Children's Exposure to the Flame Retardant TDCPP in Indoor Environments: A Risk Assessment

by

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Abstract

Tris(1,3-dichloro-2-propyl) phosphate (TDCPP) is an organophosphate additive flame retardant used in consumer products. Due to the phase out of the persistent and endocrine disrupting polybrominated diphenyl ether (PBDE) flame retardant commercial mixtures in 2005, the use of TDCPP has increased. However TDCPP is considered a suspected human carcinogen by the Consumer Product Safety Commission (CPSC, 2006), and it has recently been detected in both infant products, residential furniture, and in indoor air and dust particles at levels that are equivalent to, and in some cases higher than, levels of PBDEs (Kolpin et al, 2002 and Stapleton et al, 2009). Levels of TDCPP in indoor dust are particularly worrisome as children are known to have greater exposure to dust relative to adults, and therefore greater exposure to chemicals found in dust, including flame retardants, lead and pesticides (Xue et al, 2007). Due to these facts, more research is necessary to understand the magnitude of exposure that children are receiving to TDCPP in indoor environments and from contact with consumer products.

With this in mind, the goal of this research study was to investigate children's exposure to TDCPP in indoor environments, and quantify exposure from both hand to mouth contact and exposure to house dust to compare with exposure limits set by the CPSC and the state of California. In the spring of 2012, a cohort of toddlers and young children residing in and around Durham, North Carolina were recruited into this research study. In every home, a research team collected house dust samples (n=30) and handwipe samples from 43 toddlers. Handwipes and house dust samples were analyzed in the laboratory for several organophosphate flame retardants (OPFRs), including TDCPP, tris (2-chloroethyl) phosphate (TCEP), and tris (1-chloro-isopropyl) phosphate (TCPP), using gas chromatography mass spectrometry (GC/MS). Detection frequencies for TCEP, TCPP and TDCPP were 48.8%, 70.5% and 95.3% in handwipes, and 97.0%, 97.0% and 100% in house dust. Based on levels of TDCPP in house dust, the estimated daily dose for children's median exposure to TDCPP was 273 ng/day, and 1242 ng/day for children residing in homes with very high TDCPP dust levels (i.e. 99^{th} percentile). Using levels of TDCPP measured in the handwipes, the estimated daily dose for children's median exposure to TDCPP was 833 ng/day, and 5242 ng/day for children with high levels of TDCPP on their hands (e.g. 99^{th} percentile). California's acceptable daily dose of TDCPP is listed as 5.4 micrograms/day. Therefore, based on our estimates of children's exposure to TDCPP from hand to mouth contact measured here, a small percentage of children may be at an increased risk for cancer.

Table of Contents

Introduction Page 4

Hypotheses Page 6

Methods Page 7

Results of Analyses Page 11

OPFRs in House dust Page 12

OPFRs in Handwipes Page 13

Correlation between Handwipes and Dust Page 13

OPFR Handwipe and Dust Correlations Page 15

Age vs Handwipe Levels Page 17

Gender vs Handewipes Page 18

Socioeconomic Variables Page 19

Influence of Handwashing on OPFR Exposure Page 20

Handwipe OPFR levels among siblings Page 22

Exposure Estimate Table Page 22

Discussion Page 23

Conclusion Page 25

Acknowledgement Page 25

Appendix A Page 26

References Page 33

Introduction

Flame retardants (FR) are a class of chemicals that are used to reduce the flammability of materials in the home and in some consumer products (i.e. foam containing furniture). These chemicals are generally heavily halogenated and release halogen radicals when under flammable conditions, presumably slowing ignition of the material. They are traditionally added to polyurethane foams to meet California's Technical Bulletin 117 (TB 117) flammability standard, which requires a material to withstand an open flame for 12 seconds with minimal loss of foam (California 2000). TB 117 was intended to decrease fire related deaths occurring from furniture catalyzed ignitions. To meet this flammability standard, flame retardants such as polybrominated diphenyl ethers (PBDEs), have been use in high volumes over the past few decades. A commercial mixture of PBDEs, PentaBDE, was the dominant mixture used to meet TB 117 until research demonstrated that levels of PBDEs were increasing rapidly in humans and the environment. Examples of exposure include evidence of PBDEs in human breast milk in arctic regions (Ikonomou et al 2002, Meironyte et al 1999) and food webs (Wolkers et al 2004), demonstrating the chemical's stability and tendency to travel extensive distances. PBDEs are persistent molecules and have chemical structures that resemble thyroid hormones, giving rise to concerns that PBDEs may alter thyroid hormone regulation and hamper neurodevelopment. Studies with birds, rodents, and fish have found associations between PBDEs and thyroid hormone levels and/or neurodevelopmental deficits (Winter et al 2013, Viberg et al 2005, Viberg et al 2003, Tomy et al 2004). Research has shown that environmental exposures to PBDEs are widespread, yet human exposure is also a primary concern. Other research has shown that PBDEs accumulate in house dust, office dust, and manufacturing facilities (Stapleton et al 2012, Watkins et al 2011, and Kang et al 2011). Not only are PBDEs present in home and working environments at significant levels, they have also been found in human serum, hair, and breast milk from people around the world (Stapleton et al 2012, Kang et al 2011, Cui et al 2012), indicating that PBDE exposure is a widespread.

Recently, PentaBDE, was voluntarily phased out in the United States in 2005 due to its environmental persistence and the public awareness of its health implications. A higher PBDE congener mixture, DecaBDE, is also currently being phased out of production (US EPA 2012). The European Union had previously banned PBDE production of Penta- and OctaBDE (2003) and DecaBDE (2008) (Environmental Working Group 2008).

With the phase out of PBDEs from production, another FR, Tris(1,3-dichloro-2-propyl) phosphate (TDCPP), is increasingly being applied to polyurethane foam to replace PentaBDE. TDCPP was previously used in children’s pajamas in the 1970s until it was found to be a mutagenic chemical (Gold et al, 1978). The National Toxicology Program (NTP) also confirmed TDCPP’s health effects after a two year rodent exposure study demonstrated its carcinogenicity (Subcommittee on Flame-Retardant Chemicals, 2000).

Its reemergence as a FR in polyurethane foam is quite interesting. TDCPP is considered a suspected carcinogen by the Consumer Product Safety Commission (CPSC, 2006) because of its identification on TDCPP’s health hazards. In 2012, the state of California added TDCPP to Proposition 65, indicating that TDCPP has carcinogenic properties and the potential for human exposure. Proposition 65, a law passed in 1986, aims to protect California citizens from carcinogenic and mutagenic chemicals entering drinking water supplies, and to ensure that the listed chemicals are properly identified on consumer products. In addition, TDCPP has recently been found in household dust at levels that are equivalent to, and in some cases higher than, levels of PBDEs (Kolpin et al, 2002 and Stapleton et al, 2009). Furthermore, TDCPP appears to be the most frequently used flame retardant in baby products containing polyurethane foam (Stapleton et al 2011). This is concerning because in addition to carcinogenic properties, TDCPP was found to decrease semen quality and alter hormone levels in men (Meeker and Stapleton 2010), indicating that TDCPP is a potential endocrine disrupter. Dishaw et al also presented data that TDCPP, similar to organophosphate pesticides, may also be a developmental neurotoxin (Dishaw et al 2011).

Levels of TDCPP in indoor dust are particularly worrisome as children are known to have greater exposure to dust relative to adults, and therefore greater exposure to chemicals found in dust, including flame retardants, lead and pesticides (Xue et al, 2007). Due to these facts, more research is needed to understand the magnitude of exposure that children are receiving to TDCPP in indoor environments.

Hypothesis

Based on these facts, I hypothesize that indoor dust is a significant source of exposure to TDCPP in toddlers. Furthermore, I predict that residues of TDCPP present on children's hands will be reflective of the concentration of TDCPP present in their house dust. I also hypothesize that the combined exposure will lead to exposure levels that are near or equivalent to levels established by the CPSC and the state of California as being significant for health concerns.

Furthermore, I predict that exposure will be higher for children that wash their hands less frequently than other children.

To address this hypothesis I proposed the following objectives:

1) To determine if indoor dust levels of TDCPP are significantly associated with residues of TDCPP measured on children's hands. *Paired samples of indoor dust and hand wipes were collected from 43 toddlers (ages 2-5 yrs of age) in central North Carolina. Samples were analyzed for TDCPP using mass spectrometry and statistical analyses were performed on the data to determine if they were significantly correlated.*
2) To determine if hand washing was a significant predictor of TDCPP residues on children's hands. *A questionnaire was given to all parents/guardians of the toddlers enrolled in our study which included information on demographics and hand washing behavior. Data collected from the survey was compared with TDCPP residues measured on the children's hands.*
3) To estimate children's daily exposure to TDCPP and determine if it is higher than thresholds developed for health concerns. *Using measurements of TDCPP in indoor dust and hand wipes, the total daily exposure to TDCPP in children was calculated and compared with the CPSCs Acceptable Daily Dose (ADD), and the state of California's 5.4 ug/day limit.*

Methods

Sample Collection

Parents and guardians of children enrolled in a previous study which investigated exposure to flame retardants (IRB# 15125) were re-contacted and asked to participate in a follow-up study. If the participants consented, a research team traveled to the participant's homes to collect samples for this proposed study. All participants signed informed consent prior to sample collection. A short questionnaire was also administered (Appendix A). Samples were collected over several weeks during the spring of 2012. Equipment used consisted of: a vacuum cleaner (Eureka Might Mite Canister Vacuum) with crevice attachment (which was cleaned with water and methanol in between sample collection), hand-wipes soaked in 3.0 mL of iso-propyl alcohol, rubber gloves, participant questionnaires, and storage containers. Each participant was given a gift card and children's books as compensation for their time.

After consent was given, a questionnaire was administered by one team member which collected information on the child's last hand washing, how often they washed their hands, the types of furniture in the home, typical child eating behaviors, and where the child spends most of his/her time. Once completed, the child's height and weight were taken; then a hand-wipe swipe was administered. The child's hands were wiped on both sides in long vertical strokes, and in between fingers, to collect any residue, according to methods published in Stapleton et al. (2008). Floor dust samples were also taken in the room identified by the parent as where the child most spends his/her time. The dust was collected on both hardwood and carpeted floor. Dust was collected until a sufficient amount (approximately 100 mg) had accumulated, as determined by the team member. Dust samples captured in small paper thimbles were wrapped in aluminum foil, and were placed in small individual plastic bags. Hand-wipe samples were placed into small glass vials, wrapped in aluminum foil within a plastic bag, and then transferred to a -20° Celsius freezer.

Sample Processing

TDCPP was measured in the dust and hand wipe samples using several different extraction approaches (Soxhlets and Accelerated Solvent Extraction (ASE)) using published methods (Stapleton et al., 2008; 2009). Extracts were cleaned using Florisil SPE columns and analyzed by gas chromatography mass spectrometry (GC/MS). Labeled standards were spiked into each sample prior to extraction for use as internal standards for quantification and to measure recovery of target analytes. Laboratory blanks and dust Standard Reference Materials (SRM 2585) were analyzed for quality assurance and quality control. The samples were analyzed between May and June 2012.

Exposure and Risk Assessment:

In assessing the risk of TDCPP, it was first necessary to estimate exposure from inadvertent dust ingestion and hand to mouth contact. The models presented below were used to estimate exposure from the two different pathways which were then compared to the acceptable daily dose (ADD) (CPSC, 2006) or NSRL (California) . Each model provides a different estimate of exposure made from different underlying assumptions. Equation 1 use an estimate of children's average daily intake (ADI) of house dust, found in the US EPA Children's Exposure Handbook at 100 mg/day, to estimate the mass of TDCPP ingested per day in the household.

Equation 1

$$\frac{100\ mg\ dust\ ingestion}{day} X \frac{1\ g}{1000\ mg} X \frac{ng\ TDCPP}{g\ dust} = ng\ TDCPP\ X \frac{1\ mg}{1000\ ng} = \frac{mg\ TDCPP}{day}$$

The house dust TDCPP geometric mean (GM) and 99th percentile levels were calculated from the measured distribution in this study, and the values were compared to the ADD for TDCPP.

An exposure calculation was used from Stapleton et al 2008 to estimate exposure from hand to mouth contact, as seen below in **Equation 2:**

$$E_{derm} = M_{surf}\ x\ TE\ x\ SAC\ x\ EF$$

Where E_{derm} is exposure (ng/day). M_{surf} is TDCPP mass present on both hands (ng). TE is percent transfer efficiency, which is measured as a fraction of TDCPP mass transferred per contact event. SAC is the proportion of hands contacted at each event (%), and EF is the contact frequency per 24 hour day (day^{-1}). The last three variables used in the equation are described below.

Table 1. Hand to Mouth Calculation Variables for Toddlers

Variable	Child age 1-5	reference
Contacts per hour (EF)	18	Tulve and Xue
Transfer efficiency (%) (TEF)	50	assumed
Fraction of hand contacted (SAC)	0.1	Zartarian
Hours per day exposed	**12**	**assumed**

(table adapted from Stapleton et al 2008)

Statistical Analyses

Statistical analyses were performed using GraphPad Prism 5 statistical software. Univariate analyses were performed for both the dust and handwipe data, which is shown below in **Tables 3** and **4**. A linear regression analysis was performed to determine whether indoor dust levels were significantly associated with levels in hand wipe samples. Statistical significance was set at 0.05.

Results of Analyses

Table 2 presents the characteristics of the cohort in this study. The study sampled 30 homes for house dust, with a total of 43 children participating in handwipe collections. Almost half the children in the study were between 41-54 months, and 70% declared themselves as non-Hispanic white. The age of four child participants were not available and not reported.

Table 2. Sample population characteristics (n = **43)**

Characteristic	n (%)
Child's Sex	
Female	23 (53)
Male	20 (47)
Child's Age (months)	
26-40	12 (28)
41-54	21 (49)
55-68	6 (14)
unknown	4 (9)
Child's Race/ethnicity	
Non-Hispanic black	10 (23)
Non-Hispanic white	30 (70)
Other	3 (7)

OPFRs in House Dust

As seen in **Table 3**, OPFRs were detected in almost all house dust samples, with TDCPP detected 100% of the time, and TCPP and TCEP detected in 97.0% of the samples. Values were found to be log normal. TCPP concentrations were the highest, with a range of < 20.8 – 67805 ng/g and a GM of 3316 ng/g, most likely due to its higher potential to volatilize from the parent material. TDCPP concentrations ranged from < 622 – 13,100 ng/g and had a GM of 2730.

Table 3 Levels of OPFR compounds in house dust

	Dust (ng/g), n= 30							
OPFR	% Detect	GM	Range	MDL	75th %	90th %	95th %	99th %
TCEP	97.0	342	< 4.05 - 6923	4.05	581	1100	5763	5763
TCPP	97.0	3316	< 20.8 - 67805	20.8	8955	33290	53293	60154
TDCPP	100	2730	< 622 - 13111	1.72	5041	10056	11795	12417

Table 4 Levels of OPFR compounds in handwipes

	Handwipes (ng), n= 43							
OPFR	% Detect	GM	Range	MDL	75th %	90th %	95th %	99th %
TCEP	48.8	24.0	< 22.0 - 197	22.0	62.2	103	126	170
TCPP	70.5	32.0	< 12.6 - 532	12.6	78.4	174	277	466
TDCPP	95.3	77.1	< 6.96 - 530	6.96	139	259	376	485

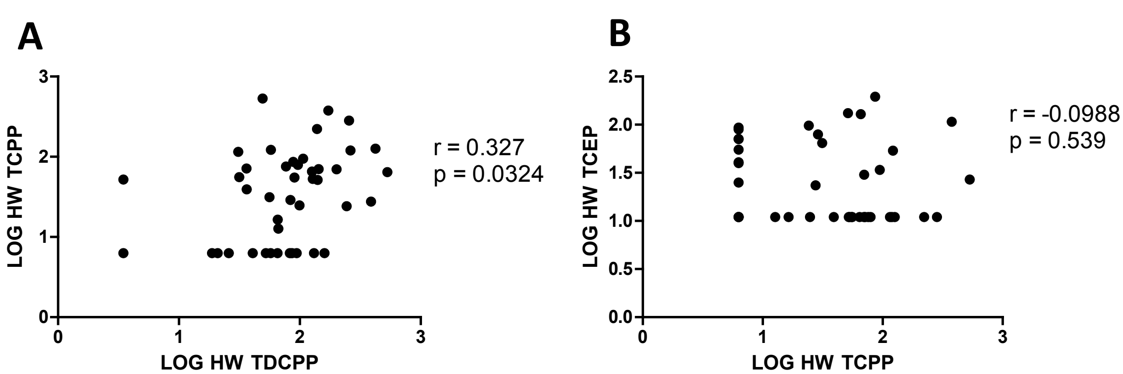
OPFRs in Handwipes

As seen in **Table 4**, OPFRs were also detected in handwipes, with TDCPP detected in 95.3% of the handwipe samples. TCPP and TCEP were detected in 70.5% and 48.8% of the samples, respectively. Values for handwipes were also found to be log normal. TDCPP levels were highest on the handwipes, with a GM of 77.1 ng and a maximum value of 530 ng.

Although TCPP had a higher maximum handwipe level (532 ng), the GM was less than half that of TDCPP (32.0 ng).

OPFR handwipe correlations

To determine if the OPFRs may have a common source, Pearson correlation coefficients were calculated for all three OPFR compounds using log transformed data. TDCPP and TCPP were significantly correlated (as seen in **Figure 1a**) ($p < 0.05$). TCPP and TCEP however, were not significantly correlated ($r = -0.0988$, $p = 0.539$). Nor was TDCPP and TCEP significantly correlated ($r = 0.180$, $p = 0.250$). The low detection frequency for TCEP (49%) is a probable contributor to these non-significant findings.



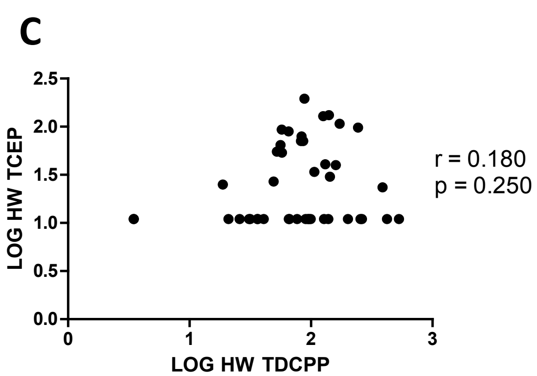


Figure 1. Correlation coefficients for **(a)** handwipe TDCPP and TCPP; **(b)** handwipe TCEP and TCPP; **(c)** handwipe TCEP and TDCPP. All values are log transformed. Only the correlation of TDCPP and TCPP were found to be significant.

OPFR dust correlation

As with the handwipe values, Pearson correlation coefficients were also calculated for all three OPFR compounds in dust using log transformed data. **Figure 2a** displays the only significant finding (r=0 .396, p = 0.0301), again suggesting that TDCPP and TCPP share a common source. No relationships were observed for TCPP and TCEP (r= 0.321, p =0.0833) nor for TCEP and TDCPP (r= 0.0345, p =0.856).

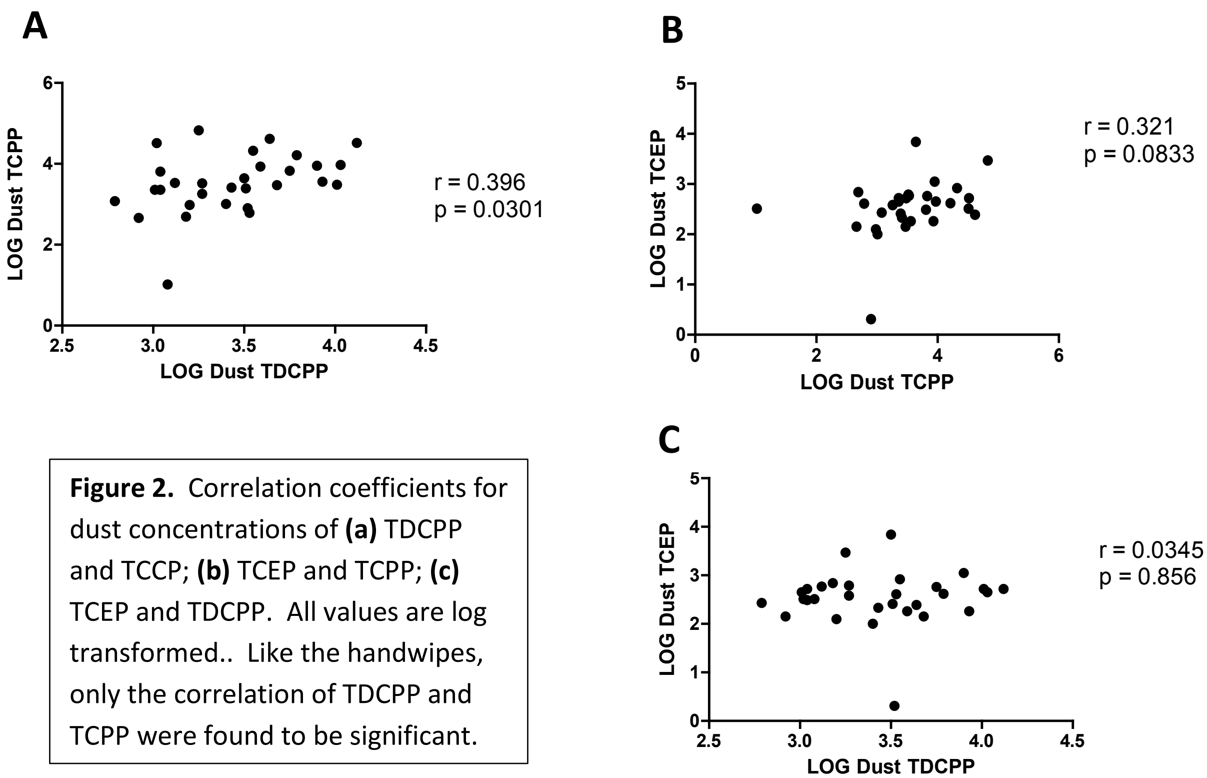


Figure 2. Correlation coefficients for dust concentrations of **(a)** TDCPP and TCCP; **(b)** TCEP and TCPP; **(c)** TCEP and TDCPP. All values are log transformed.. Like the handwipes, only the correlation of TDCPP and TCPP were found to be significant.

Correlations between Handwipes and Dust

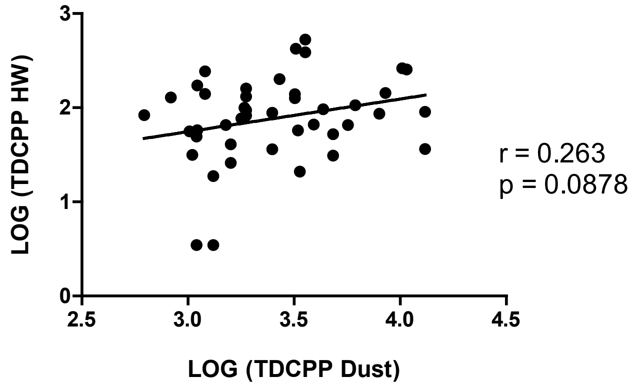


Figure 3: Association between TDCPP levels in handwipes and indoor dust samples.

Linear correlation analyses were performed to assess whether handwipes OPFR levels were predictable based on levels measured in house dust. **Figure 3** presents the relationship between the paired dust and handwipe samples for TDCPP. Although not significant at alpha =0.05, the relationship was suggestive, with p= 0.09. The relationship between TCPP in handwipes and housedust was not significant (**Figure 4**). This analysis was not performed for TCEP due to low detection in the handwipes.

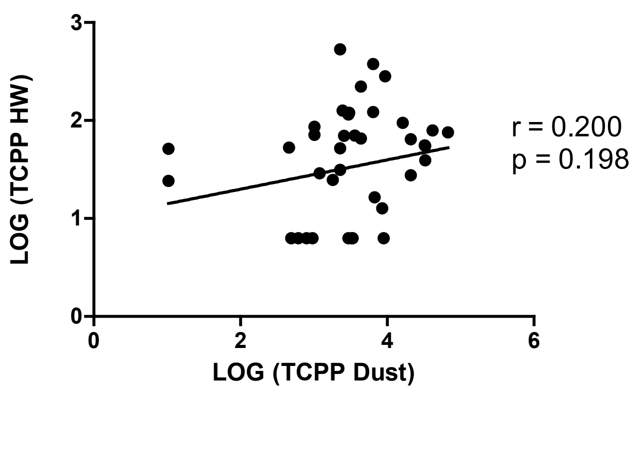


Figure 4: Association between TCPP levels in handwipes and indoor dust samples.

Due to the small sample size, a grouped analysis, based on median level in house dust, was conducted to see if levels of the paired handwipes were statistically different. These categorical data analyses, in contrast to the graphs of continuous data above, give more statistical power to our findings. The dust groups were determined by using the geometric mean (GM) for either TDCPP or TCPP. Dust concentrations below the GM were placed into the low group, and values higher were placed into the high group. The High Dust mean for TDCPP was found to be significantly higher (p=0.0235) than the lower handwipe group mean (**Figure 5**), but the same relationship was not found for TCPP, seen in **Figure 6**.

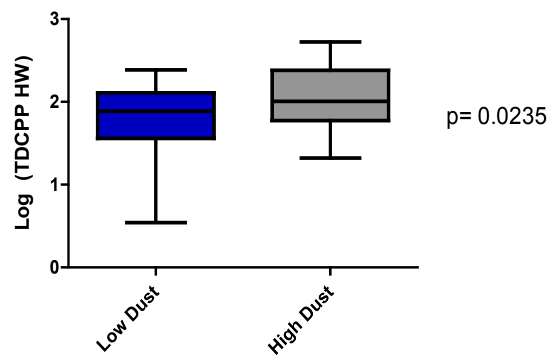


Figure 5: High, Low Dust groups and corresponding spread of handwipe levels for TDCPP.

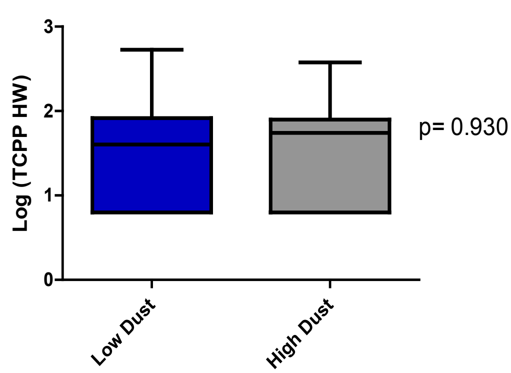


Figure 6: High, Low Dust groups and corresponding spread of handwipe levels for TCPP.

Age vs. Handwipes

Analyses were performed to determine if children's age was significantly associated with the TDCPP and TCPP levels measured on children's hands. As seen in **Figure 7,** age was not significantly associated for TDCPP, although the trend was positive. **Figure 8** displays a non-significant finding for TCPP. Analyses were also performed by grouping age into tertiles, however, no significant differences were observed.

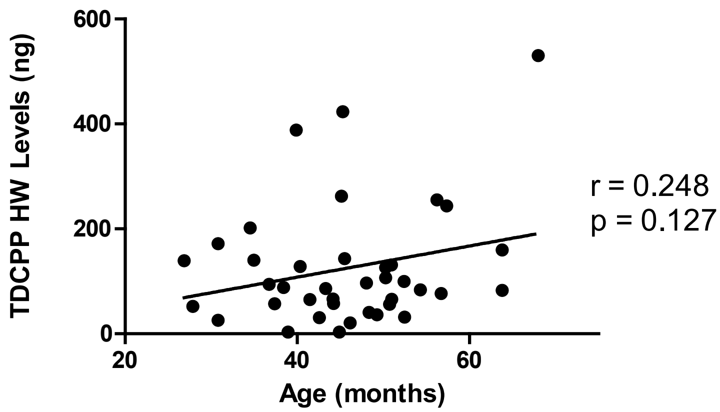


Figure 7: Linear regression of children's age in months and associated handwipe levels for TDCPP (ng).

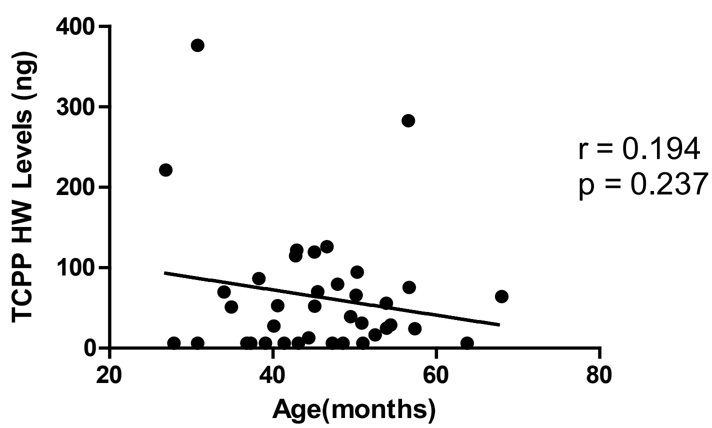


Figure 8: Linear regression of children's age in months and associated handwipe levels for TCPP (ng).

***Gender vs. Handwipes*.**

No significant findings were found for the two tailed t-test comparisons between TDCPP or TCPP levels measured on handwipes for boys relative to girls (p= 0.885 and p=0.672) (see **Figure 9**).

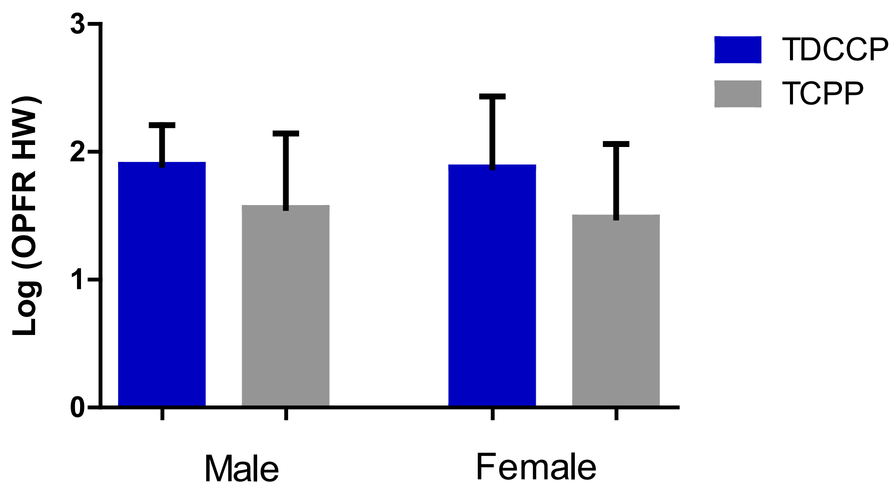


Figure 9: TDCPP and TCPP levels measured on handwipes collected from both boys and girls. Error bars represent one standard deviation.

Socioeconomic Variables.

To determine if exposure may be different among children of different races, a t-test was conducted on the log transformed TCPP and TDCPP handwipe data. As seen in **Figure 10**, there were no significant differences observed. Non-white and white children had mean handwipes levels of 120 ng and 113 ng respectively for TDCPP, and 90 ng and 63 ng for TCPP.

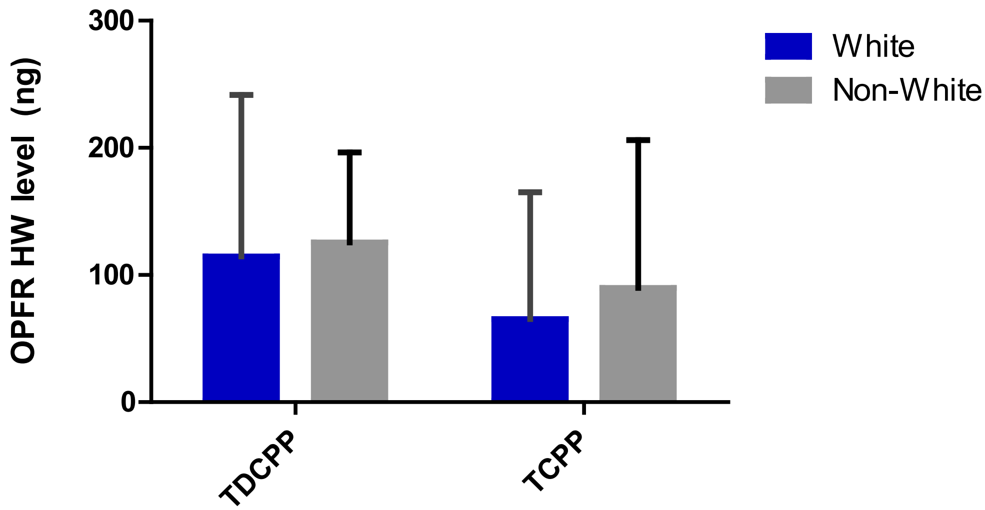


Figure 10: TDCPP and TCPP levels measured in handwipes from white and non-white children. Error bars represent one standard deviation.

Influence of Handwashing on OPFR Exposure.

Data collected from the questionnaire was used to determine if handwipe levels were significantly higher in children that washed their hands less frequently. We also examined the influence of the time since the last handwashing event. **Figure 11** and **12** presents TDCPP and TCPP handwipe data, respectively, plotted based on the child's hand washing frequencies and whether or not they lived in a house with high or low TDCPP/TCPP dust levels. The dust geometric mean was used to determine "high" and "low" dust groups. **Figure 13** and **14** presents the TDCPP handwipe data plotted based on the child's reported last hand washing event and whether or not they lived in a house with high or low TDCPP dust levels. A two-way ANOVA was conducted but neither variable was significant for both OPFR chemicals.

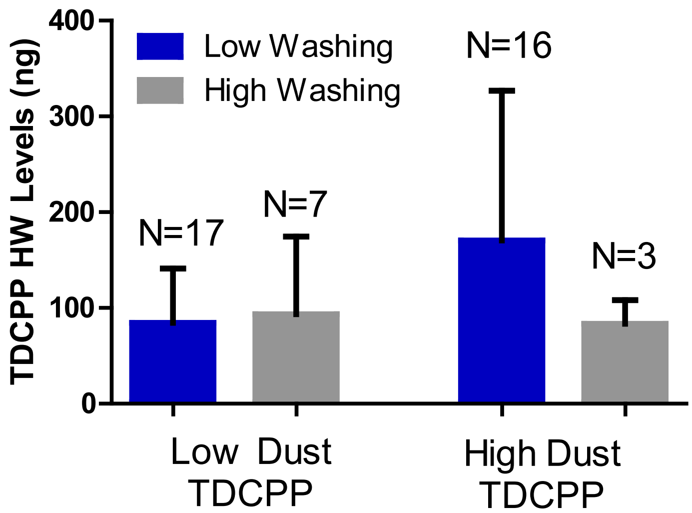


Figure 11: Differences in TDCPP levels measured on handwipes categorized by high or low dust group and by the frequency of handwashing on a daily basis. Low and High Washing were grouped as washing frequencies 0-4 times and >5 times daily, respectively.

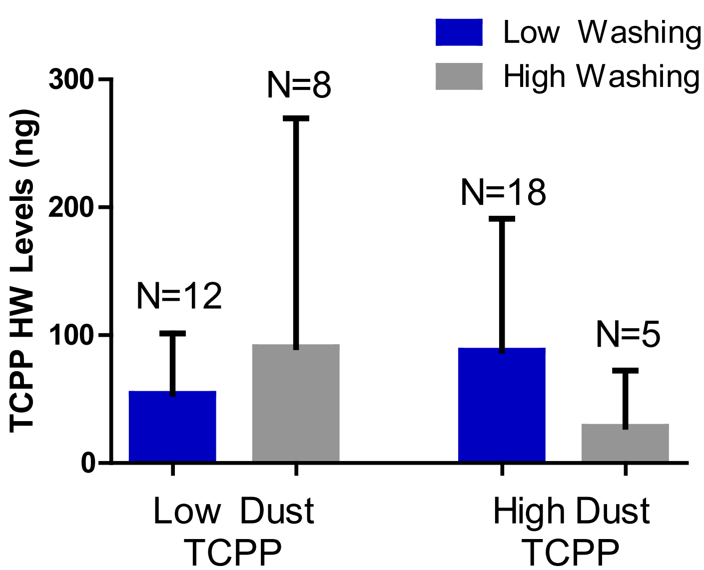


Figure 12: Differences in TCPP levels measured on handwipes categorized by high or low dust group and by the frequency of handwashing on a daily basis. Low and High Washing were grouped as washing frequencies 0-4 times and >5 times daily, respectively.

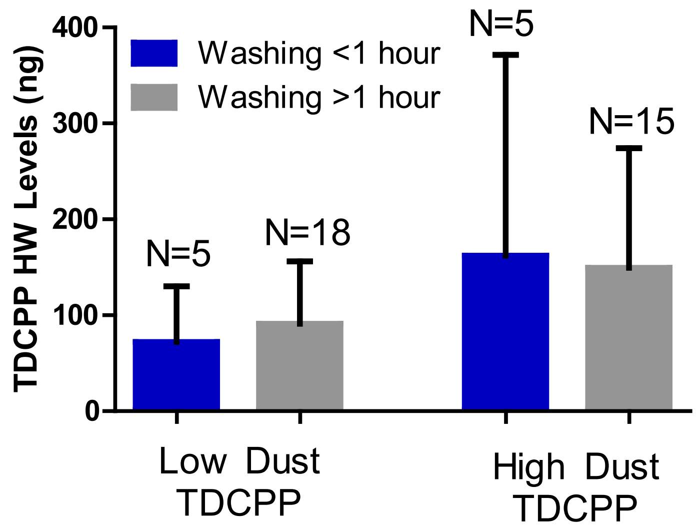


Figure 13: Differences in TDCPP levels measured on handwipes categorized by high or low dust group and whether or not the participant washed their hands within an hour of sample collection.

Handwipe OPFR levels among siblings

Several sets of siblings were involved in this study. **Figure 15** shows the eleven sibling sets from the data set and the levels of TDCPP measured on each siblings hands. Each set is displayed vertically, with the handwipe levels being displayed on the y axis. Although not proven statistically, a grouping effect does seem to be apparent within each set, although some varying in contrast to other sets. Further analysis is needed to determine if the variability within a set of siblings is significantly smaller than the variability among homes.

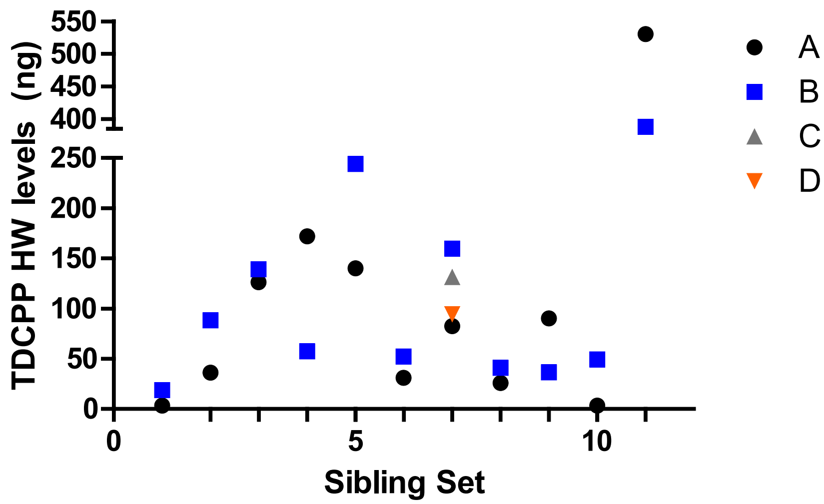


Figure 15: Handwipe TDCPP levels among eleven sibling sets.

Exposure estimates for dust and hand to mouth contact.

According to the US EPA Exposure Handbook, an average child is estimated to ingest approximately 100 mg of dust per day. Using this estimate, the GM, 95^{th} and 99th percentile exposure levels were calculated and are presented in **Table 5** for each OPFR (US EPA 2008). TCPP presents the highest OPFR exposure for all three levels because it was most abundant in indoor dust. However, estimates provided by the hand to mouth model demonstrate higher exposure to TDCPP. It is worth noting that TCPP also has comparable exposure to TDCPP at the 99^{th} percentile level.

A value of 5.2 micrograms/day of TDCPP exposure was calculated for children with the highest 1% of TDCPP levels measured on their hands, suggesting that a small percentage of the children in this study are very near or above the NSRL of 5.4 ug/day. One child did exceed this standard with an estimated exposure of 5.7 ug/day.

Discussion

The data collected suggests that house dust is a chronic source of exposure to the tested OPFRs, especially to TDCPP. The detection frequency for TDCPP was high in handwipes (95.3%), and suggests that exposure from hand to mouth contact is common in most households. The OPFR compounds observed in this study can be compared to previous research with flame retardants in an effort to compare potential overall exposures. Such exposure estimates were calculated in Stapleton et al 2012, where dust concentrations and handwipe levels of PBDEs were measured. The summed concentration range of four major BDE congeners in dust was found to be 152 to 74,560 ng/g. Stapleton et al also showed PBDE handwipe levels to be from 3.3-2,187 ng. Similar to Stapleton's study, Watkins et al investigated the effects of handwashing on levels of PBDEs from office employees (Watkins 2011). The pentaBDE mixture levels in dust ranged from 141 to 61,264 ng/g, while pentaBDE handwipe levels ranged from 13.8 to 2,864 ng. They also found that the office employees who washed their hands less frequently had 3.3 times higher levels of PBDE residues on their hands. Both Stapleton and Watkins demonstrate consistency in the levels of PBDEs in the interior environment.

In comparison, the total levels of OPFR in dust ranged from 647 to 87,839 ng/g. This similarity between OPFR and PBDE dust levels may suggest that OPFRs are now being used as consistently as PBDEs were in the past. The OPFR levels measured on handwipes were found to be slightly lower than PBDEs, ranging from 41.5-1,259 ng.

Concern over human exposure to FR has made headline news within the past year, and TDCPP was among those discussed. These exposure concerns gained enough attention that the state of California evaluated the potential health effects of TDCPP and subsequently added it to California's Proposition 65 list, which classifies chemicals that have no reproductive or carcinogenic properties. Directly following this placement, the state of California developed a No Significant Risk Level (NSRL) of 5.4 micrograms/day for TDCPP, which indicates that exposure levels above this value could lead to cancer risks above their "no significant" cancer risk of 1 in 10^4. Also, the CPSC has had an established Acceptable Daily Dose (ADD) exposure for TDCPP, which was found at 5 ug/kg/day.

To understand if levels of OPFRs found in this study's house dust and handwipe samples could expose children to levels above these thresholds, two models were used. A dust ingestion model (Equation 1) relied on dust OPFR concentrations to determine daily exposure, assuming that children ingest 100 mg of dust per day. The hand to mouth contact model incorporated daily hand to mouth frequency and the mass of the chemical found on the handwipes. The models were only used for TDCPP because it is the only OPFR to have an established daily exposure value. To exceed the CPSC's ADD level, a child of average mass in this study (16.3 kg) would need to ingest 81.5 micrograms per day. This data shows that both models fall well below this established level.

Table 5. Estimates of children's exposure to OPFRs (ng/day) based on measurements made in house dust and handwipes

	Dust Ingestion model			Hand to Mouth contact model		
	GM	95th percentile	99th percentile	GM	95th percentile	99th percentile
TCEP	34.2	576	576	NQ	NQ	NQ
TCPP	331	5329	6015	345	2990	5037
TDCPP	273	1180	1242	833	4058	5242

NQ- not quantified due to low detection frequency

California's no significant risk level (NSRL) value is set at 5.4 ug/day. No children using the dust model exceeded the NSRL. Using the handwipe model, however, one child with the highest handwipe level (530 ng) is estimated to receive an exposure of 5.7 micrograms TDCPP/day, above the NSRL, which increases this child's risk of developing cancer. Although this finding does not represent the entire cohort, as the 99th percentile fell below the NSRL, the data shows that a small percentage of the population is being exposed to levels higher than California's no-significant risk level.

Additionally, previous work with TDCPP in dust has found values much higher than observed in this study 20,415 ng/g 95th percentile and 56,090 ng/g max (Meeker and Stapleton 2010), which suggests that the TDCPP dust levels found in this study may be underestimating the percentage of children who could be exposed. Although handwipe levels have not been published elsewhere for TDCPP, the general positive correlation of house dust concentrations predicting handwipe levels suggests that children in similar environments will be at greater risk of exposure.

Conclusions

Our data demonstrates that similar to PBDEs, children are receiving chronic exposure to OPFRS, especially TDCPP. Dust levels of TDCPP were found to be at comparable levels to previous research on PBDEs, but TDCPP dust/handwipe levels may not be as strongly correlated. To conclusively test this relationship, we hypothesize that collecting more samples may provide a stronger relationship.

We demonstrated with the two model presentations, that a small percentage of children are receiving exposure levels to TDCPP that exceeds the NSRL, and that this study's dust concentrations may under represent concentrations found in other homes based on previous dust concentration findings. We also conclusively showed that the dust ingestion model well under predicted exposure values when compared to the hand to mouth contact model. The hand to mouth contact model, if more accurately depicts real life behavior, predicts exposure estimates four to five times higher that of the dust model.

By analyzing the handwashing habits data from the questionnaire (see appendix), it was determined that daily handwashing frequency did not have any effect on TDCPP residues on children's hands. Nor was there any difference in residue levels when observing the time of last handwashing.

Future studies can address data gaps by seeking to better understand the extent of exposure to toddlers in the home environment, such as those that also incorporate TDCPP metabolite analysis with paired dust/ handwipe samples, and those that attempt to better understand exposure sources and routes.

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Appendix A

ENCOUNTER/INTERVIEW FORM

Date:__________________ Recorded By:________________________

I. BACKGROUND INFORMATION

PARENT/GUARDIAN

1. Parent's/ Guardian Name(s): **1)**____

2)____

___ Mother ___ Father ___Step-Mother ___Step-Father ___Guardian(s)

___ Adoptive Mother ____Adoptive Father

Child's Name:__________________________ Sex: _____ M _____F

Child's Height (inches)___________________ Weight (lbs) __________

2. Street Address_______________________________________

3. City:_______________________ State____ Zip______

4. Home Phone Number____________ Alt Contact Phone___________________

5. Child's Date of Birth_______________________________

6. Born in: ______________(town) ___________ (state) _________(country)

7. Parent's/Guardians Marital Status

___Married ____ Single ____Widowed ____Divorced ____Partners living together

8. Ethnicity: ☐ Hispanic or Latino ☐ Non-Hispanic or Non-Latino

Race: (may answer Yes to more than one)

American Indian/Alaskan Native:	☐ No	☐ Yes
Asian	☐ No	☐ Yes
Native Hawaiian or other Pacific Islander	☐ No	☐ Yes
Black or African American	☐ No	☐ Yes
White	☐ No	☐ Yes

II. Educational Background

9. Parent/Guardian Education (check all that apply):

Parent 1:

____ Primary School
____ Some High School
____ High School
____ Some College
____ Associates Degree
____ Bachelor's Degree
____ Graduate Deg. (e.g. Master's, Ph.D., M.D.)

Parent 2:

____ Primary School
____ Some High School
____ High School
____ Some College
____ Associates Degree
____ Bachelor's Degree
____ Graduate Deg. (e.g. Master's, Ph.D., M.D.)

III. Parent's/Guardians Work History

Parent 1:

10. Employment: ______employed ____ Not employed

11. If employed, what is your primary job and how many hours/week do you work in this position: ____

12. What is your second job and how many hours/week do you work in this position (if applicable)____

Other jobs and hours (if applicable)____

13. Have you ever worked in any of the following fields over the past 5 years (check all that apply). If you answered yes to any of the categories below, please state how long (in months) you worked in that position:

________ Cleaning Service (Maid/Janitor) __________ Electronics Assembly/Repair

________ Furniture Manufacture __________ Carpet Cleaner

________ Carpenter/Construction __________ Computer Technician

Parent2:

14. Employment: ______employed ____ Not employed

15. If employed, what is your primary job and how many hours/week do you work in this position: ____

16. What is your second job and how many hours/week do you work in this position (if applicable)____

Other jobs and hours (if applicable)____

17. Have you ever worked in any of the following fields over the past 5 years (check all that apply)? If you answered yes to any of the categories below, please state how long (in months) they worked in that position:

_______ Cleaning Service (Maid/Janitor) __________ Electronics Assembly/Repair

_______ Furniture Manufacture __________ Carpet Cleaner

_______ Carpenter/Construction __________ Computer Technician

IV.Child's Behavioral Traits

18. How often does your child suck their thumb?
____never ____seldom ____occasionally ____frequently

19. Does your child use a pacifier now? ____ Yes ____ No
If yes, how many hours per day? ________________________________

20. Have they used a pacifier in the past but not now? ____ Yes ____ No
If yes, how many months did they use a pacifier? _________________________
If yes, how many hours per day were they using a pacifier?_________________

21. How often do they put their hand(s) in their mouth?
____ never
____ 0-2 times per hour
____ 2-5 times per hour
____ 5-10 times per hour
____ More than 50% of the time their hand(s) is in their mouth.

22. How often does your child lick their fingers after eating finger foods?
___ never ____seldom ____ occasionally ___frequently

23. How many times a day does your child wash their hands?

____ never
____ 0-2 times per day
____ 2-4 times per day
____ > 5 times per day

VII. Home Environment

24. What type of flooring is found in your child's bedroom?
____ Carpet ____ Hardwood ___ Tile ____ Vinyl ____ Cement
____ Other (please describe)____

25. What type of flooring is found in your child's playroom (or area in which the child spends the majority of their time?)
____ Carpet ____ Hardwood ___ Tile ____ Vinyl ____ Cement
____ Other (please describe)____

26. Approximately how many pieces of the following furniture pieces do you have in your home now and which contain polyurethane foam:

_____ couch
_____ chair
_____ chair specifically designed for toddler/children

27. Did you have any of the following items in your house now (check all that apply):

☐ rocking chair/glider with foam
☐ changing table with foam pad
☐ pack-n-play
☐ boppy pillow/nursing pillow
☐ foam containing sleep positioner
☐ children's tent/tunnel

Home Characteristics:

46. How long have you lived in your current residence? (please state your answer in years or months)____

47. Do you live in a: ___ House ____Apartment/Condo ____Townhome
____ Other (Please describe)____

48. How many TVs are in your home?_____
If you have a TV, how many hours per day is the TV on?__________

49. How many computers are in your home? _________________________________

If you have a computer, how many hours per day are you using the computer (include use during/at work if applicable)__________________________

50. Do you have a large screen TV (greater than 50”) in your home?

______Yes _____No _______Don’t Know

51. Do you have a video game system (e.g. Wii, Playstation) in your home?

______Yes _____No _______Don’t Know

52. Do you have any pets? _____ yes ____ no

If yes, how many do you have: ___ Dogs ___ Cats ___ Other

Are they primarily housed: _______ indoors ________outdoors

53. Have you purchased any new furniture in the last year such as new living room furniture, a new mattress, new carpets/floors, a new TV, ? ____ Yes ____ No ____ Don’t know

If yes, please list what items are new____

____

54. How many times a month is your home vacuumed?

____ None ____ 1-2 times ____ 3-4 times/month ____ more than 4 times/month

55. Which of the following describes your home’s flooring? (check one)

____ Mainly carpeted (e.g. more than 50%)

____ Mainly wood floors (e.g. more than 50%)

____ Mixed carpet/wood floors (equal wood and carpet floors)

____ Other (describe)____________________________________

56. What time of cooling system does your home have?

_____ Central air conditioning

_____ Window air conditioning units (how many_______)

______ No cooling system

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