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A pilot study on semivolatile organic compounds in senior care facilities: Implications for older adult exposures☆

Karen Arnold [a], João Paulo Teixeira [b, c], Ana Mendes [b, c], Joana Madureira [b, c], Solange Costa [b, c], Amina Salamova [a, *]

[a] School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405, United States
[b] National Health Institute Dr. Ricardo Jorge, Porto, Portugal
[c] EPIUnit – Instituto de Saúde Pública, Universidade do Porto, Porto, Portugal

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ABSTRACT

The occurrence of five groups of semivolatile organic compounds (SVOCs) (total of ~120 distinct chemicals) was investigated in senior care facilities in the United States and in Portugal. Indoor settled dust samples were collected from fourteen facilities, and the concentrations of organophosphate esters (OPEs), brominated flame retardants (BFRs), polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides (OCPs), and polychlorinated biphenyls (PCBs) were measured in these samples. Overall, OPEs, PAHs, and BFRs were the most abundant, and OCPs and PCBs were the least abundant SVOC groups in dust collected from both U.S. and Portuguese facilities. ∑OPE, ∑PAH, and ∑BFR concentrations were significantly higher in U.S. facilities than those in Portuguese facilities ($P < 0.001$), while ∑OCP and ∑PCB concentrations were not different between the two countries ($P < 0.05$). The samples were collected from three different microenvironments, including bedrooms, living rooms, and corridors. ∑OPE, ∑PAH, and ∑BFR concentrations were up to five times higher in corridors compared to bedrooms and living rooms. ∑OCP and ∑PCB concentrations were overall higher in bedrooms and in living rooms and lower in corridors.

1. Introduction

Older adults are particularly susceptible to environmental exposures due to deterioration of their physiological systems (Geller and Zenick, 2005; Bentayeb et al., 2013; Hong, 2013). Indoor chemical exposures are of special concern for older adults residing in senior care (assisted living and long-term care) facilities, because they spend around 95% of their time indoors and are exposed to indoor contaminants for long periods of time on a daily basis (Almeida-Silva et al., 2014). Although limited, evidence from prior studies suggests that there are significant associations between exposure to indoor air pollutants in senior care facilities and adverse health outcomes among their residents (Almeida-Silva et al., 2015; Bentayeb et al., 2015; Maio et al., 2015; Mendes et al., 2015, 2016). Studies on older adults living in senior care facilities have demonstrated that older adults are at the risk of respiratory health impairment, even at moderate levels of air pollutants, particularly if they are over 80 years old and live in poorly ventilated facilities (Maio et al., 2015). However, these prior assessments of indoor exposures in senior care facilities have focused on common indoor pollutants, such as particulate matter, ozone, nitrogen dioxide, and volatile organic compounds, and have not addressed exposures to a large group of ubiquitous indoor contaminants, semivolatile organic compounds (SVOCs), including flame retardants, plasticizers, and pesticides.

Occurrence and fate of indoor SVOCs are emerging research topics, as SVOCs have not been as widely studied as other classes of indoor contaminants, such as airborne particles and inorganic gaseous pollutants, due to analytical challenges in measuring SVOCs (Weschler and Nazaroff, 2008). Nonetheless, many SVOCs are contaminants of global concern due to their persistence in the environment, bioaccumulation in biota and humans, and significant negative effects on human and ecosystem health. Indoor environments have been shown to be a major source of human exposure to SVOCs because these chemicals are used in many

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* Corresponding author. 702 N Walnut Grove Avenue, Bloomington, IN 47405, United States.
E-mail address: asalamov@indiana.edu (A. Salamova).

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household applications (Harrad, 2010). These applications include construction materials, floor coverings, furniture, electronics, cleaning products, personal care products, and pesticides, among others. For example, organophosphate esters (OPEs) are commonly used as flame retardants and plasticizers in foam, floor polishes, furniture, paints, electronics and building materials (van der Veen and de Boer, 2012). Similarly, brominated flame retardants (BFRs) are also added to a variety of flammable materials to slow down ignition and reduce flammability. Both OPEs and BFRs are additive components and not physically bound to the materials in which they are used; thus they can be released into the surrounding environment (Wu et al., 2016). Some other SVOCs, such as polycyclic aromatic hydrocarbons (PAHs), originate from incomplete combustion processes, such as heating with fossil fuels or cooking (Oliveira et al., 2017). Several SVOC groups, including polychlorinated biphenyls (PCBs), some organochlorine pesticides (OCPs) and polybrominated diphenyls (PBDEs), were produced globally in large volumes for decades, but were banned due to their toxicity. PCBs were produced as components of electrical, heat transfer, and hydraulic equipment from 1930s to 1970s, when their production and use were banned (Breivik et al., 2004). DDT (*p,p′*-1,1,1-trichloro-2,2-*bis*(*p*-chlorophenyl)ethane) was an important insecticide extensively used in agricultural crops and to control insect-borne diseases from 1945 to 1973, when its production and use were banned in the U.S. At the same time that DDT and PCBs were being phased out, PBDEs began to be used as flame retardants in plastic and foam in consumer products such as electronics and furniture (Whitehead et al., 2015). All three PBDE commercial mixtures – Penta-BDE, Octa-BDE, and Deca-BDE – were globally banned during 2004–2013. However, due to ongoing fire safety regulations, Penta- and Octa-BDE products were replaced with other flame retardants such as 2-ethylhexyl tetrabromobenzoate (EHTBB) and *bis*(2-ethylhexyl) tetrabromophthalate (BEHTBP) that are the main components of the Firemaster®550 and Firemaster® BZ-54 mixtures, and Deca-BDE product was replaced with decabromodiphenyl ethane (DBDPE) (Stapleton et al., 2009). While some of the phased-out SVOCs, such as PCBs and PBDEs, have been studied more extensively in the indoor environment, limited research has been done on indoor exposure to their replacements (Mitro et al., 2016).

Once SVOCs are introduced to an indoor environment, they can partition to indoor air, dust, and surfaces, persist for years, bioaccumulate in indoor residents and have significant impacts on their health. It has been shown that indoor SVOC levels are higher than their outdoor levels, reflecting their extensive use in household applications (Harrad, 2010). Many SVOCs, such as organic flame retardants, phthalates, phenols, and fragrances, have been detected in various indoor environments, including residential houses, offices, childcare centers, and stores (Mitro et al., 2016). Senior care facilities may potentially have elevated exposure levels to many SVOCs due to their intense cleaning, pest control, and fire safety protocols (Makris et al., 2000). Health effects of SVOC exposure are of particular concern for older adults, as this exposure has been associated with cardiovascular and metabolic disorders in elderly cohorts (Lee et al., 2011, 2012; Bae et al., 2012; Lind et al., 2014). Despite these risks, very few studies targeted indoor exposures in senior care facilities and the health effects of these exposures on facilities' residents (Bentayeb et al., 2015; Maio et al., 2015; Mendes et al., 2016), and none of these studies focused on exposure to SVOCs.

The main goal of this pilot study was to assess the levels of SVOCs in dust collected from senior care facilities in the U.S. and in Portugal. Five SVOC groups (~120 distinct compounds), including OPEs, BFRs (including PBDEs), PAHs, OCPs, and PCBs, were measured in settled dust collected from various microenvironments (bedrooms, living rooms, and corridors) in fourteen senior care facilities in the U.S. and in Portugal. This is the first study reporting SVOCs in senior care facilities and presenting important information on indoor SVOC exposures in a vulnerable population of older adults.

2. Materials and methods

2.1. Sample collection

Settled floor dust samples were collected in eleven senior care facilities in Porto, Portugal (n = 28) during the spring of 2013 and in three facilities in Indiana, U.S. (n = 14) during the summer of 2015. Indiana facilities were located in rural areas and privately operated. Porto facilities were located within the Porto urban area. Portugal has an established network of public and private senior care facilities within the 'Portuguese Social Charter' (GEP/MSESS, 2007–2012) involved in environmental exposure and health research (Mendes et al., 2015; Teixeira et al., 2015). This made it easier to collect a larger number of samples in the facilities throughout Porto. In the U.S., our pilot study was the first to recruit and work with senior care facilities with the purpose of investigating environmental exposure. Because of this, recruitment of facilities was slow and yielded a lower number of samples collected in the U.S.

In both countries, the samples were collected in the main living areas, such as living rooms, bedrooms, and corridors. Each sample represented a one-time dust collection. All facilities were cleaned according to their regular schedule on a daily basis. A portable vacuum cleaner, requiring a dedicated electrical outlet, was used to collect the dust. The wand and the attachment were rinsed with isopropyl alcohol and allowed to dry before a pre-cleaned nylon sock was inserted into the wand and held in place by the attachment before each sample collection. The sampling area was vacuumed twice to ensure collecting as much dust as possible. After the area was vacuumed, the nylon sock was removed, and the end of the sock was twisted and folded down to keep the dust in the sock. The sock was then wrapped in aluminum foil and sealed before placing it in a polyethylene Ziploc bag for storage. The samples were stored at −25 °C until laboratory analyses. This sampling protocol was used for collecting dust samples in both Portugal and in the U.S.

2.2. Sample analyses

Samples were removed from the freezer and allowed to reach room temperature before the sieving process. The dust from the nylon sock was emptied and then sieved using a 500 μm sieve (Newark USA Standard Test Sieve) to remove the coarse particles. Approximately 0.1 g of dust was placed in glass centrifuge tubes then spiked with surrogate recovery standards for OPEs (d_{12}-*tris*(2-chloroethyl) phosphate [TCEP] and $^{13}C_{18}$-triphenyl phosphate [TPHP]), PAHs (d_{10}-phenanthrene and d_{10}-pyrene), BFRs (BDE-77, -166, and $^{13}C_{12}$-209), OCPs (δ- and ε-hexachlorocyclohexane [HCH], and dibutyl chlorendate [DBC]), and PCBs (PCB-14, -65, and -166). Five mL of 1:1 (v:v) acetone and hexane mixture was added to the samples and vortexed for 1–2 min, sonicated (Branson 5510) for 30 min, and then centrifuged (Beckman CS-6R) for 5 min at 3200 RPM. The top organic layer of the mixture was separated and placed in a clean centrifuge tube. The extraction was repeated twice, and all three organic layers were combined together. The resulting extract was then concentrated via rotary evaporation, the solvent was exchanged to hexane, and the extract was further concentrated to ~2 mL for fractionation. The extract was fractionated using 4 g of 3.5% (w:w) water (HPLC Grade) deactivated silica gel packed in