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Thirdhand Smoke Exposes Children Living with Smokers and Nonsmokers to Tobacco

Smoke Toxicants: Racial, Income, and Housing Disparities in Hand Nicotine and Saliva

Cotinine Levels.

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Abstract

Background: Children may be involuntarily exposed to chemical residue from thirdhand tobacco smoke (THS) in environments where tobacco has previously been used. Factors contributing to this exposure among children of nonsmokers with no known secondhand smoke (SHS) exposure are currently unknown.

Objective: To understand the contribution of THS residue to the overall tobacco smoke exposure (TSE) among children of nonsmokers and smokers.

Methods: We conducted a prospective observational cohort study of parents and their children (≤ 11 years; $N=1013$) at a children's hospital in the US. Hand nicotine (HN) and saliva cotinine (SC) were markers of THS pollution and TSE, respectively. Children were considered protected from tobacco smoke if there were no household smokers or vapers, strict household smoking bans, and no SHS exposure during the past week. Cluster-adjusted regression models were used to test hypotheses about HN and SC levels.

Results: Overall, 94.5% and 98.9% of protected and unprotected children had detectable HN, respectively. Children who were Black and protected (GeoM= 6.0 ng/wipe; 95%CI=[3.8, 9.1]) or unprotected (GeoM= 43.8 ng/wipe; 95%CI=[33.6; 57.1]) had approximately three times higher HN levels than children who were White and protected (GeoM= 1.8 ng/wipe; 95%CI=1.6; 2.0]) or unprotected (GeoM= 15.0 ng/wipe; 95%CI=[11.2; 19.8]). Unprotected children whose parents had $\leq$ high school education had HN levels that were almost 12 times higher (87.8 ng/wipe) than unprotected children of parents who graduated college (7.5 ng/wipe). Unprotected children with $\leq$ \$15,000 household income had HN levels >25 times higher (73.3 ng/wipe) than unprotected children with $>$ \$90,000 income (≤ 2.8 ng/wipe). Household smoking bans were unsuccessful in lowering HN levels in Black children, but they were successful for White children ($\chi^2(3)=12.7$,

$p < 0.01$). HN was associated with SC in children with no SHS exposure ($\hat{\beta} = 0.10$), with stronger associations in the presence of 1 ($\hat{\beta} = 0.28$) and 2+ active smokers ($\hat{\beta} = 0.32$; all $p < 0.01$).

Discussion: THS is a pervasive source of exposure to tobacco smoke pollutants. Stark disparities were noted, with higher exposure in Black and lower income children. Findings provide the strongest evidence to date on the contribution of THS as a significant source of overall TSE in children.

Introduction

Since the 1960s, a robust body of research reviewed in multiple U.S. Surgeon General's reports¹⁻⁴ has provided unequivocal evidence that tobacco smoke exposure (TSE) at any level is hazardous to children's health. These conclusions have been largely drawn from studies of children who live with smokers and are exposed to tobacco smoke toxicants by inhaling secondhand smoke (SHS). Research conducted over the past 20 years in laboratory and field settings has demonstrated that SHS leaves behind a toxic mixture of chemical residue on surfaces and in dust that can persist for years after smokers move out,⁵ quit smoking,⁶ or pass away.^{7,8} Also known as thirdhand smoke (THS), this chemical mixture includes numerous compounds found in SHS as well as novel compounds known to cause cancer⁸⁻¹⁰, birth defects⁸, reproductive harm,^{8,11} and cardiovascular,¹² pulmonary,¹³⁻¹⁵ and neurodevelopmental^{18,14-17} harm. Children who live with smokers are exposed to both SHS from active smoking and THS from tobacco residue left behind from past smoking.^{8,14,15} Thus, when prior studies measured TSE levels in smokers' children, these levels represented both exposure to SHS+THS.¹⁸ Levels of TSE are highest in smokers' children who are toddlers, of non-Hispanic Black ethnicity and race, from low-income households, and who live in multiunit homes.¹⁸⁻²⁰

Much prior TSE-related research has failed to recognize that in otherwise smoke-free environments, children who live with nonsmokers may be exposed to these THS pollutants through inhalation, dermal transfer, and ingestion of dust.^{8,10} Consequently, newer research raises concerns that despite significant declines in smoking prevalence throughout the U.S.²¹ and other developed countries,²² decades of permissive indoor smoking have created a toxic legacy of tobacco smoke pollutants in indoor environments for years to come.^{7,8} Unrecognized THS pollutant reservoirs can result in involuntary exposure to THS pollutants in large numbers of children believed to be otherwise protected.^{7,8}

We recently conducted a clinical screening study in Cincinnati, Ohio to examine the prevalence of THS exposure in 0-11-year-old children.²⁰ In a preliminary report on approximately half of the sample,²⁰ we demonstrated near-universal exposure to nicotine among children of smokers and nonsmokers and described strong income-related disparities. Measured by nicotine residue on children's hands, we showed that nonsmokers' children can be exposed to THS only, even if they were protected and not exposed to active SHS from smokers.²⁰ Nicotine on children's hands offers a sensitive and unobtrusive marker of children's exposure to SHS and THS that can be measured at low concentrations.^{19,23,24} Unlike cotinine, a nicotine metabolite that measures recent TSE,²⁵ nicotine on hands is not influenced by metabolic processes and is unaffected by genetic differences in the liver enzyme CYP2A6 among different racial groups.^{25,26} Our preliminary analyses showed that 95% of children whose parents believed them to be protected from tobacco smoke were still exposed, with children from low-income families showing the highest exposure levels.²⁰ We now report findings on the entire sample of 1,013 children to understand the prevalence of THS exposure in children, specific contributions from THS residue, and the role of sociodemographic, housing, and tobacco use risk factors of exposure. We hypothesized that among protected children, levels of hand nicotine (HN) and saliva cotinine (SC) would be highest in children who were younger, Black, and lived in low-income, multiunit, smaller, or older homes.

Methods

Participants and Setting

Participants were parent-child dyads recruited to an observational pediatric THS exposure trial (R01ES030743) from either: (1) the Pediatric Emergency Department or Urgent Care or (2) the clinical research center of Cincinnati Children's Hospital Medical Center (CCHMC) in Cincinnati, Ohio from February 2020 to March 2023. Parents who did and did not use tobacco products were recruited. Dyads were eligible if they/their: 1) were parents/legal guardians ≥ 18

years old who lived with their 0-11-year-old child $\geq$ four days/week; 2) had lived in their current home for $\geq$ 6 months; 3) had a complete smoking ban for $\geq$ 6 months (non-tobacco product users only); 4) denied use of cannabis; 5) had a working phone number, and no plans to move in the next six months; and 6) child denied tobacco or cannabis product use. Data from 1,013 children belonging to 862 unique family units were analyzed. The CCHMC hospital institutional review board approved this study, and parents completed written informed consent; children who were age 11 completed assent.

Parental Assessments and Child Categorization into Protected or Unprotected Groups

Parents completed electronic self-report assessments with measures of (1) sociodemographic characteristics, (2) parent tobacco use, (3) child TSE patterns, (4) housing characteristics, and (5) the last time their child's hands were washed. The sociodemographic characteristics assessed were: child: age; sex (male, female, other); ethnicity (Latino or Hispanic origin, yes or no); parent race (White, Black or African American, American Indian/Alaska Native, Native Hawaiian or other Pacific Islander, Asian, More than one race); parent education level (less than high school graduate, high school graduate, vocational/technical training graduate, some college, college graduate, any post-graduate work); and household annual income (<\$5,000, \$5,001-\$15,000, \$15,001-\$30,000, \$30,001-\$50,000, \$50,001-\$75,000, \$75,001-\$90,000, \$90,001-\$120,000, >\$120,000). Parents who smoked or vaped tobacco were asked the types of products used (cigarettes only, cigars only, vapes only, or combination) and the number of daily cigarettes smoked or e-cigarettes vaped. Child TSE patterns were assessed with two questions: (1) Home smoking rules: What are your rules about smoking tobacco inside your home, if any? The choices were: (a) tobacco smoking is allowed any time, by anyone, (b) tobacco smoking is usually allowed with a few restrictions, (c) tobacco smoking is usually not allowed with a few exceptions, (d) only certain people are allowed to smoke tobacco inside your home, or (e) no one is ever allowed to smoke tobacco inside your home including yourself). The same questions were asked about vaping e-cigarettes

inside the home. Parents were considered to have complete home smoking bans if they chose “e” on both questions. (2) Total number of people using tobacco products around the child in the past week. Parents were asked “Which of the following people who have been around your child in the past week use any tobacco products” (options included a wide range of household members e.g., child’s mother, father, aunt, uncle, grandmother, niece, nephew, other). The total number of individuals who used tobacco was added. Housing characteristics were assessed by asking housing type with the question: “What type of home do you live in?” The options were single family home, apartment building, multiunit housing (includes houses or condominiums with attached walls), townhouse with attached walls, townhouse without attached walls, or trailer. We also asked about the home’s total square footage and the year their home was built. Finally, parents were asked when was the last time their child’s hands were washed.

Children were considered protected from tobacco smoke if parents reported that: (1) no household member smoked or vaped, (2) smoking and vaping were banned in homes and cars at all times, and (3) there had been contact with tobacco product smokers or vapers ≤ 3 times in the previous four weeks (i.e., less than once per month).

Sample Collection and Analysis

Research coordinators obtained handwipe and saliva samples from child participants. The procedure for handwipe collection and the quantification of nicotine was described previously.²⁴ Briefly, the palmar and volar surface of children’s dominant hands were wiped with prescreened cotton rounds wetted with 1% ascorbic acid.¹⁸ Analysis for nicotine was performed using a QuEChERS sample extraction procedure,^{27,28} followed by quantification using an isotope-dilution liquid chromatography-tandem mass spectrometry (LC-MS/MS) method. The method used hydrophilic interaction chromatography, positive electrospray ionization (ESI+), and multiple-reaction-monitoring (MRM). The handwipe nicotine limit of quantification (LOQ)²⁹ was 0.30 ng/wipe and the estimated method detection limit (MDL)³⁰ was 0.19 ng/wipe. Handwipe nicotine values were corrected for field blank contamination levels by subtraction. The median

(inter-quartile range) of the field blanks was 0.23 ng (0.0 – 0.41 ng/field blank wipe) and was a mean of 0.31% of the uncorrected sample level.

The collection and sample preparation for the analysis of cotinine in saliva samples were described previously.³¹ Briefly, saliva samples were provided by spitting onto or sucking on cotton swabs for >1 minute until moist and 0.5 mL was processed using a QuEChERS procedure. For samples containing less than 0.5 mL of saliva, the available volume was measured and used for normalization. Cotinine was quantified by LC-MS/MS as described previously.³² The ESI+ MRM method used C₁₈ reverse phase chromatography. Field blanks did not contain significant levels of cotinine. The saliva cotinine LOQ was 0.04 ng/sample and the MDL was 0.008 ng/sample (prior to normalization by the saliva volume).

For both the nicotine and cotinine methods, the reporting limit was equal to the MDL. Quality assurance/quality control (QA/QC) criteria included insignificant laboratory blank levels, insignificant LC injection carryover, an accuracy of $\pm 10\%$ for standard solutions run with each analytical batch, and an estimated internal standard (nicotine-*d*₄ or cotinine-*d*₃) recovery within $\pm 30\%$ of the long-run average. Raw quantification results were exported to custom semi-automated software to assess the QA/QC criteria and ensure the reporting was consistent from batch-to-batch throughout the study. Values were normalized to ng/wipe and $\mu\text{g}/\text{m}^2$ for handwipe nicotine and ng/ml for saliva cotinine.

Statistical Analysis

Analyses were conducted with Stata version 18. Age variables and income categories were determined based on our previous work which demonstrated associations with HN levels and income categories.¹⁸⁻²⁰ For interval-scale variables of Home Total Square Feet, Home Built (year), and Last Hand Washing (minutes), we created ordinal categories with approximately equal numbers of participants. HN and SC measures were log-transformed. Multivariable regression was used for models of HN. Tobit regression censored at the MDL was used for models of SC. All models used cluster adjustments (i.e., children belonging to a family) and

bootstrap robust standard errors. We initially included all sociodemographic, housing, and hand-washing variables as well as their potential interactions with HN. After removing statistically nonsignificant associations, we re-estimated the model, and we report the overall model fit and parameter estimates. Interaction effects were further investigated by testing differences between conditional effects. The Type I error rate was set at 0.05.

Results

Nicotine on Children's Hands

Prevalence and Distributional Patterns

Table 1 shows that 96.1% of children were exposed to tobacco smoke pollutants as evidenced by nicotine on hands. Nicotine residue was detected on the hands of 94.5% of protected children and 98.9% of unprotected children. The geometric mean (GeoM) level of HN in the unprotected group (22.6 ng nicotine/wipe) was 10 times higher than the GeoM level in the protected group (2.2 ng/wipe). Histograms of the HN distribution among protected and unprotected children are shown in Figure S1 in the supplemental information.

Unadjusted GeoM HN Levels by Sociodemographic, Tobacco Use, and Home Characteristics

Table 2 shows the unadjusted GeoM HN levels, showing stark differences between race, education, and income in protected versus unprotected children. Black children had approximately three times more GeoM HN levels than White children who were protected or unprotected. Unprotected children whose parents had $\leq$ a high school education had GeoM HN levels almost 12 times higher (87.8 ng/wipe) than unprotected children whose parents graduated from college (7.5 ng/wipe). Exposure disparities were even more pronounced when comparing low and high-income groups. Unprotected children with $\leq$ \$15,000 household income had GeoM HN levels > 25 times higher (73.3 ng/wipe) than children with incomes of $>$ \$90,000 ($\leq$ 2.8 ng/wipe). Protected children in the lowest-income group had GeoM HN levels six times higher than those in the high-income group (9.9 versus $\leq$ 1.7 ng/wipe).

Nicotine levels were strongly associated with parental tobacco use, household smoking rules, number of tobacco product users around the child, and hand washing. Furthermore, the more smokers around the child during the past week, the higher the GeoM HN levels. Among the unprotected group, children of parents who used tobacco products had 5-17 times higher GeoM HN (44.2-131.7 ng/wipe) than children of parental nonsmokers (7.8ng/wipe). Among protected children, complete household smoking bans were associated with lower GeoM HN levels (5.8 ng/wipe) by more than a ten-fold difference compared to no/partial smoking bans (64.5 to 91.0 ng/wipe). There was no discernable ordinal pattern in GeoM HN levels as a function of time since the last hand washing.

Concerning home characteristics, both protected and unprotected children had higher GeoM HN levels when they lived in older and smaller homes and in multiunit buildings compared to children living in single-family, newer, and larger homes (Table 2).

Factors Contributing to HN

Table 3 shows the multivariable model investigating the unique associations of HN with sociodemographics, tobacco use patterns, and home characteristics. The overall model accounts for 64% of the variance in HN (Adjusted $R^2=0.64$; Wald $\chi^2(30)=13,374.7$, $p<0.0001$). Consistent with the unadjusted mean differences, the independent associations adjusted for confounders show significant effects of sociodemographic, housing, and tobacco use characteristics, and parental efforts to protect against TSE through smoking bans.

Findings show that differences in HN levels between boys and girls were affected by the child's age ($\chi^2(3)=8.4$, $p=0.0384$). Controlling for other confounders, girls had overall lower HN levels than boys, which remained at similar levels from 2-11 years. Boys had significantly higher levels than girls from age 2-7 but had similar levels from age 0-1 year (see Figure 1, Panel A; numeric data for Panels A-F in Figure 1 are reported in Table S1 in the Supplemental Materials).

Home smoking bans protected White children from tobacco smoke pollutants more effectively than for Black children ($\chi^2(3)=12.7$, $p=0.0054$). Figure 1 (Panel B) shows that HN levels for Black children were virtually identical regardless of smoking ban status. In contrast, White children living with smoking bans had significantly lower levels of HN than White children in homes that did not adopt such protections.

Figure 1 (Panel C) shows a strong association between income and HN level that was particularly pronounced for unprotected children ($\chi^2(6)=26.6$, $p=0.0002$). Children in higher-income families had significantly lower HN levels than children in lower-income families. This association between income and HN was much weaker for families adopting smoking bans.

When comparing different household smoking rules ($\chi^2(4)=100.4$, $p<0.0001$) independent of other protective measures, adoption of a strict household smoking ban (i.e., nobody is ever allowed to smoke in the home) was the only smoking rule associated with lower HN levels (Figure 1, Panel D). Controlling for other variables, hand washing was associated with lower HN levels ($\chi^2(4)=15.3$, $p<0.0041$; Figure 1 Panel E), but only for children who washed their hands within the past 30 minutes. Finally, living in a trailer was associated with significantly higher HN levels than living in other types of homes ($\chi^2(5)=18.6$, $p<0.0023$). Controlling for other variables, children living in single-family homes, apartment buildings, multi-family homes, and townhouses had similar HN levels (Figure 1, Panel F).

Cotinine in Children's Saliva

Prevalence and Distributional Patterns

Table 1 shows that among protected children, 67.7% had detectable SC, and 93.6% of children believed to be unprotected from TSE had measurable SC levels. The GeoM level in the unprotected group was 13 times higher than in the protected group (1.77 versus 0.13 ng/ml). Histograms of the SC distribution among protected and unprotected children are shown in Figure S2 in the supplemental information.

Factors Affecting Saliva Cotinine

Table 4 shows results of the multivariable Tobit regression models in which SC was the response variable and sociodemographic, tobacco use, and home characteristics were explanatory variables. The overall model accounts for 76% of the variance in SC (Adjusted $R^2=0.7639$; $F(27,911)=49.86$, $p<0.0001$). HN played a prominent role in predicting SC through its moderating effects on child age, family income, and number of people using tobacco products around the child.

Findings show that the association between HN and SC was significantly stronger ($F(3,911)=5.78$, $p=0.0006$) among the 0-1 year and 2-4 year-olds ($\hat{\beta}=0.24$, $\hat{\beta}=0.23$) than among the 5-7 year and 8-11 year olds ($\hat{\beta}=0.13$, $\hat{\beta}=0.12$). That is, the same level of HN was associated with higher levels of SC for younger as compared to older children (see Figure 2, Panel A; numeric data for Panels A-D in Figure 2 are presented in Table S2 in the Supplemental Materials). The association between HN and SC was also significantly stronger in children from lower- versus higher-income families ($F(6,911)=2.70$, $p=0.0132$). Figure 2 (Panel B) shows that the association among the two lowest income groups ($\hat{\beta}=0.21$, $\hat{\beta}=0.26$) was 2-3 times stronger than for children in the two highest income groups ($\hat{\beta}=0.14$, $\hat{\beta}=0.09$). Figure 2 (Panel C) shows the association between HN and SC as a function of the number of smokers around the child ($F(2, 911)=14.3$, $p<0.0001$). In the absence of any smokers around a child, we observed a significant association between HN and SC ($\hat{\beta}=0.10$, $p<0.001$). In the presence of one smoker ($\hat{\beta}=0.28$, $p<0.001$) and ≥ 2 smokers ($\hat{\beta}=0.32$, $p<0.001$) the association was 2-3 times stronger. Finally, Figure 2, Panel D shows that independent of HN and other variables, household smoking bans that always/ usually prohibited home smoking were associated with significantly lower SC levels compared to always/usually allowing home smoking ($F(4, 911)=3.91$, $p=0.0037$).

Discussion

In this study of 1,013 children, we found that over nine in ten children of nonsmokers classified as protected from tobacco smoke were, in fact, not protected from THS residues left behind by smoking. As hypothesized, there were stark sociodemographic disparities in exposure to THS in protected children, with the highest levels being in children who were Black and whose parents had a lower educational level or lower income. Housing disparities were evident as both protected and unprotected children who lived in multiunit homes or in homes that were smaller or older had the highest HN levels. Differences in housing could potentially explain the sociodemographic differences in THS exposure observed in protected children. Children living in poverty may live in older, low-quality homes with poor structural building conditions, insufficient maintenance, and substandard heating and air-conditioning.^{33,34} In addition, these children may live in subsidized multiunit housing, which previously housed tenants with high smoking rates.^{35,36} These conditions may contribute to increased TSE from secondhand smoke intrusion in their homes and increased exposure to THS residue from previous smokers. Older buildings housed more residents during times when smoking rates were higher and indoor smoking norms were more permissive, allowing more THS residue to accumulate.^{7,37,38} Further, children who live in multiunit housing are exposed to higher levels of SHS from active smoking due to smoke infiltration through shared walls and spaces³⁹⁻⁴¹ and higher exposure to THS from years of former smoking inside and outside of the apartments.⁷ Additionally, prior research indicates that there are high rates of violations of indoor smoke-free rules in multiunit housing, especially in Section 8 or other low-income housing.⁴² Moreover, there are higher concentrations of tobacco retailers, tobacco promotions, or tobacco marketing in neighborhoods with a higher density of Black and/or low-income residents.⁴³⁻⁴⁵ These factors may contribute to higher rates of current and prior tobacco use in Black adults and, consequently, higher rates of exposure to SHS and THS in the children in our sample. Concerning other demographic characteristics and consistent with prior research,¹⁸⁻²⁰ we

replicated that 2-4-year-olds have higher HN levels, which is likely due to their exploratory activities. Unexpectedly, boys and 5-7-year-olds had higher HN levels compared to girls, infants, and older children. These findings may be the result of different types of activities among children in these sex and age subgroups.

The study results provide the strongest evidence to date in support of THS-only exposure in the absence of SHS exposure in children. This is demonstrated by the observation that HN is associated with SC in children with complete household smoking bans and no SHS exposure ($\beta = 0.10$). Thus, THS exposure independently contributes to TSE in the absence of SHS. Further, our findings indicate that HN is a more sensitive TSE marker than SC, as 96% of children tested positive for HN, while only 77% tested positive for SC. Further, nicotine on children's hands may be a preferable external marker of exposure risk to tobacco smoke pollutants because, unlike cotinine, an internal marker, HN is not affected by genetic factors known to vary between racial groups.^{23,25,26}

Concerning strategies to protect children from THS exposure, prior hand washing within 30 minutes of sampling was associated with lower HN levels, but these benefits were short-lived. These results are aligned with prior research that indicates that hand washing does not completely remove nicotine from the hands of smokers because pollutants can be stored in the epidermis, hair follicles, sweat ducts, and adipose tissue.⁴⁶ Moreover, this finding underscores the importance of measuring HN when assessing children's overall TSE as HN is a robust measure of the environmental sources of THS to which children may be exposed that may be missed if biomarkers such as cotinine alone are measured.^{18,24} However, aligned with prior research,^{23,24} household smoking bans in both smokers' and nonsmokers' homes were associated with lower HN levels in this large sample of children which had a wide range of income levels. This is important to highlight because, unlike sociodemographic characteristics or housing conditions, smoking bans are a modifiable, low-cost, and universally accessible strategy that can be implemented by all as a way to protect their family members against THS

and SHS exposure. Further, smoking bans were even more effective in decreasing HN levels in unprotected children, thus demonstrating that there is a way for individuals living with smokers to protect children from exposure to tobacco smoke residue. Nevertheless, perhaps the most alarming finding was that while White children who live in homes with smoking bans had lower HN levels, Black children who live with nonsmokers and whose parents may have believed that they were protected from tobacco smoke had virtually the same HN levels as Black children who lived in smokers' homes. These results provide strong impetus for a call to action against ubiquitous tobacco residue in environments in which tobacco was previously used.^{7,14,47} Young children are most vulnerable to exposure to THS due to their exploratory activities, which allow them to absorb dermally, ingest, and inhale THS pollutants from floors, furniture, toys, dust, and home surfaces.^{14,15} Nicotine, a stimulant and toxicant that is associated with pediatric respiratory,^{13-15,48,49} neurodevelopmental,^{16,17,48} and other health effects,^{1,17,48,49} is the most abundant organic chemical THS constituent.^{50,51} The high HN levels on children's hands in this study signify exposure to this dangerous chemical and many others in THS. At a minimum, these results suggest that it is crucial to strictly enforce policies that require adherence to comprehensive smoke-free homes and smoking bans in public areas. Further, since household smoking bans are not enough if the home is already polluted,^{5,7} interventions to clean THS-polluted homes need to be developed and tested.

This study's strengths include the large pediatric sample, of whom 22% were non-Hispanic Black race/ethnicity, 18% had incomes <\$15,000, and 34% lived with ≥ 1 smoker. Unlike prior TSE-related studies, we measured THS exposure in nonsmokers' children who lived in SHS-free environments and documented that they were living in THS-polluted environments, unbeknownst to their parents. Children were biochemically confirmed as being protected or unprotected from tobacco smoke using two markers of exposure: SC, a measure of children's overall TSE, and HN, a measure of THS pollution levels in children's environments. Results were ascertained using cluster-adjusted and robust statistical methods. Parent reports about

tobacco use, household smoking behaviors and bans, housing types, and hand washing allowed us to explore how home practices affect children's exposure. Further, these reports gave us the opportunity to examine the association of HN and SC conditional on levels of SHS to which children were exposed (i.e., 0, 1, or ≥ 2 smokers). The results indicate that THS uniquely contributes to children's TSE and that HN is not just "dirt that can be washed off". However, there are limitations. This is an observational study; thus, causal associations should be interpreted in the context of the strength of plausible alternative explanations. Although two biomarkers were assessed, there is no gold standard biomarker to assess SHS or THS-only exposure. Finally, parent reports may have been inaccurate due to recall or social desirability biases or lack of information about tobacco use patterns in other locations in which children spend time. Thus, reports on smoking bans or the location or frequency of children's TSE could have been over or underestimated. We did not assess if nonsmoking parents were former smokers, but if they were, then their children could have been exposed to more THS in their homes compared to children whose parents were not former smokers.

In conclusion, the study's results indicate high percentages of THS exposure among both protected and unprotected children, with strong disparities noted related to race, education, and income level. The lack of protection against THS despite household smoking bans among Black and low-income children suggests deep-seated housing disparities,⁵² low-quality housing,^{33,34} promotion of tobacco use,⁴³⁻⁴⁵ and lack of enforcement of public housing smoking bans,^{53,54} all of which may lead to higher THS exposure rates.⁵³⁻⁵⁵ Strict smoke-free housing rules with no loopholes and remediation of public housing are necessary. Further, this study highlights the widespread and enduring nature of THS pollution and demonstrates its independent contribution to exposure to tobacco smoke pollutants, underscoring the urgency to investigate its clinical impact on children and vulnerable populations.

References

1. U.S. Department of Health and Human Services. *The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, Coordinating Center for Health Promotion, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2006.
2. U.S. Department of Health and Human Services. *The Health Consequences of Smoking: 50 Years of Progress. A Report of the Surgeon General*. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2014.
3. Centers for Disease Control and Prevention (US), National Center for Chronic Disease Prevention and Health Promotion (US), Office on Smoking and Health (US). Publications and Reports of the Surgeon General. *How Tobacco Smoke Causes Disease: The Biology and Behavioral Basis for Smoking-Attributable Disease: A Report of the Surgeon General*. Atlanta, GA: Centers for Disease Control and Prevention (US); 2010.
4. Office of the Surgeon General (US), Office on Smoking and Health (US). Reports of the Surgeon General. *The Health Consequences of Smoking: A Report of the Surgeon General*. Atlanta, GA: Centers for Disease Control and Prevention (US); 2004.
5. Matt GE, Quintana PJ, Zakarian JM, et al. When smokers move out and non-smokers move in: residential thirdhand smoke pollution and exposure. *Tob Control*. Jan 2011;20(1):e1. PMID:21037269. doi:10.1136/tc.2010.037382.
6. Matt GE, Quintana PJE, Zakarian JM, et al. When smokers quit: exposure to nicotine and carcinogens persists from thirdhand smoke pollution. *Tob Control*. Sep 2016;26(5):548-556. PMID:27655249. doi:10.1136/tobaccocontrol-2016-053119.

7. Matt GE, Quintana PJE, Hoh E, et al. Persistent tobacco smoke residue in multiunit housing: Legacy of permissive indoor smoking policies and challenges in the implementation of smoking bans. *Prev Med Rep.* Jun 2020;18:101088. PMID:32368436. doi:10.1016/j.pmedr.2020.101088.
8. Matt GE, Greiner L, Record RA, et al. Policy-relevant differences between secondhand and thirdhand smoke: strengthening protections from involuntary exposure to tobacco smoke pollutants. *Tob Control.* Oct 19 2024;33(6):798-806. PMID:37263783. doi:10.1136/tc-2023-057971.
9. Diez-Izquierdo A, Cassanello-Penarroya P, Lidon-Moyano C, Matilla-Santander N, Balaguer A, Martinez-Sanchez JM. Update on thirdhand smoke: A comprehensive systematic review. *Environ Res.* Nov 2018;167:341-371. PMID:30096604. doi:10.1016/j.envres.2018.07.020.
10. Tang X, Benowitz N, Gundel L, et al. Thirdhand Exposures to Tobacco-Specific Nitrosamines through Inhalation, Dust Ingestion, Dermal Uptake, and Epidermal Chemistry. *Environ Sci Technol.* Sep 6 2022;56(17):12506-12516. PMID:35900278. doi:10.1021/acs.est.2c02559.
11. Xu B, Chen M, Yao M, et al. Metabolomics reveals metabolic changes in male reproductive cells exposed to thirdhand smoke. *Sci Rep.* Oct 22 2015;5:15512. PMID:26489853. doi:10.1038/srep15512.
12. Raghuveer G, White DA, Hayman LL, et al. Cardiovascular Consequences of Childhood Secondhand Tobacco Smoke Exposure: Prevailing Evidence, Burden, and Racial and Socioeconomic Disparities: A Scientific Statement From the American Heart Association. *Circulation.* Oct 18 2016;134(16):e336-e359. PMID:27619923. doi:10.1161/CIR.0000000000000443.

13. Ahmad S, Zafar I, Mariappan N, et al. Acute pulmonary effects of aerosolized nicotine. *Am J Physiol Lung Cell Mol Physiol*. Jan 1 2019;316(1):L94-L104. PMID:30358437. doi:10.1152/ajplung.00564.2017.
14. Jacob P, 3rd, Benowitz NL, Destailats H, et al. Thirdhand Smoke: New Evidence, Challenges, and Future Directions. *Chem Res Toxicol*. Jan 17 2017;30(1):270-294. PMID:28001376. doi:10.1021/acs.chemrestox.6b00343.
15. Matt GE, Quintana PJ, Destailats H, et al. Thirdhand tobacco smoke: emerging evidence and arguments for a multidisciplinary research agenda. *Environ Health Perspect*. Sep 2011;119(9):1218-26. PMID:21628107. doi:10.1289/ehp.1103500.
16. Castro EM, Lotfipour S, Leslie FM. Nicotine on the developing brain. *Pharmacol Res*. Apr 2023;190:106716. PMID:36868366. doi:10.1016/j.phrs.2023.106716.
17. McGrath-Morrow SA, Gorzkowski J, Groner JA, et al. The Effects of Nicotine on Development. *Pediatrics*. Mar 2020;145(3):e20191346. PMID:32047098. doi:10.1542/peds.2019-1346.
18. Mahabee-Gittens EM, Merianos AL, Jandarov RA, Quintana PJE, Hoh E, Matt GE. Differential associations of hand nicotine and urinary cotinine with children's exposure to tobacco smoke and clinical outcomes. *Environ Res*. Nov 2021;202:111722. PMID:34297932. doi:10.1016/j.envres.2021.111722.
19. Mahabee-Gittens EM, Merianos AL, Hoh E, Quintana PJ, Matt GE. Nicotine on Children's Hands: Limited Protection of Smoking Bans and Initial Clinical Findings. *Tob Use Insights*. 2019;12:1179173X18823493. PMID:30728727. doi:10.1177/1179173X18823493.
20. Matt GE, Merianos AL, Quintana PJE, Hoh E, Dodder NG, Mahabee-Gittens EM. Prevalence and Income-Related Disparities in Thirdhand Smoke Exposure to Children. *JAMA Netw Open*. Feb 1 2022;5(2):e2147184. PMID:35129597. doi:10.1001/jamanetworkopen.2021.47184.

21. Cornelius ME, Loretan CG, Jamal A, et al. Tobacco Product Use Among Adults - United States, 2021. *MMWR Morb Mortal Wkly Rep*. May 5 2023;72(18):475-483. PMID:37141154. doi:10.15585/mmwr.mm7218a1.
22. Dai X, Gakidou E, Lopez AD. Evolution of the global smoking epidemic over the past half century: strengthening the evidence base for policy action. *Tob Control*. Mar 2022;31(2):129-137. PMID:35241576. doi:10.1136/tobaccocontrol-2021-056535.
23. Mahabee-Gittens EM, Merianos AL, Stone L, et al. Hand nicotine as an independent marker of thirdhand smoke pollution in children's environments. *Sci Total Environ*. Nov 25 2022;849:157914. PMID:35952873. doi:10.1016/j.scitotenv.2022.157914.
24. Matt GE, Merianos AL, Stone L, et al. Changes and stability of hand nicotine levels in children of smokers: Associations with urinary biomarkers, reported child tobacco smoke exposure, and home smoking bans. *Environ Int*. Nov 2023;181:108239. PMID:37852151. doi:10.1016/j.envint.2023.108239.
25. Benowitz NL, Bernert JT, Foulds J, et al. Biochemical Verification of Tobacco Use and Abstinence: 2019 Update. *Nicotine Tob Res*. Jun 12 2020;22(7):1086-1097. PMID:31570931. doi:10.1093/ntr/ntz132.
26. Zhu AZ, Renner CC, Hatsukami DK, et al. The ability of plasma cotinine to predict nicotine and carcinogen exposure is altered by differences in CYP2A6: the influence of genetics, race, and sex. *Cancer Epidemiol Biomarkers Prev*. Apr 2013;22(4):708-18. PMID:23371292. doi:10.1158/1055-9965.EPI-12-1234-T.
27. Paya P, Anastassiades M, Mack D, et al. Analysis of pesticide residues using the Quick Easy Cheap Effective Rugged and Safe (QuEChERS) pesticide multiresidue method in combination with gas and liquid chromatography and tandem mass spectrometric detection. *Anal Bioanal Chem*. Nov 2007;389(6):1697-714. PMID:17909760. doi:10.1007/s00216-007-1610-7.

28. Lehotay SJ, de Kok A, Hiemstra M, Van Bodegraven P. Validation of a fast and easy method for the determination of residues from 229 pesticides in fruits and vegetables using gas and liquid chromatography and mass spectrometric detection. *J AOAC Int.* Mar-Apr 2005;88(2):595-614. PMID:15859089.
29. Armbruster DA, Pry T. Limit of blank, limit of detection and limit of quantitation. *Clin Biochem Rev.* Aug 2008;29 Suppl 1(Suppl 1):S49-52. PMID:18852857.
30. U.S. Federal Government. Code of Federal Regulations. 40 CFR Appendix B to Part 136 - Definition and Procedure for the Determination of the Method Detection Limit-Revision 1.11. *Title 40 - Protection of Environment.* Authenticated U.S. Government Information; 2011.
31. Mahabee-Gittens EM, Matt GE, Lopez-Galvez N, et al. Thirdhand Smoke Exposure (ADVOCATE) Study Protocol: Assessment, Detection, and Validation of Clinical Associations. *Pediatr Res.* 2025 (In Press).
32. Quintana PJE, Hoh E, Dodder NG, et al. Nicotine levels in silicone wristband samplers worn by children exposed to secondhand smoke and electronic cigarette vapor are highly correlated with child's urinary cotinine. *J Expo Sci Environ Epidemiol.* Oct 2019;29(6):733-741. PMID:30728487. doi:10.1038/s41370-019-0116-7.
33. Hernandez D, Swope CB. Housing as a Platform for Health and Equity: Evidence and Future Directions. *Am J Public Health.* Oct 2019;109(10):1363-1366. PMID:31415202. doi:10.2105/AJPH.2019.305210.
34. 2023 National — General Housing Data — All Occupied Units. American Housing Survey (AHS) Table Creator. United States Census Bureau web site ([www.Census.gov](https://www.census.gov)). Accessed January 21, 2025. https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html?s_areas=00000&s_year=2023&s_tablename=TABLE1&s_bygroup1=1&s_bygroup2=1&s_filtergroup1=1&s_filtergroup2=1

35. Feinberg A, Lopez PM, Wyka K, et al. Prevalence and Correlates of Smoking among Low-Income Adults Residing in New York City Public Housing Developments-2015. *J Urban Health*. Aug 2017;94(4):525-533. PMID:28656541. doi:10.1007/s11524-017-0180-z.
36. Hood NE, Ferketich AK, Klein EG, Wewers ME, Pirie P. Smoking behaviors and cessation interests among multiunit subsidized housing tenants, Columbus, Ohio, 2011. *Prev Chronic Dis*. Jul 3 2013;10:E108; quiz E108. PMID:23806803. doi:10.5888/pcd10.120302.
37. Berg CJ, Haardorfer R, Windle M, Solomon M, Kegler MC. Smoke-Free Policies in Multiunit Housing: Smoking Behavior and Reactions to Messaging Strategies in Support or in Opposition. *Prev Chronic Dis*. Jun 25 2015;12:E98. PMID:26111158. doi:10.5888/pcd12.140479.
38. Nguyen KH, Gomez Y, Homa DM, King BA. Tobacco Use, Secondhand Smoke, and Smoke-Free Home Rules in Multiunit Housing. *Am J Prev Med*. Nov 2016;51(5):682-692. PMID:27423656. doi:10.1016/j.amepre.2016.05.009.
39. Tsai J, Homa DM, Neff LJ, et al. Trends in Secondhand Smoke Exposure, 2011-2018: Impact and Implications of Expanding Serum Cotinine Range. *Am J Prev Med*. Sep 2021;61(3):e109-e117. PMID:34419235. doi:10.1016/j.amepre.2021.04.004.
40. Kraev TA, Adamkiewicz G, Hammond SK, Spengler JD. Indoor concentrations of nicotine in low-income, multi-unit housing: associations with smoking behaviours and housing characteristics. *Tob Control*. Dec 2009;18(6):438-44. PMID:19679890. doi:10.1136/tc.2009.029728.
41. Repace JL. Secondhand smoke Infiltration in multiunit housing: Health effects and nicotine levels. *Indoor Environments*. 2024/06/01/ 2024;1(2):100013. doi:10.1016/j.indenv.2024.100013.
42. Thorpe LE, Anastasiou E, Wyka K, et al. Evaluation of Secondhand Smoke Exposure in New York City Public Housing After Implementation of the 2018 Federal Smoke-Free Housing

Policy. *JAMA Netw Open*. Nov 2 2020;3(11):e2024385. PMID:33151318.

doi:10.1001/jamanetworkopen.2020.24385.

43. Kaviany P, Senter JP, Collaco JM, et al. Spatial analysis of tobacco outlet density on secondhand smoke exposure and asthma health among children in Baltimore City. *Tob Control*. Jan 19 2022. PMID:35046128. doi:10.1136/tobaccocontrol-2021-056878.

44. Ribisl KM, D'Angelo H, Feld AL, et al. Disparities in tobacco marketing and product availability at the point of sale: Results of a national study. *Prev Med*. Dec 2017;105:381-388. PMID:28392252. doi:10.1016/j.ypmed.2017.04.010.

45. Lee JG, Henriksen L, Rose SW, Moreland-Russell S, Ribisl KM. A Systematic Review of Neighborhood Disparities in Point-of-Sale Tobacco Marketing. *Am J Public Health*. Sep 2015;105(9):e8-18. PMID:26180986. doi:10.2105/ajph.2015.302777.

46. Northrup TF, Stotts AL, Suchting R, et al. Handwashing Results in Incomplete Nicotine Removal from Fingers of Individuals who Smoke: A Randomized Controlled Experiment. *Am J Perinatol*. Nov 2022;39(15):1634-1642. PMID:34634832. doi:10.1055/s-0041-1736287.

47. Wu JX, Lau ATY, Xu YM. Indoor Secondary Pollutants Cannot Be Ignored: Third-Hand Smoke. *Toxics*. Jun 30 2022;10(7). PMID:35878269. doi:10.3390/toxics10070363.

48. England LJ, Aagaard K, Bloch M, et al. Developmental toxicity of nicotine: A transdisciplinary synthesis and implications for emerging tobacco products. *Neurosci Biobehav Rev*. Jan 2017;72:176-189. PMID:27890689. doi:10.1016/j.neubiorev.2016.11.013.

49. Gibbs K, Collaco JM, McGrath-Morrow SA. Impact of Tobacco Smoke and Nicotine Exposure on Lung Development. *Chest*. Feb 2016;149(2):552-561. PMID:26502117. doi:10.1378/chest.15-1858.

50. Aquilina NJ, Havel CM, Cheung P, et al. Ubiquitous atmospheric contamination by tobacco smoke: Nicotine and a new marker for tobacco smoke-derived particulate matter, nicotelline. *Environ Int*. May 2021;150:106417. PMID:33561671. doi:10.1016/j.envint.2021.106417.

51. Jacob P, 3rd, Goniewicz ML, Havel CM, Schick SF, Benowitz NL. Nicotelline: a proposed biomarker and environmental tracer for particulate matter derived from tobacco smoke. *Chem Res Toxicol*. Nov 18 2013;26(11):1615-31. PMID:24125094. doi:10.1021/tx400094y.
52. Sabado-Liwag M, Zamora M, El-Toukhy S. Current state of unhealthy living characteristics in Black/African American and Latino populations: Tobacco use. *Prog Cardiovasc Dis*. Mar-Apr 2022;71:27-36. PMID:35490867. doi:10.1016/j.pcad.2022.04.009.
53. Anastasiou E, Feinberg A, Tovar A, et al. Secondhand smoke exposure in public and private high-rise multiunit housing serving low-income residents in New York City prior to federal smoking ban in public housing, 2018. *Sci Total Environ*. Feb 20 2020;704:135322. PMID:31787288. doi:10.1016/j.scitotenv.2019.135322.
54. Zajac L, Gallate X, Gu G, et al. Disparities in Marijuana and Tobacco Smoke Incursions Among New York City Families During Early Months of the COVID-19 Pandemic. *J Public Health Manag Pract*. May-Jun 01 2022;28(3):248-257. PMID:34750327. doi:10.1097/PHH.0000000000001440.
55. Twum F, Tome J, Ledel E, et al. The Diverging Trend in Exposure to Environmental Tobacco Smoke Among US Children. *J Racial Ethn Health Disparities*. Jun 2024;11(3):1718-1729. PMID:37326795. doi:10.1007/s40615-023-01645-y.

Table 1. Prevalence and concentrations of hand nicotine and saliva cotinine in overall sample and protected and unprotected subgroups.

	Total Sample	Unprotected: Exposed to Tobacco Smoke ^A	Protected: Unexposed to Tobacco Smoke ^B
Hand Nicotine (ng/wipe)			
N Children; N Families	1,013; 862	363; 324	650; 541
% >LOQ [95% CI]	96.1 [94.5;97.2]	98.9 [96.9;99.6]	94.5 [92.3;96.1]
GeoMean, ng/wipe [95% CI]	5.6 [4.9;6.2]	22.7 [19.4;26.5]	2.2 [1.9;2.5]
Min-Q1-Mdn-Q3-Max, ng/wipe	0-1.0-2.7-12.5-2341.6	0-3.4-22.5-115.2-2341.6	0-0.7-1.6-4.2-233.2
Hand Nicotine (ng/ml)			
GeoMean, µg/m ² [95% CI]	1.2 [1.1;1.4]	4.2 [3.4; 5.1]	0.4 [0.4;0.5]
Min-Q1-Mdn-Q3-Max. µg/m ²	0-0.1-0.4-1.6-300.2	0-0.5-2.9-13.3-300.2	0-0.1-0.2-0.6-85.2
Saliva Cotinine			
N Children – N Families	939 -- 803	326 -- 294	613 -- 512
% >LOQ [95% CI]	76.7 [73.9;79.3]	93.6 [89.3;96.2]	67.7 [63.5;71.6]
GeoMean [95% CI]	0.54 [0.47;0.62]	1.77 [1.43;2.14]	0.13 [0.11;0.16]
Min-Q1-Mdn-Q3-Max	0-0.02-0.07-0.54-516.38	0-0.11-1.06-4.83-516.38	0-0-0.04-0.11-14.85

^AUnprotected means that one or more of the following were true: the child's parents or guardians used tobacco products; the child was near one or more smokers during the past week; home smoking rules allowed smoking all the time, usually, sometimes, or by certain people.

^BProtected means that all of the following were true: the child's parents or guardians did not use tobacco products; there were no smokers near the child during the past week; smoking was never allowed at home without exceptions.

Abbreviations: LOQ: level of quantitation; GeoMean: geometric mean; CI: confidence interval; Min: minimum; Mdn: median; Max: maximum; ng/wipe: nanograms per hand wipe; µg/m²: micrograms per meter squared; ng/ml: nanograms per milliliter of saliva

Table 2. Unadjusted geometric mean hand nicotine levels (ng/wipe) for the overall (N=1,013), unprotected (N=363), and protected (N=650) subgroups for different home characteristics.

	Total Sample				Unprotected: Exposed to Tobacco Smoke ^A				Protected: Unexposed to Tobacco Smoke ^B			
	GeoMean [95% CI] ^C		N	%	GeoMean [95% CI] ^C		N	%	GeoMean [95% CI] ^C		N	%
Child Age, years												
0-1	5.0	[3.7;6.6]	177	17.5	24.2	[14.0;41.5]	64	17.6	1.6	[1.2;2.2]	113	17.4
2-4	6.4	[5.0;8.0]	270	26.7	21.9	[13.7;34.6]	99	27.3	2.8	[2.3;3.4]	171	26.3
5-7	5.8	[4.7;7.1]	253	25.0	22.9	[13.9;33.8]	90	24.8	2.5	[2.0;3.0]	163	25.1
8-11	5.1	[4.1;6.3]	313	30.9	23.9	[15.5;34.7]	110	30.3	1.6	[1.6;2.2]	203	31.2
Missing			0				0				0	
p-value ^D	0.5779				0.9883				0.0001			
Child Sex												
Male	6.3	[5.2;7.5]	498	49.2	31.1	[21.9;43.9]	168	46.3	2.4	[2.1;2.7]	330	50.8
Female	4.9	[4.0;6.0]	515	50.8	17.2	[13.0;22.7]	195	53.7	2.0	[1.7;2.3]	320	49.2
Missing			0				0				0	
p-value ^D	0.1055				0.0051				0.1529			
Parent Ethnicity												
Non-Hispanic	5.7	[5.0;6.5]	966	95.5	22.6	[17.8;28.6]	353	97.8	2.2	[2.0;2.4]	613	94.3
Hispanic	3.2	[1.7;5.7]	45	4.5	18.1	[6.5;47.8]	8	2.2	1.9	[0.8;3.8]	37	5.7
Missing			2				2				0	
p-value ^D	0.0622				0.9020				0.6950			
Parent Race												
White	3.6	[3.0;4.2]	720	71.1	15.0	[11.2;19.8]	201	55.4	1.8	[1.6;2.0]	519	80.0
Black/African American	21.9	[16.4;29.0]	221	21.8	43.8	[33.6;57.1]	141	38.8	6.0	[3.8;9.1]	80	12.3
Other	2.6	[1.6;4.1]	30	3.0	4.1	[0.7;14.5]	8	2.2	2.2	[1.3;3.4]	22	3.4
More than one	5.8	[3.1;10.4]	41	4.1	25.4	[9.4;66.2]	13	3.6	2.6	[1.5;4.4]	28	4.3
Missing			1				0				1	
p-value ^D	<0.0001				<0.0001				<0.0001			
Parent Education												
Less than High School	50.3	[25.1;99.9]	35	3.5	87.8	[46.8;164.0]	27	7.4	7.1	[4.0;12.0]	8	1.2
High School Graduate	28.6	[21.5;38.1]	157	15.5	49.3	[34.3;70.7]	109	30.0	7.9	[4.5;13.3]	48	7.4
Vocational/Technical	8.8	[3.9;18.6]	37	3.7	25.8	[10.3;62.6]	16	4.4	3.6	[1.7;6.9]	21	3.2
Some College	9.9	[7.4;13.2]	183	18.1	31.4	[19.0;51.6]	90	24.8	2.8	[2.0;3.8]	93	14.3
College Graduate	2.7	[2.3;3.3]	299	29.5	7.5	[4.9;11.1]	82	22.8	1.7	[1.4;2.0]	217	33.4
Post-Graduate	1.9	[1.6;2.4]	302	29.8	3.6	[1.9;6.3]	39	10.7	1.7	[1.4;2.1]	263	40.5
Missing			0				0				0	
p-value ^D	<0.0001				<0.0001				<0.0001			

Parent Income												
≤\$15,000	44.1	[33.1;58.6]	185	18.3	73.3	[56.9;94.3]	137	37.7	9.9	[6.4;15.1]	48	7.4
\$15,001-\$30,000	14.9	[9.4;23.34]	87	8.6	34.9	[21.9;55.1]	54	14.9	3.2	[1.8;5.3]	33	5.1
\$30,001-\$50,000	7.6	[4.9;11.5]	106	10.5	23.0	[13.6;38.6]	48	13.2	2.7	[1.8;3.9]	58	9.0
\$50,001-\$75,000	3.4	[2.6;4.4]	124	12.3	8.9	[5.0;15.3]	41	11.3	2.0	[1.5;2.5]	83	12.8
\$75,001-\$90,000	2.7	[2.0;3.5]	98	9.7	5.1	[2.5;9.6]	19	5.2	2.3	[1.6;3.1]	79	12.2
\$90,001-\$120,000	1.8	[1.4;2.3]	130	12.9	2.7	[1.5;4.3]	24	6.6	1.7	[1.4;2.0]	106	16.4
>\$120,000	1.7	[1.5;2.0]	281	27.8	2.8	[1.5;4.28]	40	11.0	1.6	[1.3;1.9]	241	37.2
Missing			2					0				2
p-value ^D	<0.0001				<0.0001				<0.0001			
Parent Tobacco Use												
None	3.1	[2.7;3.4]	855	84.4	7.8	[6.2;9.7]	205	56.5	2.2	[1.9;2.5]	650	100.0
Cigarettes - only	131.7	[97.5;177.7]	81	8.0	131.7	[103.3;167.8]	81	22.3			0	0
Cigars - only	44.2	[28.8;67.5]	37	3.7	44.2	[30.7;63.3]	37	10.2			0	0
Vaping - only	55.4	[16.1;184.7]	12	1.2	55.4	[14.8;199.9]	12	3.3			0	0
Combination	67.1	[43.5;103.2]	28	2.8	67.1	[42.6;105.3]	28	7.7			0	0
Missing			0					0			0	
p-value ^D	<0.0001				<0.0001				NA			
Home Smoking Rules												
Allowed anywhere	64.5	[43.3;95.5]	54	5.3	64.5	[41.3;100.4]	54	14.9			0	0
Usually allowed	91.0	[64.3;128.6]	55	5.4	91.0	[65.7;125.8]	55	15.2			0	0
Usually not allowed	61.4	[31.8;117.7]	42	4.1	61.4	[35.2;106.6]	42	11.6			0	0
Only certain people	55.1	[35.5;80.7]	45	4.4	55.1	[37.0;81.7.4]	45	12.4			0	0
Complete ban	2.7	[2.5;3.0]	817	2.8	5.8	[4.6;7.2]	167	46.0	2.2	[1.9;2.5]	650	100.0
Missing			0					0				0
p-value ^D	<0.0001				<0.0001				NA			
People Using Tobacco Products Around Child – past week												
0	2.3	[2.1;2.6]	664	65.5	6.1	[2.3;14.2]	14	3.9	2.2	[1.9;2.5]	650	100.0
1-2	16.8	[12.5;22.5]	208	20.5	17.2	[12.9;22.9]	208	57.3			0	0
3+	38.3	[26.3;55.5]	141	13.9	38.3	[26.8;54.3]	141	38.8			0	0
Missing			0					0			0	
p-value ^D	<0.0001				<0.0001				NA			
Type of Home												
Single-family	3.3	[2.9;3.7]	762	75.4	11.5	[8.7;15.1]	198	54.7	2.0	[1.7;2.2]	564	86.9
Multiunit	28.2	[19.8;40.1]	126	12.5	53.2	[37.0;76.2]	87	24.0	6.4	[4.2;9.4]	39	6.0
Multi-family	16.1	[7.8;32.2]	47	4.6	32.5	[12.9;79.71]	32	8.8	3.1	[2.4;7.6]	15	2.3
Townhouse w/ walls attached	18.6	[9.9;34.1]	58	5.7	54.9	[36.1;83.1]	32	8.8	4.4	[2.4;7.6]	26	4.0
Townhouse w/out walls attached	5.1	[0.4;25.7]	8	0.8	13.8	[4.7;37.2]	5	1.4	0.4	--	3	0.5
Trailer	62.4	[16.9;223.8]	10	1.0	158.8	[55.9;447.7]	8	2.2	0.6	--	2	0.3

Missing p-value ^D	2				1				1			
	<0.0001				<0.0001				<0.0001			
Home Total Square Feet												
<1162	18.0	[14.3;22.7]	252	25.1	43.9	[32.7;58.6]	153	43.0	4.1	[3.0;5.3]	99	15.3
1162-1665	6.3	[4.6;8.3]	250	24.9	21.7	[14.0;33.2]	101	28.4	2.4	[1.9;2.8]	149	23.0
1666-2400	3.1	[2.5;4.0]	258	25.7	9.4	[5.7;15.0]	67	18.8	2.0	[1.5;2.6]	191	29.5
>2400	2.0	[1.6;2.4]	243	24.2	5.4	[2.6;10.4]	35	9.8	1.7	[1.4;2.0]	208	32.1
Missing			10					7			3	
p-value ^D	<0.0001				<0.0001				<0.0001			
Home Built												
<1943	9.1	[6.87;11.9]	255	25.2	41.1	[28.9;58.1]	105	28.9	2.7	[2.1;3.4]	150	23.1
1943-1968	7.1	[5.2;9.6]	256	25.3	23.6	[14.7;37.7]	108	29.8	2.6	[2.0;3.4]	148	22.8
1969-1997	5.6	[4.2;7.5]	253	25.0	22.2	[15.1;32.3]	95	26.2	2.1	[1.7;2.6]	158	24.3
>1997	2.4	[1.9;2.8]	249	24.6	6.6	[4.3;9.7]	55	15.2	1.7	[1.4;2.0]	194	29.8
Missing			0					0			0	
p-value ^D	<0.0001				<0.0001				0.0001			
Last Hand Washing												
<30 min	5.4	[4.0;7.1]	204	20.3	20.3	[13.4;30.3]	78	21.7	2.0	[1.6;2.5]	126	19.5
31-60 min	8.1	[5.3;12.3]	102	10.2	31.8	[17.9;56.1]	44	12.3	2.4	[1.8;3.3]	58	9.0
61-120 min	3.8	[3.1;4.6]	192	19.1	13.7	[8.0;22.8]	53	14.8	2.2	[1.7;2.6]	139	21.6
121-240 min	6.2	[4.5;8.4]	194	19.3	31.1	[21.3;45.4]	70	19.5	2.2	[1.6;2.7]	124	19.2
>240 min	5.7	[4.3;7.4]	312	31.1	21.4	[14.7;31.0]	114	31.8	2.3	[1.9;2.8]	198	30.7
Missing			9				4				5	
p-value ^D	0.0116				0.0750				0.7013			

Notes:

Abbreviations: GeoMean: geometric mean; CI: confidence interval

^A Unprotected means that one or more of the following were true: the child's parents or guardians used tobacco products; the child was near one or more smokers during the past week; home smoking rules allowed smoking all the time, usually, sometimes, or by certain people.

^B Protected means that all of the following were true: the child's parents or guardians did not use tobacco products; there were no smokers near the child during the past week; smoking was never allowed at home without exceptions.

^B Confidence intervals rely on robust standard errors adjusted for family clusters and were estimated based on bootstrap replications.

^D p-value for null hypothesis χ^2 -test that population mean hand nicotine levels are equal.

Table 3. Multiple regression model of hand nicotine levels (ng/wipe) based on child and family characteristics (Adjusted R²=0.64; N=999; $\chi^2(39)=13,151$; p<0.0001)

Explanatory Variables	$\hat{\beta}$	SE ^A	z	p	95% Confidence Interval	
Child Age, years						
0-1	Ref					
2-4	0.2040	0.0640	3.19	0.001	0.0785	0.3295
5-7	0.2308	0.0656	3.52	<0.001	0.1022	0.3595
8-11	0.1487	0.0672	2.21	0.027	0.0170	0.2804
Child Sex (Female)	0.0313	0.0660	0.47	0.635	-0.0980	0.1606
Child Age X Child Sex	$\chi^2(3)=8.40$, p=0.0384					
2-4 X Female	-0.1391	0.0835	-1.67	0.096	-0.3026	0.0245
5-7 X Female	-0.2389	0.0827	-2.89	0.004	-0.4010	-0.0767
8-11 X Female	-0.1326	0.0753	-1.76	0.078	-0.2802	0.0151
Unprotected^B from Tobacco	0.4588	0.1123	4.09	<0.001	0.2387	0.6789
Child Race						
White/Caucasian	Ref					
Black/African American	0.1687	0.0693	2.43	0.015	0.0328	0.3045
Other	0.0048	0.0833	0.06	0.954	-0.1585	0.1681
Multi Racial	0.0605	0.0664	0.91	0.362	-0.0696	0.1906
Unprotected^B X Child Race	$\chi^2(3)=12.66$, p=0.0054					
Black/African American X Unprotected	-0.2774	0.1027	-2.70	0.007	-0.4787	-0.0760
Other X Unprotected	-0.6225	0.2368	-2.63	0.009	-1.0867	-0.1584
Multi Racial X Unprotected	-0.2878	0.1610	-1.79	0.074	-0.6033	0.0277
Family Income						
≤\$15,000	Ref					
\$15,001-\$30,000	-0.3012	0.1177	-2.56	0.010	-0.5318	-0.0706
\$30,001-\$50,000	-0.3779	0.0947	-3.99	<0.001	-0.5635	-0.1922
\$50,001-\$75,000	-0.4253	0.0907	-4.69	<0.001	-0.6031	-0.2474
\$75,001-\$90,000	-0.3984	0.1017	-3.92	<0.001	-0.5976	-0.1991
\$90,001-\$120,000	-0.4594	0.0927	-4.96	<0.001	-0.6410	-0.2778
>\$120,000	-0.4767	0.0898	-5.31	<0.001	-0.6527	-0.3007
Family Income X Unprotected^B	$\chi^2(6)=26.63$, p=0.0002					
\$15,001-\$30,000 X Unprotected	0.1916	0.1498	1.28	0.201	-0.1019	0.4852
\$30,001-\$50,000 X Unprotected	0.0640	0.1896	0.34	0.736	-0.3075	0.4356
\$50,001-\$75,000 X Unprotected	-0.1399	0.1374	-1.02	0.309	-0.4092	0.1295
\$75,001-\$90,000 X Unprotected	-0.4273	0.1446	-2.95	0.003	-0.7108	-0.1439
\$90,001-\$120,000 X Unprotected	-0.4387	0.1359	-3.23	0.001	-0.7050	-0.1724
>\$120,000 X Unprotected	-0.3450	0.1268	-2.72	0.006	-0.5935	-0.0966
Home Smoking Rules						
$\chi^2(4)=100.38$, p<0.0001						
Allowed anywhere	0.6927	0.1102	6.28	<0.001	0.4766	0.9088
Usually allowed	0.8052	0.0880	9.15	<0.001	0.6327	0.9777
Usually not allowed	0.6864	0.1029	6.67	<0.001	0.4848	0.8880
Only certain people	0.6344	0.0998	6.36	<0.001	0.4388	0.8299
Complete ban	Ref					
Last Hand Washing						
$\chi^2(4)=15.32$, p=0.0041						
<30 min	Ref					
31-60 min	0.1324	0.0477	2.78	0.006	0.0389	0.2260

61-120 min	0.0694	0.0390	1.78	0.075	-0.0070	0.1457
121-240 min	0.1451	0.0465	3.12	0.002	0.0539	0.2363
>240 min	0.1167	0.0370	3.15	0.002	0.0441	0.1893
Type of Homes	$\chi^2(5)=18.56, p=0.0023$					
Single-family	Ref					
Multiunit	0.1365	0.0547	2.50	0.013	0.0293	0.2436
Multi-family	0.0345	0.0967	0.36	0.722	-0.1551	0.2241
Townhouse, walls attached	0.0073	0.0780	0.09	0.925	-0.1455	0.1601
Townhouse, no walls attached	-0.5187	0.2581	-2.01	0.044	-1.0245	-0.0128
Trailer	0.4155	0.1736	2.39	0.017	0.0753	0.7557
Constant	0.6791	0.1156	5.87	0.000	0.4525	0.9057

A: SE: robust standard errors based on bootstrapping and family cluster adjustment

B: Unprotected means that one or more of the following were true: the child's parents or guardians used tobacco products; the child was near one or more smokers during the past week; home smoking rules allowed smoking all the time, usually, sometimes, or by certain people.

Table 4. Tobit regression model (left-censored at saliva cotinine level of quantitation, N=219) of saliva cotinine based on hand nicotine levels (ng/wipe), child and family characteristics (R²=0.75, N=938, F(27, 911)=49.04, p<0.0001)

Explanatory Variables	$\hat{\beta}$	SE	t	p	95% Confidence Interval	
Hand Nicotine (log10)	0.2212	0.0469	4.72	<0.001	0.1292	0.3132
Child Age, years						
0-1	Ref					
2-4	-0.0245	0.0277	-0.88	0.377	-0.0789	0.0299
5-7	0.0060	0.0247	0.24	0.809	-0.0426	0.0546
8-11	-0.0005	0.0257	-0.02	0.983	-0.0510	0.0499
Child Age X Hand Nicotine	F(3,911)=5.78, p=0.0006					
2-4 X Hand Nicotine	-0.0161	0.0425	-0.38	0.706	-0.0995	0.0674
5-7 X Hand Nicotine	-0.1160	0.0358	-3.24	0.001	-0.1864	-0.0457
8-11 X Hand Nicotine	-0.1247	0.0350	-3.57	<0.001	-0.1933	-0.0560
Family Income						
≤\$15,000	Ref					
\$15,001-\$30,000	-0.0859	0.0571	-1.51	0.132	-0.1979	0.0261
\$30,001-\$50,000	-0.1308	0.0543	-2.41	0.016	-0.2374	-0.0241
\$50,001-\$75,000	-0.0919	0.0610	-1.51	0.132	-0.2117	0.0279
\$75,001-\$90,000	-0.1075	0.0521	-2.06	0.039	-0.2099	-0.0052
\$90,001-\$120,000	-0.1099	0.0608	-1.81	0.071	-0.2291	0.0093
>\$120,000	-0.1097	0.0491	-2.24	0.026	-0.2060	-0.0134
Family Income X Hand Nicotine	F(6,911)=2.70, p=.0132					
\$15-\$30K X Hand Nicotine	0.0514	0.0446	1.15	0.250	-0.0362	0.1390
\$30K-\$50K X Hand Nicotine	0.0442	0.0508	0.87	0.384	-0.0555	0.1439
\$50K-\$75K X Hand Nicotine	-0.0357	0.0753	-0.47	0.635	-0.1836	0.1121
\$75K-\$90K X Hand Nicotine	-0.0353	0.0510	-0.69	0.489	-0.1353	0.0648
\$90K-\$120K X Hand Nicotine	-0.0720	0.0833	-0.86	0.388	-0.2355	0.0915
>\$120K X Hand Nicotine	-0.1211	0.0451	-2.69	0.007	-0.2097	-0.0326
Home Smoking Rules	F(4,911)=3.91, p=0.0037					
Allowed anywhere	0.0844	0.0538	1.57	0.117	-0.0211	0.1899
Usually allowed	0.1783	0.0644	2.77	0.006	0.0519	0.3047
Usually not allowed	-0.0195	0.0457	-0.43	0.670	-0.1091	0.0701
Only certain people	0.1219	0.0480	2.54	0.011	0.0277	0.2162
Complete ban	Ref					
People Using Tobacco Products Around Child – past week						
0	Ref					
1-2	-0.0460	0.0299	-1.54	0.124	-0.1046	0.0127
3+	-0.0500	0.0439	-1.14	0.256	-0.1362	0.0363
People Using Tobacco Products X Hand Nicotine	F(2,911)=14.26, p<0.0001					
1-2 X Hand Nicotine	0.1764	0.0396	4.45	<0.001	0.0987	0.2541
3+ X Hand Nicotine	0.2187	0.0442	4.95	<0.001	0.1320	0.3053
Constant	0.0538	0.0502	1.07	0.284	-0.0447	0.1523

Figure Legends

Figure 1:

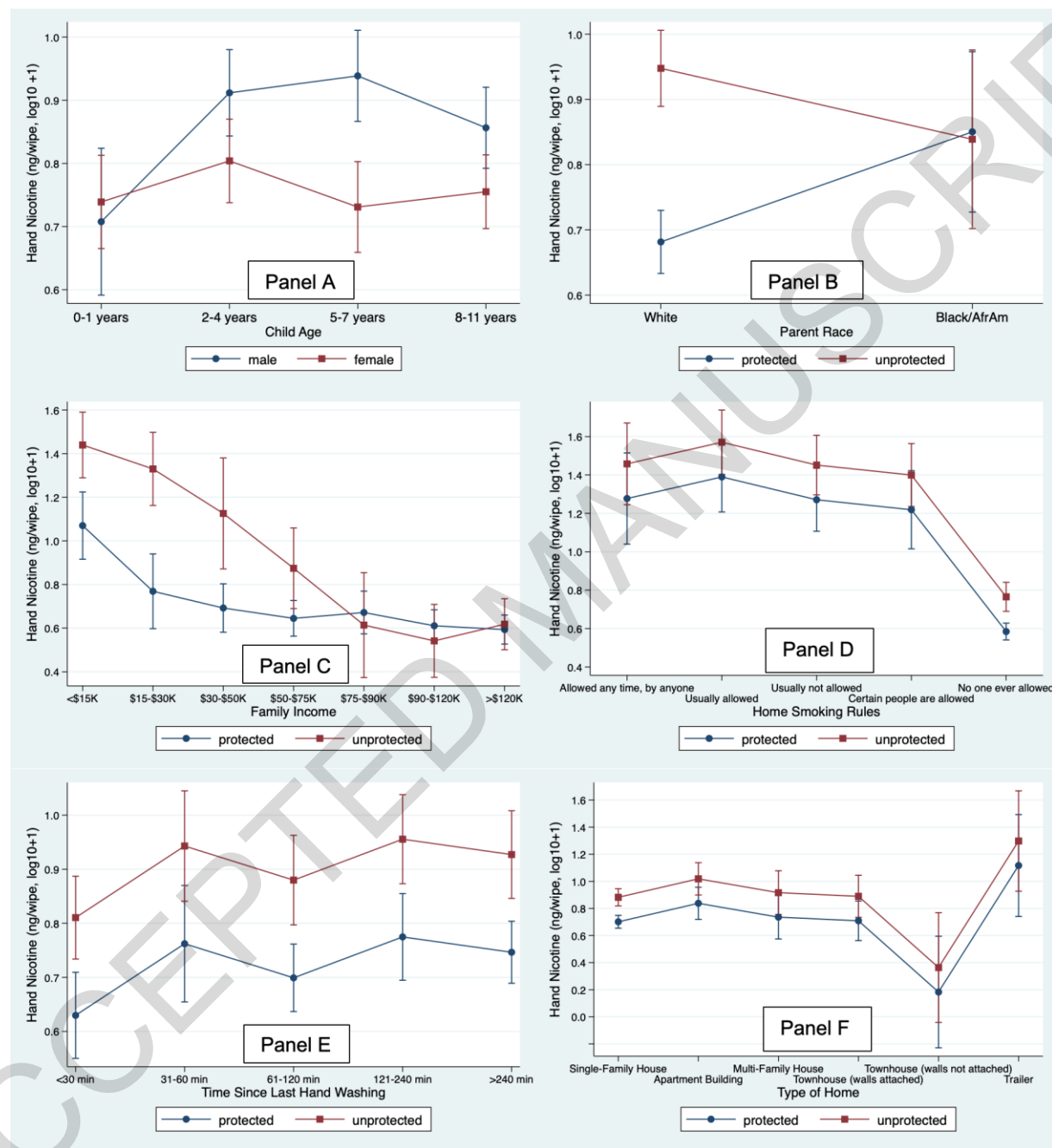


Figure 1 Caption

Mean hand nicotine levels and 95% confidence intervals for statistically significant interaction and main effects based on the multiple regression model presented in Table 3 (N=999). Panel A: child age X sex interaction; Panel B: parent race X tobacco smoke protection interaction; Panel C: family income X tobacco smoke protection interaction; Panel D: home smoking rules main effect; Panel E: time since last hand washing main effect; Panel F: type of home main effect. The exact numeric values can in found in the supplemental information in Table S1.

Figure 2:

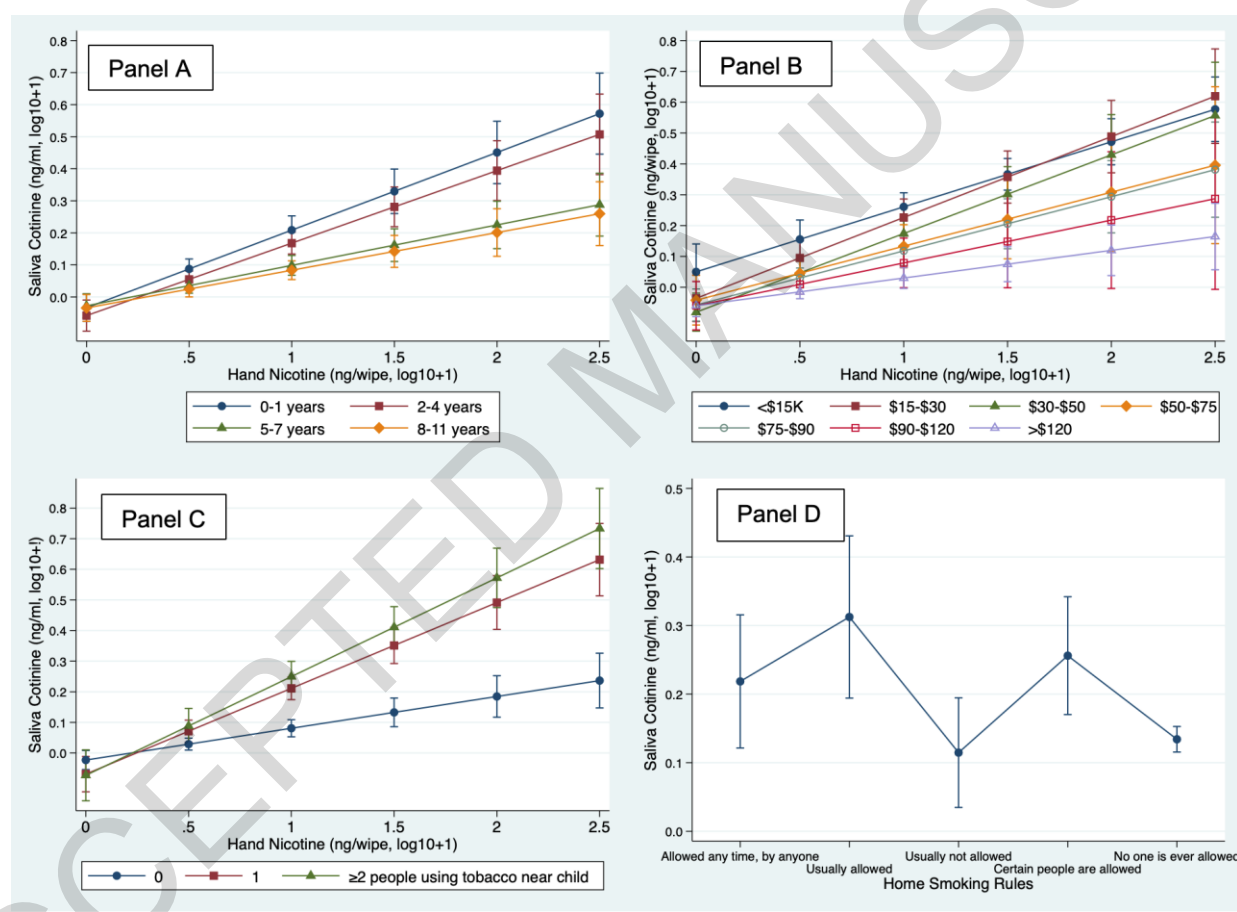


Figure 2 Caption

Mean saliva cotinine levels and 95% confidence intervals for statistically significant interaction and main effects based on the Tobit regression model presented in Table 4 (N=938). Panel A:

child age X hand nicotine interaction; Panel B: family income X hand nicotine interaction; Panel C: number of smokers near child X hand nicotine interaction; Panel D: home smoking rules main effect. The exact numeric values can in found in the supplemental information in Table S2.