	4.5-41.6		6.5	8.1 (3.4, 13.4)	0.7-102.0	
MiBP	0.542	100	3.9	3.9 (1.4, 11.2)	0.7-19.3	83.3	2.4	2.3 (0.9, 7.9)	0.3-26.8	0.538
			4.1	4.3 (1.8, 9.9)	0.9-17.3		2.9	4.4 (1.4, 6.8)	0.2-24.5	
MBzP	0.063	100	1.1	1.2 (0.5, 3.0)	0.1-6.8	83.3	0.6	1.0 (0.3, 1.8)	0.03-5.6	0.758
			1.2	1.4 (0.4, 2.7)	0.3-4.8		0.7	0.9 (0.8, 1.8)	0.02-5.0	
Σ DEHP[b]	--	--	25.0	16.9 (12.7, 58.7)	7.0-173.5	--	15.7	14.9 (8.4, 29.7)	3.6-102.4	0.623
			26.1	22.0 (9.8, 48.9)	7.7-142.9		18.9	22.3 (10.2, 41.8)	3.5-73.5	

[a] Rows shaded in grey indicate specific gravity-corrected concentrations in ng/mL. [b] Σ DEHP represents the molar sum of MEHP, MEHHP, MEOHP, MECPP metabolites in ng/mL. [c.] P-values from Wilcoxon rank sum test comparing specific gravity-corrected phthalate biomarker concentrations between hairdressers

from Black and Dominican salons; p-values ($p<0.05$) are bolded; MCPP, MEHP, and MiBP had DF<70% for hairdressers 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; MBzP: Monobenzyl phthalate

Table A.12. Specific gravity-corrected geometric mean phthalate metabolite concentrations (ng/mL) for hair salon services provided on day of biospecimen collection (n=23, 2018-2019).

Services Provided	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[a]
Chemical straightening or relaxing											
Yes	21.7	222.9	1.0	15.1	8.3	0.9	6.0	7.8	4.1	0.7	35.0
No	78.3	147.6	0.3	6.2	6.9	0.9	3.8	10.0	3.2	1.0	19.4
Bleaching											
Yes	4.4	96.8	2.9	28.7	7.4	0.1	5.6	6.0	2.9	1.4	40.4
No	95.7	165.2	0.4	7.1	7.2	1.0	4.1	10.0	3.4	0.9	21.4
Semi-permanent hair color											
Yes	17.4	169.2	0.9	13.8	18.5	2.2	6.0	13.1	6.7	1.4	47.7
No	82.6	159.8	0.4	6.6	5.9	0.8	3.9	8.8	3.0	0.8	18.7
Permanent Hair Color											
Yes	21.7	295.6	0.9	8.6	10.2	2.6	6.1	16.0	5.1	1.2	29.3
No	78.3	136.4	0.4	7.3	6.5	0.7	3.8	8.2	3.0	0.8	20.4
Hair extensions (no glue)											
Yes	82.6	234.5	0.3	7.3	8.4	1.4	5.2	20.6	4.3	0.9	24.7
No	17.4	149.2	0.5	7.6	6.9	0.9	4.0	8.0	3.2	0.9	21.5
Hair extensions (with glue)											
Yes	8.7	105.9	0.4	12.4	4.2	1.1	3.2	8.3	4.1	0.3	27.0
No	91.3	168.0	0.4	7.2	7.5	0.9	4.3	9.6	3.3	1.0	21.6

Services Provided	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[a]
Hair drying with blow dryer											
Yes	34.8	163.6	0.3	5.9	6.4	0.9	4.0	8.3	2.9	0.7	17.9
No	65.2	160.3	0.6	8.6	7.7	1.0	4.3	10.2	3.7	1.0	24.6
Flat iron											
Yes	21.7	198.7	0.2	10.7	5.6	0.3	4.2	7.2	2.6	0.5	24.2
No	78.3	152.3	0.5	6.8	7.7	1.3	4.2	10.2	3.7	1.1	21.5
Putting hair in rollers											
Yes	26.1	261.3	0.4	4.5	5.8	1.0	3.7	7.3	3.2	1.3	15.4
No	73.9	136.2	0.4	9.0	7.7	0.9	4.3	10.4	3.5	0.8	25.0
Brazilian blowout or keratin											
Yes	4.4	243.6	0.7	7.9	9.5	3.1	5.5	8.7	6.9	0.9	25.7
No	95.7	158.4	0.4	7.5	7.1	0.9	4.1	9.5	3.3	0.9	21.9
Braids											
Yes	13.0	49.0	0.2	3.3	3.5	0.1	2.3	12.8	1.5	0.6	9.1
No	87.0	193.0	0.5	8.5	8.0	1.3	4.6	9.1	3.8	1.0	25.2
Sister locs/locs											
Yes	4.4	103.7	1.4	5.3	6.7	4.0	6.1	38.2	12.9	3.4	22.0
No	95.7	164.7	0.4	7.6	7.2	0.9	4.1	8.9	3.2	0.9	22.0
Haircut											
Yes	43.5	204.1	0.7	15.9	11.8	1.4	5.8	9.5	4.4	0.9	40.7
No	56.5	134.7	0.3	4.2	4.9	0.7	3.2	9.4	2.8	0.9	13.7
Hair washing											
Yes	60.9	119.3	0.4	5.6	5.6	0.6	3.7	8.1	2.8	1.0	16.2
No	39.1	258.2	0.5	12.0	10.5	2.0	5.0	12.2	4.6	0.8	35.7
Deep conditioning											
Yes	4.4	64.4	0.3	3.6	4.3	0.1	3.2	10.0	0.9	2.1	11.1
No	95.7	168.3	0.4	7.8	7.3	1.0	4.2	9.4	3.6	0.9	22.7
Gloves worn on day of biospecimen collection											

Services Provided	%	MEP	MCPP	MECPP	MEHHP	MEHP	MEOHP	MnBP	MiBP	MBzP	Σ DEHP[a]
Yes	63.6	148.6	0.4	7.5	6.6	0.6	3.5	7.4	2.5	0.6	20.7
No	36.4	178.8	0.5	6.9	7.5	1.5	4.9	14.3	5.1	1.4	22.2

Abbreviations: 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; MBzP: Monobenzyl phthalate

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