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Prenatal PBDE exposures among African American women living in metropolitan Atlanta:

Exposure in home environment

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Master of Public Health

Environmental Health

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Bachelor of Science

Taipei Medical University

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Abstract

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Dust concentrations of polybrominated diphenyl ethers (PBDEs) collected in households with 34 pregnant African American women living in metropolitan Atlanta area during 20-24 gestational week were measured using gas chromatography mass spectrometry. Demographic and housing characteristic data were collected through home survey questionnaire during home visit. Dust samples were sieved twice to a particle size of less than 150 μm and analyzed for six congeners (PBDE-47, -85, -99, -100, -153, and -154). Among all commercial mixtures selected in this study, PBDE-47, -85, -99, and -154 were detected in all samples (100%), while PBDE-100 were detected in 28 samples (82.3%) and PBDE-153 were detected in 32 samples (94.1%). Among all selected PBDE congeners, PBDE-99 had the largest geometric mean (380.25) while PBDE-154 had the smallest geometric mean (24.20). In addition, we observed that PBDE-47, -99, and -100 have wider intervals among all 34 samples. Income level had a significant association with PBDE-85, while birth outcome shown significant association with PBDE-47, -85, -153, and -154. Also, there are associations between housing characteristics and PBDE exposure. To be more precise, there was association between type of household and PBDE-85, -153, and -154; identification of paint chips or dust from paint and PBDE-47, -100; using mops to clean floors and PBDE-47, -85, -99, and -154; using vacuums to clean floors and six of the selected PBDE congeners, shaking the rugs or mats and PBDE-47 and -100; and floor cleaning frequency and PBDE-85 and -153. Results indicate that PBDEs are still detectable in household after the usage prohibition since 2004 in the United States. Dust concentration of PBDES are associate with population and housing characteristics.

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Prenatal PBDE exposures among African-American women living in metropolitan Atlanta: Exposure in Home Environment

Background

Polybrominated diphenyl ethers (PBDEs) are flame-retardant chemicals that are commonly found in electronic enclosures, plastics, and foam for cushioning. They operate through the release bromine radicals that could reduce both the rate of combustion and dispersion of fire at high (ATSDR, 2017; Hooper & McDonald, 2000), thus providing an extension of time for people to escape from fire or even to extinguish it. In general, due to the high trapping efficiency and low decomposing temperature, organo-bromine compounds are the predominant flame retardant that commonly utilize in our daily life. Currently, the largest application for brominated-based compounds is in the production of brominated flame retardants, which accounted for 46% of total global consumption in 2013 according to Gulf Resources, Inc. Among all brominated flame retardants, PBDEs are additive flame retardants that blended with polymers and more likely to leach out of the products (O. Hutzinger, 1987). With 10 hydrogen atoms contained in diphenyl ether molecules and could be exchanged with bromine, there are 209 possible congeners that could be mainly produced at three different degrees of bromination, i.e., penta-BDE, octa-BDE, and deca-BDE, and further classified through their average bromine content (Ballschmiter & Zell, 1980). In the commercial penta-BDE [32534-81-9], 70% consists of 42% of tetra-BDEs (mainly PBDE-47), 45% penta-BDEs (PBDE-99 and PBDE-100), and 7% hexa-BDEs (PBDE-153 and PBDE-154) since continuing bromination of PBDE-47 would yield PBDE-99 and to a lesser extend PBDE-100 (Alaee, 2003).

The United States Environmental Protection Agency (EPA) has found that certain PBDE congeners are not only bio-accumulative but also toxic to human and the environment since PBDEs could be released into the air, water, and soil wherever they are produced or used. Because of the demonstration of high affinity for lipids, high hydrophobicity, and low degradative, lower molecular weight PBDE congeners are almost completely absorbed, slowly eliminated, highly accumulative in human breast milk, serum, and adipose tissue (Gouin, 2003). Although the United States no longer permits penta- and octa-BDE usage since 2004 (*Technical Fact Sheet Polybrominated Diphenyl Ethers (PBDEs) and Polybrominated Biphenyls (PBBs)*, 2014), their component congeners are still detectable in humans and the environment (EPA, 2010). Moreover, studies have found that PBDEs in U.S. house dust are at a higher level than those found in other countries because of greater use of PBDE containing products in households in the United States that other countries (Frederiksen, Vorkamp, Thomsen, & Knudsen, 2009; Rose et al., 2010; Sjodin et al., 2008).

Individuals, however, can be exposed to PBDEs from ingesting contaminated foods or dusts and soils, inhaling contaminated air, or having skin contact with contaminated products. Ingestion of house dust accounts for 80-90% of total PBDEs exposures of the general population in the United States (ATSDR, Polybrominated Diphenyl Ethers -ToxFAQs™, 2017). Residential house dust contains PBDEs that mixed with consumer products from which have the potential to bound with the environment when the conditions are ideal (ATSDR, 2017). Since measures of PBDEs in house dust indicated widespread regular contamination in homes (Jones-Otazo et al., 2005; Wilford, Harner, Zhu, Shoeib, & Jones, 2004), house dust could be seen as a reservoir of consumer commercial products, and therefore play an important role in human exposure to PBDEs.

Health effects.

PBDEs are used in plenty of consumer products and commonly enter human bodies through ingestion, inhalation, and skin contact (ATSDR, 2017). Studies had shown that prenatal PBDEs exposure is associated with different health effects, such as endocrine disruption, adverse birth outcomes, and adverse neurological development. A primary concern is that prenatal PBDEs exposure would affect children's neuro and brain system development. Potential mechanism have been proposed to explain cognitive deficits observed in animals after PBDE exposure during critical development periods due to the quantity change in cholinergic nicotinic receptors in the hippocampus (Viberg, 2003) and the induction of apoptotic cerebellar granule cell death. In addition, PBDEs can interfere thyroid hormone pathways that thus interfere normal brain development since PBDE congeners would alter thyroid function and thyroid hormones are essential for normal brain development, PBDE congener exposures could therefore indirectly alter thyroid-regulated brain development and further explain the neurodevelopmental effects after neonatal PBDE exposure(Porterfield, 2000). A meta-analysis shown strong evidence that prenatal PBDE exposure would damage children's intelligence since the study found sufficient evidence of toxicity based on diminished intelligence associated with increased exposure to PBDEs (Lam et al., 2017). Potential mechanism of PBDEs among cognitive function have been postulated to include induced neural apoptosis, decreased neuronal migration and altered neurotransmitter release and function (Dingemans, van den Berg, & Westerink, 2011).

Another study conducted in New York also indicated that PBDE exposure during both prenatal and postnatal periods might cause memory domains dysfunction in early stage of life development (Cowell et al., 2018). Although the mechanism of PBDEs exposure as endocrine disruptors still need further evaluation, there is a potential mechanism that PBDE induced reduction in serum T4 is displacement of T4 from the serum binding protein transthyretin (TTR) or thyroxine binding globulin (TBG), which shared the similarity with the mechanism that previously identified for polychlorinated biphenyls (PCBs) (Allen et al., 2016; Brouwer, 1993). In addition, a human study in California also found that prenatal exposure to PBDE congeners found in the penta-BDE flame retardant mixture was associated with later menarche in girls (Harley et al., 2017).

Significance in the Southeast as in an African American population.

Although numerous studies illustrated the elevated risk of several environmental exposure and adverse birth and developmental outcomes, exposure characterization among African American women in the U.S. southeast is still limited. The Southeast region is more likely to be distinct due to differences in climate, housing characteristics, population characteristics, traffic density, culture, and racial/ ethnic composition. There is also evidence provided that although the preterm birth rates decreased from 2007 to 2014, it rose for the second straight year in 2016 (Ferré C, 2016). In Georgia, 12.7 percent of babies are born early according to March of Dimes statistics. Although the number is improving in recent years, it is still below the national average. (March of Dimes, 2018 premature birth report card) The preterm birth rate among African American women (14%) was about 50 percent higher than white women (9%) in the United States. However, the preterm birth rate among African-American women is 46% higher than the rate among all other women according to the March of Dimes premature birth report in 2018. This research would provide fundamental information for prenatal PBDE exposure among pregnant African American living in the metropolitan Atlanta area for future studies since according to United States Census Bureau population estimation for year of 2018, 52.3% of the population living in Atlanta, Georgia is Black or African American.

Methods

Study participants.

Participants were pregnant African American women enrolled in a parental study that investigating the maternal microbiome and preterm birth and the women unique to the C-CHEM[2] study, a study that aim to assess the complicated interaction among prenatal and postnatal environment – toxicant exposures, the microbiome, and the metabolome – and their influence among neurodevelopment, birth outcome, and infant health. Pregnant women were recruited from Emory University Hospital Midtown and Grady Memorial Hospital which provide prenatal care up to 3000 women together annually. Women were eligible to participate if they were African American born in the United States, aged from 18 to 40; with singleton pregnancy; and without chronic medical problems or chronic medication use. The study procedures were approved by the Institutional Review Board at Emory University. Among 175 eligible participants, there were only 34 participants for whom we had sieved dust samples collected from a home visit during 20-24 gestation week that had more than 200 mg. The reason of missing PBDE measurement was due to the insufficient volume of house dust sample after sieving.

Home survey data collection.

Home visit were conducted during 20-24 gestation week to collect demographic data, home product use information, and environmental samples as well. The beginning of the pregnancy was determined by either calculate the first day of woman's last menstrual cycle or the corresponding age of the gestation as estimated by a more accurate method if available. Participants were asked about their marital status, education level, annual income, and their enrollment of health insurance. In addition to demographic information, interviewers also collected housing characteristic information through home environment questionnaires since the majority PBDE exposure was from household furniture and decorations.

Household characteristics.

Household characteristics were evaluated by home environment questionnaires to ascertain information about sources of residential chemical exposure. The questionnaire obtained the information about residential characteristics, including construction materials, age of the house, type of residence (e.g. single-family home, apartment, or mobile home) as well as neighborhood information (e.g. distance to the nearest industrial plant, dump or waste sites). In addition, we acquired information about the characteristic of the cleaning products and frequency.

Household vacuum dust collection.

Dust is the predominant PBDE exposure pathway for the general population of the United States (EPA, 2010; Lorber, 2008). Previous study had also suggested that in addition to dietary intake, house dust contributed most of the PBDE intake for both toddler and adult in China (Ni et al., 2013). PBDEs, those with higher molecular weight in particular, are not very volatile and tend to accumulate in dust. In addition, a previous study in Denmark concluded that since penta-mix PBDE congeners in dust were significantly correlated with those in air and placenta samples, indoor exposure could be seen as an important pathway for human PBDE exposure (Vorkamp, Thomsen, Frederiksen, Pedersen, & Knudsen, 2011). We therefore collected vacuumed dust sample in household to represent the PBDE exposure in home environment. Prior to the home visit, participants were instructed not to vacuum their floors so there would be enough dust volume for sample collection. Participants would identify the room in which they spent most of their time and the room was sampled by vacuuming rugs or floors using a 1 m^2 template to collect dust sample according to the standard operating procedures. Samples were then transported to the Laboratory for Exposure Assessment and Method Development in Environmental Research (LEADER) at Emory University's Rollins School of Public Health. Although the primary pathways for PBDE exposure among human are ingestion and dermal contact, we tend to collect particle size less than 150 μm, since particles with this size are more likely to adhere to skin and would results in dermal exposure and skin to mouth transfer followed by ingestion and not inhalable into lung. Therefore, house dust sample were sieved twice to a particle size of less than 150 μm by using screens to obtain the fine fraction. After sieving to the certain particle size, sieved sample would then be stored at room temperature in solvent-cleaned amber jar until analysis.

PBDE exposure.

Dust sample (50 mg) were extracted and analyzed similar to the procedure described in Hammel et al (2007) and an established GC-MS/MS instrument method. In brief, analysis began by introducing 125 μL PBDE solution with 7.5 ng/mL in MeOH and then add 25 mL dichloromethane (DCM). These extracts were capped and vortex using multi-vortexer at 2000 rpm for 2 min followed 5 minutes sonication and centrifugation for 2 minutes at 2000 rpm with a radius of 7.5 cm, which represents that the relative centrifugal force (RCF) relative to gravity (g) is 335 g. The dust was extracted with 1:1 dichloromethane/ hexane (v/v) via sonication extraction then evaporated by using TurboVap®. With Florisil® cartridges conditioned with 6 mL n-hexane, samples were poured and could therefore collected breakthrough. With 2.5 mL n-hex in each sample tube, they were capped and vortexed using multi-vortexer at 2000 rpm for 2 minutes, sonicated for 5 minutes, and the centrifuge for 2 minutes at 2000 rpm in single-rotor centrifuge. These extracts were purified using Florisil® cartridges, eluting the F1 fraction for PBDEs with 8 mL n-hexane and the F2 fraction for OPFRs with 10 mL ethyl acetate. The extractant was dried by using TurboVap® and reconstituted in 50 μL of nonane in glass inserts prior to instrumental analysis. The final extracts were analyzed on a gas chromatography/mass selective detection (GC/MSD) at the Laboratory for Exposure Assessment and Method Development in Environmental Research (LEADER) at Emory University's Rollins School of Public Health (Agilent Technologies; 5975 GC/MSD System). The mass spectrometer ion source and quadrupole temperatures were maintained at 250 °C during the program. The GC/MSD was operated using electron impact ionization and in SIM mode. Blanks and QC samples were included with each run. All dust samples were analyzed for six congeners: PBDE-47, -85, -99, -100, -153, and -154 using gas-chromatography/ mass selective detection (GC-MS/ MS) in house (Agilent Technologies; 5975 GC/MSD System). Two samples were injected in the pulsed splitless mode at 280 °C. For quantification, a solvent-based calibration curve was included. For BDE-47, -85, -99, -153, and -154, the concentrations were 0.1, 0.25, 0.5, 1.25, 2.5, 12.5, 35, and 37.5 ng (per gram dust). We would report the amount of material collected per square meter in ng/g, referred to as dust loading for each dust sample. The result will be described with the demographic information by using various statistical methods with PBDE concentration data on prenatal exposure. Methods accuracy was within 100 +/- 20%. Method precision was less than 15%, as determined by relative standard deviation. The LODs derived from the standard calibration curves are expressed in ng/gram for dust samples in Table 1. PBDE concentrations were blank subtracted and duplicates were averaged.

Quality control.

In each analytical run, a laboratory background sample, a solvent-based (methanol) calibration curve and two quality control (QC) samples (with CEEP dust and National Institute of Standard and Technology Standard Reference Material 2585 (NIST SRM 2585) dust sample, which contained certified concentrations for six selected PBDEs congeners analyzed for this study) were prepared and analyzed concurrently with unknown samples.

Statistical analysis.

Statistical analyses were conducted using SAS statistical software (version 9.4; SAS Institute Inc., Cary, NC). Analyses were performed for analytes detected in more than 80% of samples. The LODs were derived from the standard calibration curves and expressed in ng/g for dust sample in Table 3. Based on the distribution of the congeners measured in this study and previous studies, we calculated the geometric means and illustrated the PBDE congener distributions with quantiles. In preliminary analyses, Spearman correlation coefficient were performed to assess the correlation between selected PBDE congeners. In addition, t-test and one-way ANOVA test were also conducted to determine the association between identified PBDE exposures and demographic and household characteristics. Through all analyses, the statistical results were determined at a level of α=0.05 for statistical significance.

Results

Characteristics of the study population and households.

Overall, a total of 34 dust samples were eligible for this study were collected from pregnant women who reside in metropolitan Atlanta area during their pregnancy. Participants with insufficient amount of dust samples collected in home visits were excluded. Characteristics of the study population are shown in Table 1 with numbers and percentages.

In brief, among these eligible participants, their mean age was 26 years (range, 19-35). 85% of the participants reported their marital status as single, 32.4% of the participants reported they were not in a relationship and 38.2% reported that they were in a relationship and lived together with their partner. As for education level, the majority of the participants were graduated high school of general educational development (47.1%) while there were around 20% of the participants possessed with a college or higher degree. There majority (38.2%) of participants had their annual income lower than the U.S. poverty line, however, there were still 14.7% of participants who had their annual income higher than 400% of the U.S. poverty line. All participants possessed with insurance during pregnancy, 82.4% were from Medicaid and 17.6% were from private insurance through employer. 32.4% of the participants were recruited from Emory University Hospital Midtown and 67.6% of them were recruited from Grady Memorial Hospital. Among 34 participants, 55.8% were full-term birth, while there were still 38.2% were pre-term or early-term birth (Table 1).

From household characteristic information collected through home survey questionnaires during home visits, there were 30% of the population living in a house which had been built for more than 20 years. Majority (38.2%) of the participants were living in a brick or concrete built single-family home while 26.5% of them were living in an apartment with more than one room. Half of the population were living more than 400 meters away from industrial plant, dump or waste sites. 57.6% of the participants reported that they had noticed paint chips or dust from paint in their home. Most of the families were using mops (91.2) and brooms (94.1) to clean the floors, while 79.4% of the participants reported that they clean the floors a few times a week, daily or more often (Table 2).

PBDE detection and concentration in dust samples.

Table 3 showed distribution of PBDE concentrations collected in house dust by congeners: PBDE-47, PBDE-85, PBDE-99, PBDE-100, PBDE-153, and PBDE-154 measured at 34 metropolitan Atlanta households in ng/g dust. Among all commercial mixtures selected in this study, PBDE-47, PBDE-85, PBDE-99, and PBDE-154 were detected in all samples (100%), while PBDE-100 were detected in 28 samples (82.3%) and PBDE-153 were detected in 32 samples (94.1%). Among all selected PBDE congeners, PBDE-99 had the largest geometric mean (380.25) while PBDE-154 had the smallest geometric mean (24.20). In addition, we observed that PBDE-47, PBDE-99. PBDE-100 have wider intervals among all 34 samples. Figure 1 shows the correlation between PBDE congener concentrations and indicates that the selected PBDE congeners were highly correlated through the result from Spearman correlation coefficient (with all Spearman r >= 0.95) (Table 4).

Associations with PBDE exposures.

In this study, we aimed to investigate the association between population and housing characteristics and PBDE exposures. Based on t-test and one-way ANOVA test, we could conclude that marital status, education levels, insurance type were not associated with PBDE exposures among PBDE congeners selected in this study. However, income level had a significant association with PBDE-85. In addition, birth outcome shown significant association with PBDE-47, PBDE-85, PBDE-153, and PBDE-154 (Table 5).

In addition to the association between characteristics of study population and PBDE exposure at household level, we also investigate the association between housing characteristics and PBDE exposures. According to the results obtained from t-test and one-way ANOVA, we could conclude that age of household, the distance from industrial plant, dump or waste sites, age of couch or sofa were not associated with PBDE exposure. However, there was association between type of household and PBDE-85, PBDE-153, PBDE-154; identification of paint chips or dust from paint and PBDE-47 and PBDE-100; using mops to clean floors and PBDE-47, PBDE-85, PBDE-99, and PBDE-154; using vacuums to clean floors and six of the selected PBDE congeners, shaking the rugs or mats and PBDE-47 and PBDE100; and floor cleaning frequency and PBDE-85 and PBDE-153. The relationship between housing characteristics and PBDE congeners would be illustrated in the following paragraphs.

Discussion

In this study, we aimed to investigate the prenatal environmental PBDE exposures among pregnant African-American women who live in metropolitan Atlanta area, which is a particular population that assumed to be more likely to give preterm birth than other populations in the United States, to evaluate PBDE body burden and identify potential residential resources of environmental PBDE exposures. In this study population, we observed that preterm birth rate is much higher than the preterm birth rate among overall U.S. population (10%). In this study population, we observed higher PBDE-85 concentration level among pregnant African-American women living in a specific type of household. In addition, we also observed that PBDE-47, PBDE-85, PBDE153, and PBDE-154 congeners' concentrations shown associations with birth outcome, in this case, preterm- or early-term birth. In addition to the observation of association with population demographic characteristics, we also see the appearance of association with housing characteristics: PBDE-85, PBDE-153, and PBDE-154 shown association with type of households; PBDE-47 and PBDE-100 shown association with identification of paint chips or dust from paint, PBDE-47, PBDE-85, PBDE-99, and PBDE-154 shown association with cleaning floors by mops; all selected PBDE congeners shown association with cleaning floors by vacuums; PBDE-47 and PBDE-100 shown relationship with cleaning floors by shaking rugs or mats; and PBDE-85 and PBDE-153 shown to be related to floor cleaning frequencies. Result of our dust samples suggested correlations between each of the selected PBDE congeners. From the results, we still expected to see the appearance of penta-BDE in households since penta-BDE was commonly applied to foam reduce flammability and also adhered to rigorous flammability standards for decades. However, with increasing public awareness of its toxicity and bioaccumulation among human bodies, the use of penta-BDE is now expected to be decreased.

Dust samples were usually dominated by either penta- or deca-BDE with smaller amount of octa congeners (Allen et al., 2008). A previous study characterized the resources of PBDE exposure in residential dust indicated that furniture condition urban density, resident ethnicity, household income were potential determinants of PBDE concentrations in dust (Whitehead et al., 2013). While public awareness of flame retardants usage is now increasing worldwide, there are still countries lack of regulatory control over PBDE applications. Thailand, for example, a study found that without a strong regulatory control over PBDE applications, PBDEs were observed commonly in domestic dust samples, and the congener pattern for residential dust were predominated by PBDE-48 and PBDE-99 (Muenhor & Harrad, 2018). One previous study conducted in Netherland investigated the association between PBDE levels in dust and interior residential patterns suggested that less frequent vacuum cleaning and dusting were associated with higher concentration of flame retardants in dust (Sugeng, de Cock, Leonards, & van de Bor, 2018). A PBDE exposure study investigating association between diet and indoor environment also mentioned newer homes tend to have lower air exchange rates than older households, which could therefore increase concentrations of indoor air pollutants(Rose et al., 2010). A previous study collected samples from a cohort in North Carolina found that the presence of specific flame retardant in sofa in household was associated with an increase in the concentration of that flame retardant in house dust sample (Hammel et al., 2017).

Comparing exposure risk factors from previous studies, we expected to see higher PBDE concentration among pre-term and early-term birth participants. In addition, we also anticipated to observe association between PBDE exposure and housing characteristics. Our findings suggest that dust sample collected from home through vacuum during home visit provide PBDE result similar with previous studies. Concentrations of PBDE-47 and PBDE-99 had significantly higher maximum concentration among all selected PBDE congeners while all selected PBDE congeners were correlated.

A strength of our study is due to the limitation of house dust PBDE concentration in Southeastern region among the United States. We collected house dust samples by vacuuming rugs or floors with standard operating procedures that could help reduce operation error. However, the limitation of our study is that we only able to focus on a smaller number of homes from the entire cohort study since most of the dust samples did not have enough amount for further laboratory analysis after sieving to a particular particle size. Nevertheless, our findings still have applications for PBDE exposure assessment in the indoor environment in Southeast region among the United States with a certain population.

Conclusions

Housing characteristic appear to contribute environment PBDE exposure due to the flame retardants usage in furniture and household decorations to increase inflammability by regulations. In spite of limitations with this study, this study could be seen as an initial step of PBDE congeners' distribution in dust samples measured at household environment in Southeast United States that evaluate pregnant African-American women's body burden in relation to PBDE exposure through house dust samples. With increasing public awareness among flame retardant usage and their potential health effect, further work should also investigate the interaction of PBDEs with other chemicals that could easily found in home environment.

Reference

Alaee, M. (2003). An overview of commercially used brominated flame retardants, their applications, their use patterns in different countries/regions and possible modes of release. *Environment International, 29*(6), 683-689. doi:10.1016/s0160-4120(03)00121-1

Allen, J. G., Gale, S., Zoeller, R. T., Spengler, J. D., Birnbaum, L., & McNeely, E. (2016). PBDE flame retardants, thyroid disease, and menopausal status in U.S. women. *Environ Health, 15*(1), 60. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/27215290. doi:10.1186/s12940-016-0141-0

ATSDR. (2017). *Toxicological profile for Polybrominated Diphenyl Ether*. Retrieved from Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service: https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=901&tid=183

Ballschmiter, K., & Zell, M. (1980). Analysis of polychlorinated biphenyls (PCB) by glass capillary gas chromatography. *Fresenius' Zeitschrift für analytische Chemie, 302*(1), 20-31. doi:10.1007/bf00469758

Brouwer, M. C. L. E. K. W. M. W. E. M. S. S. A. (1993). Structure-dependent, competitive interaction of hydroxy-polychlorobiphenyls, -dibenzo-p-dioxins and -dibenzofurans with human transthyretin. *Chemico-Biological Interactions, 88*. doi:10.1016/0009-2797(93)90081-9

Cowell, W. J., Margolis, A., Rauh, V. A., Sjodin, A., Jones, R., Wang, Y., . . . Herbstman, J. B. (2018). Associations between prenatal and childhood PBDE exposure and early adolescent visual, verbal and working memory. *Environ Int, 118*, 9-16. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/29787900. doi:10.1016/j.envint.2018.05.004

Dingemans, M. M., van den Berg, M., & Westerink, R. H. (2011). Neurotoxicity of brominated flame retardants: (in)direct effects of parent and hydroxylated polybrominated diphenyl ethers on the (developing) nervous system. *Environ Health Perspect, 119*(7), 900-907. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/21245014. doi:10.1289/ehp.1003035

EPA. (2010). *An exposure assessment of polybrominated diphenyl ethers*. Retrieved from https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=210404

Ferré C, C. W., Olson C, Sharma A, Barfield W. (2016). *Effects of Maternal Age and Age-Specific Preterm Birth Rates on Overall Preterm Birth Rates — United States, 2007 and 2014*. Retrieved from

Frederiksen, M., Vorkamp, K., Thomsen, M., & Knudsen, L. E. (2009). Human internal and external exposure to PBDEs--a review of levels and sources. *Int J Hyg Environ Health, 212*(2), 109-134. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/18554980. doi:10.1016/j.ijheh.2008.04.005

Gouin, T. (2003). Modelling the environmental fate of the polybrominated diphenyl ethers. *Environment International, 29*(6), 717-724. doi:10.1016/s0160-4120(03)00116-8

Hammel, S. C., Hoffman, K., Lorenzo, A. M., Chen, A., Phillips, A. L., Butt, C. M., . . . Stapleton, H. M. (2017). Associations between flame retardant applications in furniture foam, house dust levels, and residents' serum levels. *Environ Int, 107*, 181-

189. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/28750223. doi:10.1016/j.envint.2017.07.015

Harley, K. G., Rauch, S. A., Chevrier, J., Kogut, K., Parra, K. L., Trujillo, C., . . . Eskenazi, B. (2017). Association of prenatal and childhood PBDE exposure with timing of puberty in boys and girls. *Environ Int, 100*, 132-138. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/28089583. doi:10.1016/j.envint.2017.01.003

Hooper, K., & McDonald, T. A. (2000). The PBDEs: an emerging environmental challenge and another reason for breast-milk monitoring programs. *Environmental Health Perspectives, 108*(5), 387-392. Retrieved from https://doi.org/10.1289/ehp.00108387. doi:10.1289/ehp.00108387

Jones-Otazo, H. A., Clarke, J. P., Diamond, M. L., Archbold, J. A., Ferguson, G., Harner, T., . . . Wilford, B. (2005). Is House Dust the Missing Exposure Pathway for PBDEs? An Analysis of the Urban Fate and Human Exposure to PBDEs. *Environmental Science & Technology, 39*(14), 5121-5130. Retrieved from https://doi.org/10.1021/es048267b. doi:10.1021/es048267b

Lam, J., Lanphear, B. P., Bellinger, D., Axelrad, D. A., McPartland, J., Sutton, P., . . . Woodruff, T. J. (2017). Developmental PBDE Exposure and IQ/ADHD in Childhood: A Systematic Review and Meta-analysis. *Environ Health Perspect, 125*(8), 086001. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/28799918. doi:10.1289/EHP1632

Lorber, M. (2008). Exposure of Americans to polybrominated diphenyl ethers. *J Expo Sci Environ Epidemiol, 18*(1), 2-19. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/17426733. doi:10.1038/sj.jes.7500572

Muenhor, D., & Harrad, S. (2018). Polybrominated diphenyl ethers (PBDEs) in car and house dust from Thailand: Implication for human exposure. *J Environ Sci Health A Tox Hazard Subst Environ Eng, 53*(7), 629-642. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/29432049. doi:10.1080/10934529.2018.1429725

Ni, K., Lu, Y., Wang, T., Kannan, K., Gosens, J., Xu, L., . . . Liu, S. (2013). A review of human exposure to polybrominated diphenyl ethers (PBDEs) in China. *Int J Hyg Environ Health, 216*(6), 607-623. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/23491027. doi:10.1016/j.ijheh.2013.02.002

O. Hutzinger, H. T. (1987). Polybromninated dibenzo-p-dioxins and dibenzofurans: the flame retardant issue. *Chemosphere, 16*(8-9). doi:https://doi.org/10.1016/0045-6535(87)90181-0

Porterfield, S. P. (2000). Thyroidal dysfunction and environmental chemicals—potential impact on brain development. *Environmental Health Perspectives, 108*. doi:doi: 10.1289/ehp.00108s3433

Rose, M., Bennett, D. H., Bergman, Å., Fängström, B., Pessah, I. N., & Hertz-Picciotto, I. (2010). PBDEs in 2−5 Year-Old Children from California and Associations with

Diet and Indoor Environment. *Environmental Science & Technology, 44*(7), 2648-2653. Retrieved from https://doi.org/10.1021/es903240g. doi:10.1021/es903240g

Sjodin, A., Papke, O., McGahee, E., Focant, J. F., Jones, R. S., Pless-Mulloli, T., . . . Patterson, D. G., Jr. (2008). Concentration of polybrominated diphenyl ethers (PBDEs) in household dust from various countries. *Chemosphere, 73*(1 Suppl), S131-136. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/18501952. doi:10.1016/j.chemosphere.2007.08.075

Sugeng, E. J., de Cock, M., Leonards, P. E. G., & van de Bor, M. (2018). Electronics, interior decoration and cleaning patterns affect flame retardant levels in the dust from Dutch residences. *Sci Total Environ, 645*, 1144-1152. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/30248839. doi:10.1016/j.scitotenv.2018.07.127

Technical Fact Sheet Polybrominated Diphenyl Ethers (PBDEs) and Polybrominated Biphenyls (PBBs). (2014). Retrieved from https://www.epa.gov/sites/production/files/2014-03/documents/ffrrofactsheet_contaminant_perchlorate_january2014_final_0.pdf

Viberg, H. (2003). Neonatal exposure to polybrominated diphenyl ether (PBDE 153) disrupts spontaneous behaviour, impairs learning and memory, and decreases hippocampal cholinergic receptors in adult mice. *Toxicology and Applied Pharmacology, 192*(2), 95-106. doi:10.1016/s0041-008x(03)00217-5

Vorkamp, K., Thomsen, M., Frederiksen, M., Pedersen, M., & Knudsen, L. E. (2011). Polybrominated diphenyl ethers (PBDEs) in the indoor environment and associations with prenatal exposure. *Environ Int, 37*(1), 1-10. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20609475. doi:10.1016/j.envint.2010.06.001

Whitehead, T. P., Brown, F. R., Metayer, C., Park, J. S., Does, M., Petreas, M. X., . . . Rappaport, S. M. (2013). Polybrominated diphenyl ethers in residential dust: sources of variability. *Environ Int, 57-58*, 11-24. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/23628589. doi:10.1016/j.envint.2013.03.003

Wilford, B. H., Harner, T., Zhu, J., Shoeib, M., & Jones, K. C. (2004). Passive Sampling Survey of Polybrominated Diphenyl Ether Flame Retardants in Indoor and Outdoor Air in Ottawa, Canada: Implications for Sources and Exposure. *Environmental Science & Technology, 38*(20), 5312-5318. Retrieved from https://doi.org/10.1021/es049260x. doi:10.1021/es049260x

Tables and figures

Table 1. Characteristic of the study population (N=34), Atlanta, GA.

	Measurement	Number (%)
Age	Mean	25.62
	Minimum	19
	Maximum	35
Marital Status	Single	29 (85.3)
	Married	5 (14.7)
Relational Status	Not in a Relationship	11 (32.4)
	In a Relationship, Not Living together	9 (26.4)
	In a Relationship, Living together	13 (38.2)
	Missing	1 (2.9)
Education	8th Grade or Less	0 (0)
	Some High School	4 (11.8)
	Graduated High School of GED	16 (47.1)
	Some College or Technical School	7 (20.6)
	Graduated College	5 (14.70)
	Some Graduate Work or Degree	2 (5.9)
Income	<100%	13 (38.2)
	100-132%	0 (0)
	133-149%	4 (11.4)
	150-199%	4 (11.4)
	200-299%	1 (2.9)
	300-399%	1 (2.9)
	400% or Greater	5 (14.7)
	Missing	6 (17.6)
Hospital	Emory	11 (32.4)
	Grady	23 (67.6)
Insurance	Medicaid	28 (82.4)
	Private through Work, etc.	6 (17.6)
	Private through Federal Marketplace	0 (0)
Birth Outcome	Full-term	19 (55.9)
	Early-term	8 (23.5)
	Preterm	5 (14.7)
	Missing	2 (5.9)

Table 2. Characteristics of households (N=34), Atlanta, GA

	Measurement	Number (%)
Age of household	Less than 5 years	2 (5.9)
	5-10 years	7 (20.6)
	10-20 years	9 (26.47)
	More than 20 years	10 (29.41)
	Missing	6 (17.7)
Type of household	Brick or concrete single-family home	13 (38.2)
	Wood or siding single-family home	3 (8.8)
	Brick or concrete multifamily home	1 (2.9)
	Apartment with single room	4 (11.8)
	Apartment with more than one room	9 (26.5)
	Mobile home	0 (0)
	Other	4 (11.8)
Distance from industrial plant, dump or waste site	Less than 15m (50 ft)	0 (0)
	15-60m (50-200ft)	1 (3.57)
	60-400m (200ft to 0.25 mile)	2 (7.1)
	400m or more	14 (50.0)
	Missing	11 (39.3)
Paint chips or dust from paint	Yes	14 (42.4)
	No	19 (57.6)
Age of couch or sofa	Less than 5 years	15 (51.7)
	More or equal to 5 years	14 (48.3)
	Missing	1
Cleaning type	Mops	31 (91.2)
	Brooms	32 (94.1)
	Vacuums	27 (79.4)
	Shake out rug/ mat	14 (41.2)
Floors cleaning frequency	Daily or more often	14 (41.2)
	A few times a week	13 (38.2)
	Once every couple of weeks	6 (17.7)
	Once in a month or less	1 (2.9)

Table 3. Distribution of PBDE Congener Concentrations by Volume (ng/g) in Samples of 34 African-American Women Recruited from Emory University Hospital Midtown and Grady Memorial Hospital

Congener	LOD ng/g dust	Mean (GM) ng/g	Min ng/g	25th percentile ng/g	Median ng/g	75th ng/g	Max ng/g
PBDE47	0.05	252.38	18.26	91.73	219.53	686.92	6741.10
PBDE85	1.25	24.44	3.46	8.72	20.75	46.21	519.49
PBDE99	0.25	380.25	34.82	117.83	346.70	654.86	8166.61
PBDE100	0.125	64.46	6.84	21.98	51.87	175.66	1720.28
PBDE153	1.25	44.53	5.92	14.08	35.80	114.73	888.12
PBDE154	1.25	24.20	3.78	11.55	28.47	72.45	801.34

Table 4. Spearman correlation coefficient between PBDE congeners.

PBDE Congeners	PBDE-47	PBDE-85	PBDE-99	PBDE-100	PBDE-153	PBDE-154
PBDE-47	-	0.9725	0.9652	0.9841	0.9487	0.9426
PBDE-85	0.9725	-	0.9856	0.9803	0.9732	0.9856
PBDE-99	0.9652	0.9856	-	0.9869	0.9839	0.9860
PBDE-100	0.9841	0.9803	0.9869	-	0.9720	0.9710
PBDE-153	0.9487	0.9732	0.9839	0.9720	-	0.9820
PBDE-154	0.9426	09856	0.9859	0.9710	0.9820	-

Table 5. Association between PBDE congeners and population characteristics (p-value[a])

Population Characteristics	PBDE47	PBDE85	PBDE99	PBDE100	PBDE153	PBDE154
Marital Status	0.89	0.62	0.98	0.95	0.62	0.99
Education	0.84	0.87	0.88	0.91	0.90	0.89
Income	0.52	0.03	0.24	0.31	0.13	0.26
Insurance	0.59	0.11	0.79	0.96	0.24	0.80
Birth Outcome	0.04	0.04	0.62	0.40	0.03	0.05

Abbreviation:
[a] t test, and one-way ANOVA.

Table 6. Association between PBDE congeners and housing characteristics (p-value[a])

Housing Characteristics	PBDE47	PBDE85	PBDE99	PBDE100	PBDE153	PBDE154
Age of household	0.89	0.62	0.98	0.95	0.62	0.99
Type of household	0.62	0.02	0.16	0.27	0.0005	0.05
Distance from industrial plant, dump or waste site	0.54	0.40	0.42	0.41	0.34	0.36
Paint chips or dust from paint	0.03	0.32	0.66	0.0002	0.66	0.95
Age of couch or sofa	0.08	0.47	0.94	0.09	0.44	0.67
Cleaning type						
Mops	0.10	0.02	0.02	0.16	0.25	0.03
Brooms	0.58	0.32	0.28	-	0.30	0.30
Vacuums	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Shake the rugs/ mats	0.04	0.46	0.80	0.00031	0.91	0.79
Floors cleaning frequency	0.20	0.01	0.11	0.14	0.04	0.12

Abbreviations:

[a] t test, and one-way ANOVA.

Figure 1. PBDE exposure pathway within household.

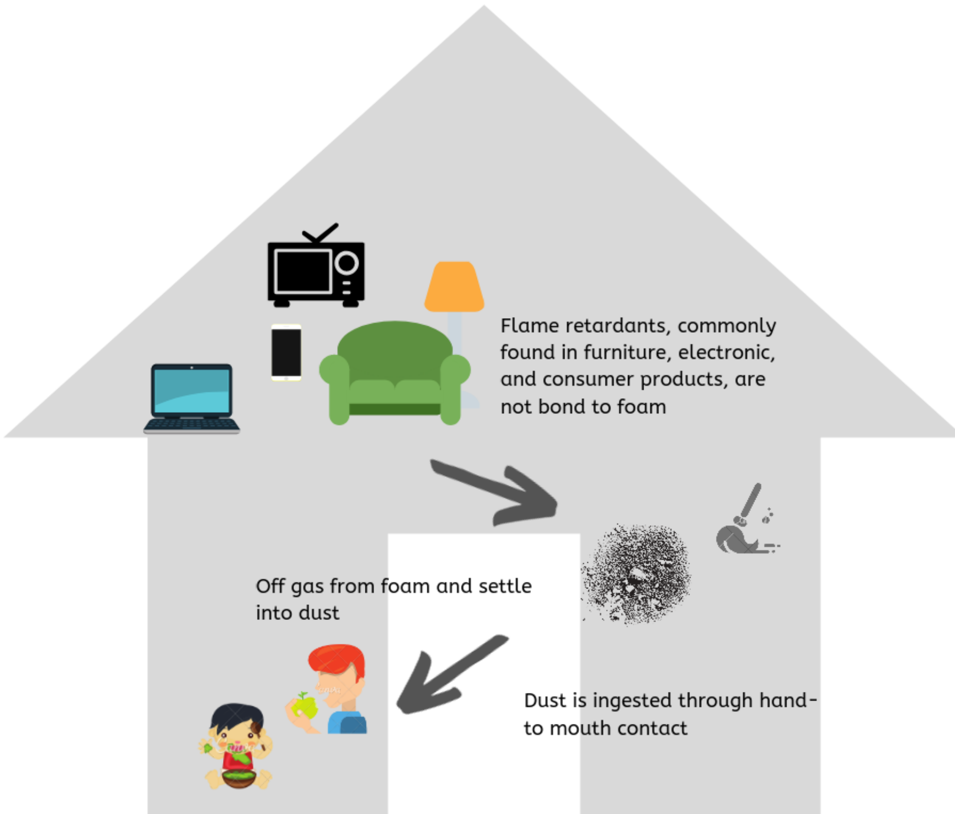

Figure 2. Correlation between six selected PBDE congeners: PBDE-47, PBDE-85, PBDE-99, PBDE-100, PBDE-153, and PBDE-154 (Spearman Correlation Coefficient).