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Residential insecticide usage in northern California homes with young children

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Residential insecticide usage and actual application details were collected in a population-based sample of 477 households residing within 22 counties in northern California with at least one child of age $\leqslant$5 years between January 2006 and August 2008. Structured telephone interviews were conducted collecting information on residential use of insecticides, including outdoor sprays, indoor sprays, indoor foggers, applications by professionals, and pet flea/tick control during the previous year. Interviews also covered post-treatment behaviors, which influence post-application exposure levels. Altogether, 80% of the households applied some type of insecticide in the previous year, with half of this population using two or more application methods. Of the households using insecticides, half reported applying insecticides relatively infrequently (<4 times per year), whereas 11–13% reported high frequency of use (>24 times per year). Application frequency was temperature dependent, with significantly more applications during the warmer months from May through October. Spot treatments appeared to be the most prevalent application pattern for sprays. For one out of three of the indoor applications, children played in the treated rooms on the day of the application, and for 40% of the outdoor applications, pets played in the treated area on the day of the application. These findings describing the intensity of insecticide use and accompanying behaviors in families with young children may inform future insecticide exposure modeling efforts, and ultimately, risk assessments.
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Introduction

Pesticide exposure has been associated with increased risks of childhood cancer (Daniels et al., 1997; Reynolds et al., 2002); child neurodevelopment (Rosas and Eskenazi, 2008); fetal growth outcomes (Arbuckle and Sever, 1998; Whyatt et al., 2004); adult cancers (Alavanja et al., 2004) such as non-Hodgkin's lymphoma, leukemia, and breast cancer; and neurological effects (Sanborn et al., 2007). Several national- and regional-scale studies have been conducted, demonstrating that up to 90% of US households used pesticides in their house, garden, or yard, and more than half of the products applied were insecticides (Savage et al., 1981; Davis et al., 1992; Whitmore et al., 1994; Adgate et al., 2000; Colt et al., 2004). However, estimating human exposures from residential insecticide applications has been a challenge because of the lack of detailed information on the manner and patterns of applications and exposure related behaviors.

Exposure science researchers and risk assessors have developed models, for example, DEEM, CALENDEX, CARES, LIFELINE, REx, and SHEDS, to estimate residential insecticide exposures from multiple pathways and source applications, or to determine aggregated exposures (Zartarian et al., 2000; Price et al., 2001; Van Veen et al., 2001). These models require very detailed exposure scenarios as input data. For example, the SHEDS model developed by the USEPA requires input on the probability of individual application types, influence of co-occurrence of different types of applications, application frequency, and reentry time after application. Without adequate information about the actual application methods used in the real world, these models often use default values — for example, zero reentry time, to provide maximum exposure estimation — or rely on standard application protocols recommended on the product labels. However, residential users may not necessarily follow these directions (van der Jagt, 2001), thereby potentially altering their exposure.

There are additional factors that have the potential to influence exposure and are not explicitly included in models. Factors such as which rooms are commonly treated

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coupled with how much time people spend in those rooms will influence exposure. Activities following the application may modify exposures: opening windows to increase ventilation or cleaning surfaces after the treatment may decrease exposure, whereas allowing children and pets to play in the treated area shortly after an application (when concentrations will be highest) may increase exposures. Given the lack of population-based data on these types of factors, this project obtained information on common conditions pertaining to pesticide applications by the general population that could aid researchers in the development of relevant scenarios for exposure assessment models and the design of field experiments (Powell, 2001; Van Veen et al., 2001). Understanding behavioral patterns of residents, particularly those with young children, is especially important as critical time windows in early development lead to higher vulnerability to the toxicity of insecticides. In addition, typical children's behaviors such as increased hand to mouth activity and crawling on floors and carpets result in higher exposures as well as internal doses (Landrigan et al., 1999; Shafer et al., 2005; Rosas and Eskenazi, 2008).

Furthermore, under current EPA guidelines, aggregate and cumulative exposure to pesticides should be considered in policy-making, meaning that exposure through all pathways and routes to all pesticides with a common mode of toxicity need to be calculated (USEPA, 2001). As the residues of insecticides used indoors may persist on the order of several years, a critical datum is the typical number of applications in a given year. In addition, one would need to consider whether the household applied multiple types of insecticide products, as they may potentially have a common mode of toxicity.

As part of the USEPA-funded Study of Use of Products and Exposure-Related Behavior (SUPERB) (Hertz-Picciotto et al., 2010), we have been collecting information on use of insecticides through various platforms, with the aim of filling these gaps in knowledge. The goals of the SUPERB study are to develop and test data collection methods for longitudinal assessment of exposure-related behaviors and to evaluate the validity and precision of these methods. We report here on information about the use of household insecticide products obtained through a baseline telephone interview of adults in households with young children living in northern California.

The objectives are (1) to examine the prevalence and frequency of use of selected types of insecticide applications in households with young children, and (2) to characterize the manner in which insecticides are applied and the distribution of post-application behaviors affecting exposure.

Methods

This paper reported a cross-sectional survey, which was the first in a 3-year longitudinal study of a random sample of households with young children. The following briefly introduces the study approach. A detailed description of the study design and data collection methods of SUPERB study can be found in Hertz-Picciotto et al. (2010).

Study Cohort

Residents with young children living in 22 counties in northern California were enrolled in this study, covering areas of the greater Sacramento and San Francisco Bay Area regions (see map in Supplementary Figure 1). Candidate households were randomly selected from the birth certificate records of children born between 2000 and 2005 in this area. In all, 97% of participating households have a child aged ≤ 5 years, with the remainder having a child who was slightly older. Two family members, including one adult and one child, were enrolled from each household. Households in which the mother had <12 years of education were over-sampled as a means to counter the well-known low rates of participation in research for this sociodemographic group (Korkeila et al., 2001). Out of 8226 households selected from northern California birth certificates by stratified random sampling, we contacted 1955 (24%) households by phone. Among the households contacted, 1763 households were eligible and 499 households (26% of those were contacted) participated in this study. A total of 458 households completed the first-year interview on insecticide use, and an additional 19 pilot households were also included, with the majority of them selected from the birth certificate records.

Data Collection

We collected information with an interviewer-administered telephone questionnaire, usually lasting 1.5–2 h. Telephone interviews were conducted between January 2006 and August 2008 by trained bilingual staff of the Department of Public Health at the University of California at Davis. Besides insecticide use, the questionnaires elicited demographic characteristics, use of personal care and household cleaning products, dietary intake, and tobacco use or exposure. No house visits were conducted for this part of the study.

Before the telephone interview, households received a package containing an insecticide product list with pictures for the products available in chain drug, grocery, and home improvement stores in the study area, to assist them in recalling insecticide product names and brands. More extensive information was obtained about self-applications of outdoor sprays, indoor sprays, indoor foggers, and the behind-the-neck treatments on pets for flea/tick control. These application methods were selected because they potentially cause higher levels of human insecticide exposure than do baits, traps, or strips, particularly through respiratory and dermal routes of intake (Grossman, 1995). Professional applications were also of interest, including applications in and around the house, lawn or garden and professional termite control. Insecticide usage information during the year before the interview was obtained and additional details such as size of application area and rooms treated were obtained for the most recent application.

Data Analysis

To adjust for differences in demographics between participants and the target population, we generated weights so that our results could be generalized to the target population. The factors that were used to generate weights included age at delivery, race or ethnicity and the education of the mothers, and whether the delivery was paid by public funds. The prevalence percentage, frequency of use of these types of applications, purchase frequency, storage, and so on were calculated based on the weighted data. We defined high-frequency users and compared their socioeconomic status and insecticide usage pattern to the overall survey population. Univariate statistics were generated for exposure scenarios of spray applications, for example, spot or area treated, place or room treated, cleaning, and ventilation after application. As data were skewed, non-parametric methods, including Wilcoxon signed-rank sum test, Wilcoxon–Mann–Whitney test, Fisher's exact test, and Spearman rank correlation coefficients were used. All data analyses were conducted using SAS 9.2 (SAS Institute, Cary, NC, USA).

Results

Demographics

The study population ($N = 477$) was diverse, with 58% Caucasians, 12% Hispanics, 12% Asians, 3% African Americans, and 15% other races. The vast majority (94%) of the households had married or non-married couples living together, and 81% lived in single-family residences. Compared with the pool of eligible households, those who participated in our study tended to be older and more educated (Hertz-Picciotto et al., 2010). Complete demographic information can be found in Supplementary Table 1.

General Insecticide Usage

Type of Applications Used A total of 80% (95% confidence intervals (CIs) = 75–85%) of the participating households reported using some sort of insecticides in the past year, and 73% (95% CIs = 68–78%) used one of the five major types of applications we investigated, that is, indoor sprays, outdoor sprays, indoor foggers, behind-the-neck treatment on pets, and professional applications. Outdoor spray was used in 42% of the surveyed households, whereas indoor spray was used by 24% of the households (Table 1). We also found that 27% of the households used pet products, including behind-the-neck pouch treatment and other flea/tick control products. Professional insecticide

Table 1. Types of insecticide applications used in the northern Californian households with young children ($N = 477$)[a].

Type of insecticide applications	Unweighted frequency	Weighted percentage (%)	SE (%)	95% Confidence interval (%)
Outdoor				
Spray	211	42.4	2.8	37.0, 47.9
Baits	75	12.4	1.6	9.2, 15.7
Trap	44	9.6	1.8	6.1, 13.2
Granules	33	7.1	1.4	4.3, 9.9
Candle	24	5.3	1.3	2.6, 7.9
Strips	14	3.7	1.2	1.4, 5.9
Foam	5	0.7	0.4	0.0, 1.5
Other	18	2.7	0.8	1.2, 4.2
Indoor				
Spray	125	23.9	2.3	19.4, 28.5
Fogger	19	4.4	1.2	2.0, 6.7
Baits	47	7.6	1.3	5.1, 10.1
Granules	14	3.5	1.2	1.3, 5.8
Candle	2	0.2	0.1	0.0, 0.5
Strips	15	4.8	1.5	1.9, 7.7
Foam	7	1.5	0.7	0.2, 2.8
Indoor or outdoor not specified or not relevant				
Professional applications	124	22.4	2.3	17.9, 26.8
Pet insecticide products	149	27.1	2.4	22.3, 31.8

[a]Questions apply to usage in the last year only. Questions on some application methods were added after the study began. The number of respondents varied between 458 and 477 for different questions.

services were hired by 22% of the households and provided outdoor and/or indoor applications. Outdoor spray was typically applied as an aerosol (57% of outdoor spray users), with a pump (46%), and/or with a hose (20%). Indoor spray was typically applied as an aerosol (79% of indoor spray users). Only 4% used indoor foggers.

Frequency of Insecticide Applications About half of the insecticide users reported relatively low application frequency, <4 times per year: specifically, 42% for outdoor spray, 51% for indoor spray, 47% for behind-the-neck treatment on pets, and 35% for professional application. Meanwhile, 11–13% of the users of indoor and outdoor sprays reported conducting applications >24 times per year, and 3% of those who hired professional applications did so >24 times per year. Indoor foggers were used at a lower rate, with a maximum frequency of 10 times per year. The weighted application frequencies of five major types of applications are summarized in Table 2 and additional information on the distributions can be found in Supplementary Table 2.

We expected that insecticide use would be more frequent during warm months, hence, we asked participants to recall the frequency of use in two time periods respectively: from May through October and from November through April. On the basis of the climate in the study region, we considered May to October as warm months and November to April as cool months. Note that this definition only applies to our study area or places with similar climate. The comparisons between warm and cool months confirmed the temperature dependence of insecticide use: both outdoor and indoor sprays were used more frequently in the warm months than in the cool months (Table 3). For each type of application, application frequencies in the warm months were not correlated with the corresponding frequencies of the same household in the cool months.

To further explore the influence of temperature, we divided the study area into hotter and cooler areas based on the temperature during the warmer months and annual precipitation. Geographically, the inland areas are hotter and drier (average daily high temperature during May–October: $84.6 \pm 5.8\,^{\circ}$F, e.g., on average Sacramento having 74 days exceeding $90\,^{\circ}$F during May–October; annual precipitation: 18.1 inches) and the coastal areas are cooler and wetter (average daily high temperature during May–October: $78.5 \pm 5.6\,^{\circ}$F, e.g., on average Oakland having 4 days exceeding $90\,^{\circ}$F during May–October; annual precipitation: 34.8 inches). Again, this definition only applies to our study area in northern California. Basic demographic characteristics of study participants were similar in the hotter and cooler areas, except that more participants in the hotter area (77%) than in the cooler area (67%) owned their residences ($P=0.014$). More households in the hotter area used outdoor sprays (51%) than in the cooler area (36%) ($P=0.001$), related to higher prevalence of home ownership. A greater fraction of homeowners used outdoor sprays in the warm months ($P=0.037$) than renters, and applied outdoor sprays more often in both warm ($P=0.041$) and cool ($P=0.010$) months. However, considering homeowners only, we still found statistically significantly higher use in the hotter region (hot *vs* cool: 53% *vs* 36%, $P=0.002$). These results are possibly because of a higher prevalence of outdoor insects in hotter areas. Although the proportion of households using outdoor sprays was higher in the hotter region, frequency of applications among the users did not differ in the two areas. The opposite pattern was true for indoor sprays: a similar percentage of households used them in the hotter and cooler regions, during the warm months, however, among those applying indoor sprays, use was more frequent in the hotter than in the cooler region ($P=0.019$). The prevalence and frequency of use of indoor sprays was the

Table 2. Frequency of insecticide applications among northern Californian households with young children ($N=477$)[a].

	Unweighted number of users	Weighted mean	SE (%)	95% Confidence interval (%)	Seasonal difference[b]
Outdoor spray	211	12.5	2.7	7.2, 17.9	
Warm months	200	10.6	2.4	5.9, 15.2	$P<0.0001$
Cool months	90	6.5	2.2	2.1, 10.8	
Indoor spray	125	13.3	2.8	7.8, 18.9	
Warm months	100	10.9	2.1	6.7, 15.1	$P=0.0035$
Cool months	76	7.9	2.2	3.5, 12.3	
Indoor fogger	19	3.2	0.8	1.4, 5.0	
Warm months	13	2.7	0.8	0.9, 4.4	$P=0.8986$
Cool months	10	2.4	0.9	0.5, 4.4	
Behind-the-neck treatment on pets	120	4.7	0.3	4.0, 5.4	
Professional applications	124	6.1	0.8	4.5, 7.8	

[a]Data were collected between January 2006 and August 2008. The warm and cool months were defined based on climate in the study areas. A year is divided into warm months (May–October) and cool months (November–April). The unit of frequency was time per year or time per warm or cool period.
[b]As data are not normally distributed, difference in the frequencies between warm and cool months was tested by Wilcoxon signed rank-sum test based on unweighted data.

Table 3. Types of insecticide applications used in combination in northern Californian households with young children ($N = 477$).

Insecticide applications used in combination	Unweighted frequency	Weighted percent (%)	SE (%)	95% Confidence interval (%)
No surveyed insecticide(s) used	**109**	**26.7**	2.6	21.6, 31.9
Single product used	**184**	**39.2**	2.8	33.7, 44.7
Outdoor spray only	60	13.9	—	—
Professional only	53	11.1	—	—
Pet insecticide products only	52	10.1	—	—
Other	19	4.2	—	—
Multiple types of products	184	34.0	—	—
Combination of two types of products	**122**	**23.0**	2.3	18.6, 27.5
Outdoor spray and indoor spray	46	9.1	—	—
Outdoor spray and pet product	24	4.6	—	—
Outdoor spray and professional	19	3.5	—	—
Other combinations	33	5.8	—	—
Combination of three types of products	**49**	**9.2**	1.5	6.2, 12.3
Outdoor spray and indoor spray & pet product	21	4.5	—	—
Other combinations	28	5.7	—	—
Combination of four types of products	**12**	**1.7**	0.5	0.7, 2.7
Combination of five (all) types of products	**1**	**0.1**	0.1	0.0, 0.3
Total	477	100	—	—

Note: Bold numbers add up to the total in each column.

same for homeowners and renters. In addition, a higher proportion of households in the hotter areas than in the cooler coastal region used multiple application methods (44% *vs* 31%), although this difference was not statistically significant. More information with regard to the comparison between the hotter/cooler areas can be found in Supplementary Table 3.

Co-occurrence of Multiple Applications Use of multiple types of applications was investigated. About half of the insecticide users, or 34% of all households, reported using multiple application methods. Of these, most used two or three application methods, and a few used up to five methods in combination. The weighted percentages of the combinations of multiple applications are shown in Table 3. Outdoor spray was used most commonly in combination with other application methods.

Participants who applied outdoor sprays were also more likely to use indoor sprays and indoor foggers ($P < 0.001$). The frequencies of application of outdoor and indoor sprays were modestly but significantly correlated among all surveyed households (Spearman's correlation coefficient (R) = 0.35, $P < 0.001$), and moderately correlated among those who used outdoor and/or indoor sprays ($R = 0.49$, $P < 0.001$). Those who hired professionals for applications were significantly less likely to use outdoor sprays and indoor foggers themselves. Furthermore, the frequency of professional applications was inversely correlated with the application frequency of each type of self-application, specifically, outdoor sprays ($R = -0.23$, $P < 0.001$), indoor sprays ($R = -0.21$, $P < 0.001$), indoor foggers ($R = -0.11$, $P = 0.032$), and behind-the-neck treatments on pets ($R = -0.13$, $P = 0.015$).

High-frequency Users In our study, we identified a number of "high-frequency" users, who reported a combination of self-applying foggers and sprays indoors and/or outdoors >24 times per year. We identified 35 such high-frequency users based on this criterion; they lived in both hotter and cooler study regions. Note that, owing to the small number of high frequency users, results in this section are not weighted.

The demographics of high-frequency users were generally similar to those of our survey population. However, compared with all surveyed households, a smaller proportion of high-frequency users had a college education (57% *vs* 65%), and relatively more high-frequency users lived in single-family houses (89% *vs* 81%). We then examined whether these characteristics predicted higher application frequency in the overall sample: across all three application methods, those who had not completed college had significantly greater frequency of use ($P = 0.004$), and, as expected, a higher frequency of outdoor spray use for those living in a single-family home ($P = 0.003$) was found. The vast majority of high-frequency users (91%) applied outdoor sprays, and the percentage who applied indoor spray was more than two times higher than the percentage of the overall survey population who used indoor sprays (63% *vs* 26%). High-frequency users were more likely to treat multiple types of pests indoors (31% *vs* 12% of overall sample), and also used pet insecticide products more often (43% *vs* 31%); only their use of professionals for applications was the same as in all surveyed households. If we had also included the frequency of professional applications when defining high-frequency users, the frequency of professional applications would have been significantly higher ($P = 0.005$) among the high-frequency users with a college degree than those without a college degree. More information on the comparison between the high-frequency users and all households can be found in Supplementary Table 3.

Insecticide Purchase and Storage It was reported that 40% and 19% of the surveyed households had purchased outdoor and indoor spray products, respectively, in the past year, with most of them purchasing one or two products. A small number of households purchased more than four products in the last year, 14 (4%) households for outdoor spray and 7 (4%) for indoor spray respectively. The number of containers purchased was positively correlated with the frequency of use for both outdoor ($R = 0.32$, $P < 0.001$) and indoor sprays ($R = 0.39$, $P < 0.001$). In addition, the number of indoor spray containers purchased was weakly correlated ($R = 0.22$, $P = 0.016$) with the number of different indoor pests that were treated, suggesting that different products were purchased for different types of pests. In all, 55% (95% CIs = 50–61%) of the households had insecticides stored indoors, mostly inside the house (25%) and/or in the garage (26%).

Applicator Outdoor insecticides were reported to be mostly applied by males (68%, 95% CIs = 60–76%), whereas applications of indoor insecticides were more evenly distributed between genders (males 49% *vs* females 51%).

Characteristics of the Insecticide Application

Outdoor Sprays

Places treated with outdoor spray: In Figure 1, we list the places around the home that the study participants treated during their last outdoor spray application. We found that 53% (95% CIs = 45–62%) of respondents ($N = 198$) sprayed the perimeter of residences, potentially to prevent pests from getting into residences. Most outdoor sprays were applied in a spotwise manner (71%, 95% CIs = 64–78%) rather than onto broad areas (28%, 95% CIs = 21–35%).

Children's and pets' presence after outdoor applications: In 11% (95% CIs = 6–17%, $N = 192$) of the households, children were reported to play in an insecticide-treated outdoor area on the day of treatment. On an average, the children who played in treated areas did so at a mean of 4.1 h (95% CIs = 1.4–6.9, $N = 24$) after the outdoor spray application. In all, 40% (95% CIs = 29–51%, $N = 100$) of the outdoor spray users who owned pets reported that their pets played in the treated outdoor area on the day of outdoor spray application.

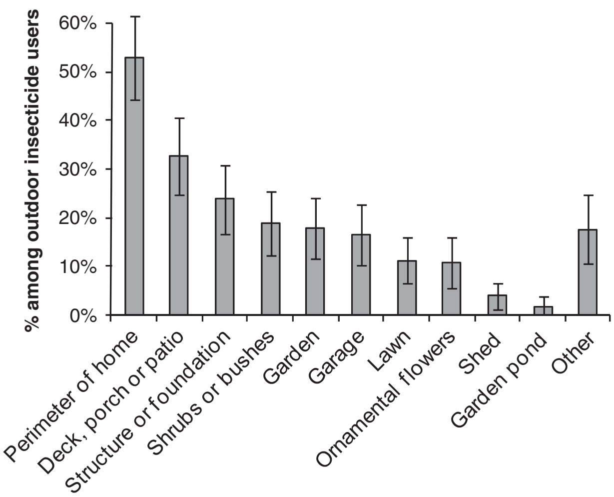

Figure 1. Places sprayed during the last outdoor spraying (N of respondents = 198): weighted percentages and their 95% confidence intervals are presented. Each of the listed places was a response option. Respondents could select more than one location. "Other" locations were fill-in values, such as windows, doors, wall, eaves, driveway, garbage can, barn, and so on.

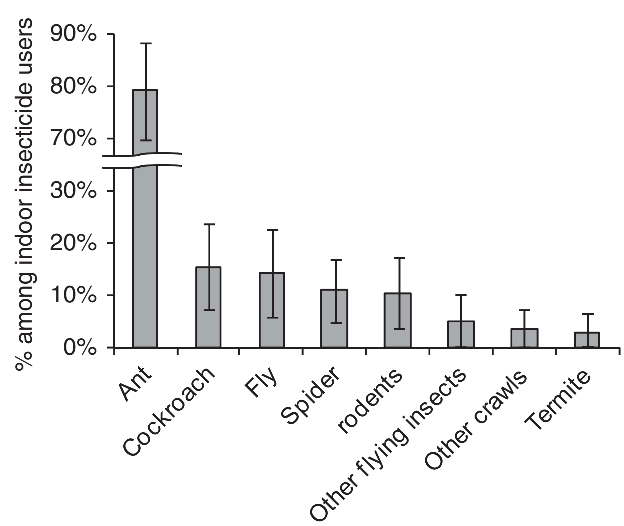

Figure 2. Pest-treated indoors in northern Californian households ($N = 135$): weighted percentages and their 95% confidence intervals are presented. These questions were asked for all households in which sprays or foggers were applied indoors. Respondents could select more than one pest.

Indoor Sprays and Foggers

Pests treated indoors: A total of 254 (55%) surveyed households in northern California reported having treated pests indoors, with 135 of them using indoor sprays or foggers, and the remainder using products other than sprays and foggers. Indoor sprays and foggers were most frequently used to treat ants (79%), followed by rare applications for spiders, cockroaches, and flies (Figure 2). The vast majority of indoor spray and fogger users treated only one or two

Table 4. Frequency (weighted percentage shown in parentheses) of area and rooms treated during the last indoor insecticide application.

Room	Indoor fogger (%)[a]	Indoor spray[b]				
		Total (%)[c]	A specific area (< 1 ft^2) (%)	Several specific areas (1–5 ft^2) (%)	Large area (> 5 ft^2) (%)	Cracks and crevices (%)
Kitchen	7 (34)	75 (60)	32 (42)	23 (27)	4 (6)	16 (25)
Bathroom	5 (24)	43 (39)	24 (48)	5 (14)	2 (3)	12 (35)
Dining room	6 (29)	18 (16)	9 (47)	3 (18)	3 (21)	3 (15)
Family room	11 (53)	18 (16)	8 (51)	3 (12)	3 (20)	4 (17)
Bedroom	11 (53)	18 (18)	7 (31)	3 (20)	3 (18)	5 (31)
Living room	10 (49)	17 (18)	6 (38)	2 (5)	2 (16)	7 (41)
Laundry room	3 (15)	10 (6)	7 (70)	1 (7)	2 (23)	—
Other[d]	4 (20)	16 (14)	9 (52)	5 (24)	—	2 (19)

[a]Weighted percentages are calculated based on the number of households applied indoor foggers ($N = 19$).
[b]Weighted percentages of each spot/area category are calculated based on the number of households spraying a particular type of room.
[c]Weighted percentages are calculated based on the number of households applied indoor spray ($N = 125$).
[d]Other rooms include basement and attic.

types of pests, whereas 9% of households treated three or more types of pests indoors.

Area and rooms treated with indoor insecticides: Sprays were applied most often in the kitchen and bathroom, whereas foggers were more often used in family room, living room, and bedroom (Table 4). For spray applications, we also collected information about the size of the area treated, which is theoretically related to the amount of insecticide applied in the room assuming a constant amount of insecticide applied per unit area. The most common response was spot applications on small areas (< 1 ft^2). Crack and crevice applications, typically advised in product use directions, were also fairly common, most often for applications in the living room, bathroom, and bedroom. Participants also reported spraying a large area (> 5 ft^2) in the kitchen, dining room, bedroom and/or family room. The majority (73%) of the indoor spray users treated one or two rooms.

Ventilation and cleaning after applications: Participants were asked whether windows were open during or after application and whether and how they cleaned the treated areas during the week after their last application. In total, 58% of indoor spray users reported having one or more windows open during or after the last use. All of the 19 fogger users left the residences after application and reentered an average of 8.4 h (95% CIs = 6.0–10.7 h) afterwards. Fifteen fogger users opened windows when returning home, and kept the windows open for an average of 3.6 h (95% CIs = 3.0–4.2 h).

A high proportion (87%) of the indoor spray users cleaned the house or the sprayed area within 1 week after application, with 39% cleaning on the day of the application. Most participants cleaned the center only rather than the whole floor after spray application (67% *vs* 13%, $N = 109$), whereas after fogger applications, participants were more likely to clean the whole floor rather than the center of the floor (51% *vs* 30%, $N = 19$). Most of the indoor spray (71%) and fogger (78%) users cleaned the center of counters within a week after application. The rest of the users reported not cleaning the floors or counters within the week after application. Additional information on the distributions for the parameters related to reentry times and cleaning can be found in Supplementary Table 4.

Children playing in indoor areas after application: In all, 33% (95% CIs = 23–43%, $N = 124$) of the respondents reported that their children played in the treated rooms on the same day of an indoor spray or fogger application, entering the treated room an average of 4.3 h (95% CIs = 2.2–6.4 h, $N = 46$) after the indoor spray or fogger application occurred.

Insecticide Applications on Pets

Type of treatment: About half (47%, 95% CIs = 43–52%, $N = 458$) of the respondents reported having furry pets. Behind-the-neck pouch treatment was the most popular pet insecticide product and was reported by 50% of the pet owners. In total, 30% of the pet owners used flea/tick shampoo or soap, and a small percentage used flea/tick collars (8%), powders (2%), and dips (1%).

Human contact with pets: Of the 217 pet-owning respondents, 33% (95% CIs = 26–41%) of the adults and 23% (95% CIs = 15–30%) of the children aged ≤5 years ($N = 180$) usually slept with pets, and 61% (95% CIs = 51–70%) of the parents with children aged ≤5 years reported that their children played with pet(s) everyday. Furthermore, 26% (95% CIs = 17–36%) of the pet insecticide users with children aged ≤5 years reported that their children played with pets after their pets were most recently treated.

Professional Applications
A total of 22% of the 477 surveyed households hired professional insecticide applicators for treatments in or around residences, lawns, or gardens in the last year, and 3% of the surveyed households used professional termite control. The frequency of treatment by professional services in or around the residence, for lawn or garden applications presents a right-skewed distribution between 1 and 36 times in the last year, with a median of 5 times per year. In contrast, 73% of those who hired termite control did so only once or twice in the last year. Over 80% of the professional applications in or around residences, lawns, or gardens involved spray or other liquid insecticides.

Discussion

Between 2006 and 2008, SUPERB collected a large amount of data on residential insecticide usage and post-application behaviors in a population-based survey of families with young children living in northern California. For example, this paper appears to be the first to contain data on use of multiple application methods, which places or rooms were treated with insecticides, and on children and pets playing in the treated area after the application.

Comparison with Existing Studies
In this study, a total of 80% of the households surveyed reported using insecticides in the previous year. This number is comparable to figures from previous studies, although with differences in experimental designs and regional variability in climates and pests. Mostly, previous studies covered a wider range of pesticides besides insecticides, for example, herbicides, rodenticides, disinfectants, and insect repellents, and may have considered usage over longer or shorter periods. For example, Savage et al. (1981) reported that in the EPA region IX where California is located, 82.5% and 62.2% of households had ever used pesticides in the house and yard respectively, during late 1970s. Adgate et al. (2000) collected residential pesticide inventory data in 1997 from households with children age 3–12 years in Minnesota, and reported a comparable prevalence of pesticide use for 88% of households during the past year. A study conducted in Detroit, Iowa, Los Angeles, and Seattle by Colt et al. (2004) found that 94.3% of subjects had ever used insecticides in or around their residences. The California Department of Pesticide Regulation conducted a telephone survey among $\sim$2600 households in northern California in 2002–2003, and reported a 51–60% prevalence of outdoor pesticide use during a 6-month period before the interview (Flint, 2003). They also found that residents in the San Francisco Bay area, which belongs to the "cool area" according to our definition, had a lower percentage of using outdoor pesticides (59.4%) than two inland areas in northern California they studied ($\sim$80%) (Flint, 2003). This is consistent with the trend we saw of lower outdoor spray insecticide usage in the cool compared with hot areas, with 36% and 53% of our sample using these products in the respective areas.

Exposure Scenarios Resulting from Insecticide Application
As van der Jagt (2001) pointed out, residential users may not necessarily follow the instructions on the product labels when applying insecticides, including the application manner and the amount used. Crack and crevice applications represent the standard instruction on the product labels and is commonly followed by professional applicators. It has also been the target application method in many pesticide exposure studies (Wright et al., 1993; Byrne et al., 1998; Zartarian et al., 2000; Price et al., 2001; Stout and Mason, 2003; Hore et al., 2005). However, results of our study suggest that only 25% of the recent indoor spray applications were crack and crevice applications. Spot applications (<1 ft^2), probably to locations where pests were discovered, were the most prevalent application method accounting for 49% of all indoor spray applications. Spot applications have received less attention from researchers, e.g., in the SHEDS model, they are not included as an application method. Although spot applications may result in lower exposures because of the smaller amount of insecticide likely applied at one time, they may be applied much more frequently than broadcast or crack and crevice applications, with 25% of insecticide users reporting applying spray insecticides indoors $\geq$12 times per year.

Potential overuse of foggers was also observed. We calculated the area treated by each fogger and compared it with the recommended area per package instructions. Area treated was calculated by dividing the area of the house, based on publicly available data by the number of foggers used in a household's most recent application. Of the 15 homes for which square footage was available, 7 applied an appropriate number of foggers, whereas 8 appear to have applied too many foggers, as the home area per fogger was significantly less than the recommended area per package directions. Basing model application rates on package directions may underestimate the amount of pesticide released into homes by actual users. Thus, discrepancies between recommended protocols and those actually used need to be taken into account in exposure models.

We also investigated other factors that may influence the fate and transport of insecticides and post-application exposures, for example, the kind of rooms treated, re-entry times, and ventilation and/or cleaning after applications. Indoor spray or fogger applications can create high aerosol concentration in the treated room a short while after the application, even for non-volatile insecticides (Stout and Mason, 2003; Berger-Preiβ et al., 1997). Over a longer period the insecticide will disperse, resulting in residues throughout the entire house, with concentrations remaining higher in the treated room(s) (Stout and Mason, 2003; Berger-Preiβ et al., 1997). Kitchens and bathrooms were the most common indoor environments treated with spray, followed by bedrooms, family rooms, and dining rooms. Spray applications in the kitchen may deposit on plates, cookware, or surfaces such as counters that may later come in contact with food, potentially increasing exposure (Vonderheide et al., 2009). Spray applications in bedrooms and family rooms where people spend a large amount of time may result in increased inhalation and dermal exposure.

The dispersion/decay distribution of insecticides after application could be influenced by ventilation and cleaning (Berger-Preiβ et al., 1997). As mentioned above, for a spray or fogger application, airborne concentrations reach a peak level during or shortly after the application, and the insecticide concentrations in the indoor areas are affected by ventilation (Wright et al., 1993; Byrne et al., 1998; Stout and Mason, 2003; Hore et al., 2005). Therefore, ventilation and cleaning right after application may reduce insecticide exposure to residents. In all, 67% of the indoor spray users of our study reported opening windows during or after their last application, and 39% cleaned their residences on the day of application. These actions may thus limit insecticide exposure of residents to some extent.

Children may be more highly exposed to insecticides when they play in the treated areas immediately following an application. Elevated surface concentrations coupled with their frequent hand-to-mouth activities would likely result in exposure through non-dietary ingestion (Gurunathan et al., 1998; Cohen-Hubal et al., 2000; Freeman et al., 2005; Hore et al., 2005). In all, 33% of parents reported that their children played in the room where the insecticide had been applied earlier that day. One might expect this figure to be downwardly biased if parents want to appear protective and underreport. Even if 33% is accurate, it confirms the importance of studying exposures occurring just after an application. Considerably fewer (11%) families reported that their children played in the treated outdoor areas on the day of application. However, we do not know whether the children did not play in the treated areas because parents intended to protect children, or because the children generally did not play outside in the treated areas. Pets entering into treated areas may transfer insecticides via their coats. Nishioka et al. (2001) found that tracking-in by active dogs may contribute 60–80% of all insecticide residues in indoor living areas. In this study, pets were reported to play in the treated area at a relatively high frequency (40%). Thus, indirect exposure through contact with pets and contact with carpet or couches where pets rest might be considerable, in particular for young children with frequent hand-to-mouth activities and/or substantial contact with pets.

Limitations

Lower education is often associated with lower response rates to surveys (Korkeila et al., 2001). Although we attempted to oversample households of parents with lower education, the respondents still overrepresented those with higher educational levels. This affected our results to some degree: the prevalence rates of using insecticides slightly decreased after weighting, whereas the frequency of use of self-applications, especially indoor foggers, increased. This was apparently because, among users, parents with lower education had a higher use frequency than those with higher education.

Survey responses are also limited by participants' knowledge, willingness to answer certain questions, and the ability to remember applications that may have occurred several months before the interview (Teitelbaum, 2002). For example, people may be absent when professionals applied pesticides, resulting in a lack of knowledge about the application details and the products used. In addition, recalled information did not allow us to quantify the amount of insecticide applied in a typical application and the consistency of the amount used per application.

In summary, this study found that four out of five of the participating northern California households with young children reported having used insecticides in the previous year. Results of this study provide a more detailed picture of potential exposure scenarios. As spot applications emerged as the most prevalent pattern, they should be considered in current pesticide exposure models. Children and pets were commonly reported to be playing in the insecticide-treated areas on the day of application, which may lead to direct or indirect human insecticide exposures.

Conflict of interest

The authors declare no conflict of interest.

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