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Preschool-Age Children's Pesticide Exposures in Child Care Centers and at Home in Northern California

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Abstract

Introduction—Young children may be exposed to pesticides used in child care centers and their family homes. We examined pesticide use and environmental and behavioral factors potentially associated with child exposures in these settings.

Method—Preschool-age children (*n* = 125) wore silicone wristbands to assess pesticide exposures in their child care centers and home environments. Information about environmental and behavioral exposure determinants was collected using parent surveys, child care director interviews, and observations.

Results—Commonly detected pesticides were bifenthrin, chlorpyrifos, cypermethrin, fipronil, and cis- and trans-permethrin. Pesticide chemical storage onsite, cracks in the walls, using

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doormats, observed pests, or evidence of pests were associated with child exposures. Exposures were higher in counties with higher agricultural or commercial pesticide use or when children lived in homes near agricultural fields.

Discussion—Young children are being exposed to harmful pesticides, and interventions are needed to lower their risk of health problems later in life.

Keywords

Environmental health; pesticides; children; child care

Introduction

The United States (U.S.) uses more than one billion tons of pesticides annually for agricultural and commercial purposes, with nearly 75% of households using pesticides for pest control (Atwood & Paisley-Jones, 2017). Pesticides are applied on farmlands, roads, in and around residential, educational, and recreational facilities; their ubiquity and potential toxicity are a public health concern (Kim, Kabir, & Jahan, 2017). In 2018, pesticides were reported to be the ninth most common substance reported to poison control centers among adults and children (Gummin et al., 2019). In addition to acute exposure, evidence suggests that chronic, low-level pesticide exposure can also substantially increase threats to long-term health (Chen, Change, Tao, & Lu, 2015).

Children exposed during critical stages of development are especially vulnerable (Lanphear, Vorhees, & Bellinger, 2005) and studies have linked pesticides to delayed psychomotor and mental development, attention deficits, and childhood cancers such as leukemia and brain tumors (Roberts, Karr, & Council on Environmental Health, 2012). Children are also more likely to be exposed to chemicals from surfaces and in house dust due to hand-to-mouth activity and playing close to the ground, while their reduced ability to metabolize toxic chemicals compared to adults, increases their risks for acute and chronic toxicity (Makri, Goveia, Balbus, & Parkin, 2004; Xue et al., 2007). They also experience greater exposure due to their higher intake of air, water, and food per unit of body weight compared to adults (Moya, Bearer, & Etzel, 2004).

Most children in the U.S. spend a significant amount of time in environments other than their home, with many preschool-age children spending half of their waking weekday hours in child care programs (Whitebook, Phillips, & Howes, 2014). The first U.S. national environmental health survey of child care centers conducted in 2001, and was a collaborative project of the Department of Housing and Urban Development (HUD), the Environmental Protection Agency (EPA), and the Consumer Products Safety Commission (CPSC). The results showed that about 75% of the centers reported at least one pesticide application in the prior year (Viet et al., 2013). Over 67% of this randomly selected nationally representative sample of licensed child care centers (n=637) used pyrethroid (cis-permethrin and trans-permethrin) or organophosphate (OP) pesticides, as their most common indoor-use pesticides. They sampled pesticides indoors using surfaces wipes (Tulve et al., 2006). Pyrethroid pesticides were detected in 100% of CA facilities studied in 2010 (Bradman et al., 2012). A survey of 637 child care center directors in CA found that 90% of them

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reported at least one pest problem and 55% had used pesticides, and that pesticides were often applied in and around playgrounds and classrooms (Bradman, Dobson, Leonard, & Messenger, 2010). In a study of 129 children's homes and 13 child care programs, pyrethroid (cyfluthrin, cis-permethrin, trans-permethrin) and organophosphate pesticides (chlorpyrifos, diazinon) were regularly applied (Morgan, Wilson, & Chuang, 2014).

Pyrethroid insecticides are a class of active ingredients found in many of the modern insecticides on store shelves and used for structural pest control by pest management professionals. Most indoor uses of organophosphate (OPs) pesticides were eliminated in 2002-2004 but use in agriculture continues. OP pesticides have been associated with adverse health outcomes such as poor respiratory health, neurocognitive disorders, reproductive harm, and various forms of cancer (Kim et al., 2017). Indoor, low-level pesticide exposure for young children is associated with serious adverse health problems later in life (Quiros-Alcala et al., 2016; Raanan et al., 2015). A meta-analysis of 16 case-control studies showed that children, from infancy to 19 years of age, exposed to chronic low-level indoor pesticides had increased risks of developing leukemia and lymphomas during later childhood (Chen et al., 2015).

Studies have measured biomarkers of pesticide exposure in children's urine and pesticide levels from carpet dust samples. In a study of 127 preschool-age children in Ohio, urinary metabolites of pyrethroids were detected in 67% of the children's urine samples, both at home and in child care (Morgan et al., 2007). In a study of 9 preschool-age children, diazinon and chlorpyrifos were found in floor dust sampled in both homes and child care centers (Wilson, Chuang, Lyu, Menton, & Morgan, 2003). The concentration of diazinon was the same in both settings but chlorpyrifos had higher concentrations in children's homes compared to their centers.

Silicone wristbands offer a novel, non-invasive approach to personal passive biomonitoring of exposures to harmful chemicals (Anderson et al., 2017). While carrying on with their day-to-day activities, participants wear lightweight, silicone wristbands which can capture a wide array of chemicals for subsequent extraction, identification, and concentration quantification. Silicone wristbands for personal passive sampling have been used to assess multipollutant exposure among pregnant woman in New Hampshire (Doherty, Pearce, Anderson, Karagas, & Romano, 2020) and middle school children in Massachusetts (Lin, Esenther, Mascelloni, Irfan, & Godri Pollitt, 2020), flame retardant exposure among preschool children in Oregon (Kile et al., 2016), as well as pesticide or pesticide residue exposure among agricultural communities in CA (Harley et al., 2019).

In CA, child care centers are required to considers alternatives to using harmful pesticides according to the Healthy Schools Act (HSA) (California Education Code, 2000). Licensed child care centers must post warning signs 24 hours before they use pesticides, have staff attend annual integrated pest management (IPM) trainings, provide annual reporting of pesticide use, post an IPM plan, designate an IPM coordinator, and adopt IPM practices. Although pesticides are required to be used as a last resort, young children in CA are still being exposed to pesticides from agricultural, commercial, and individual users.

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This study was designed to use novel silicone wristbands worn by preschool-age children to assess potential pesticide exposures to preschool-age children from both their child care centers and family homes and identify environmental and behavioral predictors of these exposures.

Materials and Methods

Study Design and Participants

This study was part of a larger randomized-control trial, Healthy Children & Environments Study (HCES), designed to reduce preschool-age children's exposure to pesticides through the implementation of a 7-month IPM intervention at child care centers. This study included children (n=125) who completed baseline wristband data collection during the first three years of the larger study (Fall-Winter, 2017-2019). Written informed consent was provided by parents/guardians and all study activities were reviewed and approved by the Committee on Human Research (CHR) at the University of California, San Francisco.

Recruitment and Sampling Design

A convenience sample of 33 child care centers were recruited from four counties in Northern CA; two counties were located in the San Francisco (SF) Bay Area (#1,3) and two counties were in the San Joaquin Valley (#2,4). The counties' inclusion criteria were: geography (urban, rural, and adjacent), percent of families at federal poverty level, percent of children under 5 years of age, and pesticide use in the past year based on the Pesticide Use Report (PUR) Data collected by CA Department of Pesticide Regulation (DPR) (California Department of Pesticide Regulation, 2017a). PUR data provides the total pounds of agricultural, structural, and commercial pesticides applied during the preceding year by county. The two SF Bay Area counties (#1,3) were primarily urban or suburban and had low agricultural pesticide use compared with the primarily rural, agricultural San Joaquin Valley counties (#2,4) (California Department of Pesticide Regulation, 2017a).

To recruit participants, child care directors were contacted in-person, by phone, or email. Enrollment criteria for centers included (1) being a licensed child care center with a director who speaks English, (2) having used pesticides (i.e., baits or sprays) in the last year, (3) having operated for at least two years with no plans to close in the next 12 months, and (4) enrolling children between three to five years of age from diverse ethnic and racial backgrounds, at least 25% of whom receive a government subsidy (e.g., Child and Adult Care Food Program (CACFP), Head Start, Child Care Development Fund, Alternative Payment program).

Five families were recruited from each center who had children in a designated classroom who met the following inclusion criteria: (1) were 3 or 4 years old, (2) planned to spend at least 6 hours per day in the center (3) planned to be enrolled in the center for the next nine months, and (4) had a parent present during enrollment who spoke either English or Spanish. The participating children were selected through a combination of direct outreach to parents by the study team and recommendations by the child care staff.

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Data collection Procedures

Study staff included Child Care Health Consultants (CCHCs), health professionals trained to provide health and safety information specific to child care settings (Alkon, Farrer, & Bernzweig, 2004), who recruited child care directors and families, administered child care director interviews, collected surveys, observed children's level of physical activity, and administered and monitored children's wristbands. Research assistants conducted objective assessments of the child care environment and health practices.

Instruments

Demographic information about child care personnel (e.g., education level, years of experience) and center demographics (e.g., staff turnover, facility age) were collected during the child care director interviews. Children's demographics and their home's environmental characteristics, including insects present, mold in the home, home address, agricultural fields visible from their home, and family's health behaviors, including frequency of cleaning floors, the presence of doormats in the home, and use of exterminators were collected in the family surveys provided in English and Spanish. Of the 125 children included in this analysis, 102 had families who completed the survey (82% completion rate).

Study staff completed the IPM Checklist with 73 items including the presence of (1) cracks observed in the child care center walls, (2) doormats present inside and/or outside the classroom adjacent to the outdoor area, and (3) pests or evidence of pests observed outdoors and indoors (Alkon et al., 2016). Study staff also completed the Health and Safety Checklist that includes key National Health and Safety Performance Standards (American Academy of Pediatrics, American Public Health Association, & National Resource Center for Health and Safety in Child Care and Early Education, 2019) and has been validated in child care centers (Alkon, Rose, Wolff, Kotch, & Aronson, 2015). The Checklist includes 66 items with two relevant items for this analysis: (1) storage of toxic substances in the original, labeled container with Safety Data Sheets (SDS) and (2) children thoroughly wash their hands with soap and water. The CCHCs also assessed children's activity level, indoors and outdoors, using a modified Environment and Policy Assessment and Observation (EPAO) rated from (1=stationery to 7=very vigorous) (Ward et al., 2008).

Wristband Data Collection Procedures.—Participating children wore one silicone wristband for 30 weekday hours at the child care center only (center-only). The wristband was removed and placed inside a sealed bag when the child left the center each day. Classroom teachers filled out wristband logs with the time on and time off for each child. Another wristband was worn continuously for 7 days and 7 nights at the home and their child care center (home/center). Parents/guardians filled out wristband logs, indicating locations where the child spent time while wearing the wristband. Some children lost one or both of their wristbands, and some center-only wristbands were worn home, thereby contaminating the wristband. In addition, we excluded center-only wristbands that were worn for less than 30 hours or more than 40 hours and home/center wristbands that were worn for more than 8 days or less than 7 days. Out of the 170 enrolled study children, 125 wore the silicone wristbands (74%) for the required time periods for adequate data

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collection; 120 were center-only and 104 were home/center wristbands and 99 wore both wristbands.

The wristbands were analyzed to identify the presence and concentration of the following 13 pesticides: dacthal, chlorpyrifos, diazinon, malathion, fipronil, bifenthrin, cyfluthrin, lamda-cyhalothrin, cypermethrin, cis-permethrin, trans-permethrin, deltamethrin, esfenvalerate.

Pesticide Use Reporting (PUR) Data.—Since 1990, information on all CA agricultural, commercial, and structural pesticide applications are reported to the CA DPR Pesticide Use Reporting (PUR) System. PUR data for all applications include date, pounds of active ingredient applied, and location to the county (Gunier, Bradman, Harley, Kogut, & Eskenazi, 2017). We obtained PUR data for 2017 on the pesticides of interest for our study (California Department of Pesticide Regulation, 2017a)

Wristbands and Chemical Analysis.—The silicone wristbands were provided by Dr. Kim Anderson's laboratory at Oregon State University (OSU) (www.fses.oregonstate.edu/methods). The silicone wristbands were stored at room temperature after data collection was complete and then shipped to OSU for analysis. The conditioning, post-deployment cleaning, and extraction of the wristbands were performed as described previously (Anderson et al., 2017; Bergmann et al., 2017; Harley et al., 2019). Briefly, the wristbands were conditioned at 300°C for 180 minutes and under vacuum prior to deployment. For post-deployment cleaning, the wristbands were rinsed to remove particulate matter and subsequently extracted in ethyl acetate. A 200 μL aliquot of extract underwent solid-phase extraction. The pesticide extraction surrogates were tetrachloro- meta-xylene (TCMX) and decachlorobiphenyl. The internal standard was 4,4'-dibromooctafluorobiphenyl.

The analytical method has been described in detail previously (Harley et al., 2019). Briefly, gas chromatography (GC) dual micro-electron capture detection (μECD) based on the US EPA pesticide method 8081B (Donald et al., 2016; Vidi et al., 2017) was used which yielded quantitative time-weighted average concentrations of 72 pesticides. Donald et al. (2016) described the confirmation process for identifying the target analytes and the determination of instrument limits of detection (LODs). The average LOD for the pesticides detected in >10% of wristbands was 2.8 pg/μL (range = 0.7 to 5.1 pg/μL).

Wristband's Quality Control.—Quality control samples included instrument blanks and laboratory processing blanks. All target analytes in these blanks were below limits of detection. Continuing calibration verification solutions were performed for 25 compounds, and >70% of the compounds were within 30% of the true value. Two samples were lost during processing, while five were not quantifiable due to high background interferences. 11-23% of sample analytes had interference. To demonstrate instrument precision, sample duplicates (n=7) were also analyzed; relative percent differences between detected analytes in duplicate runs was 6%. To assess instrument accuracy, six wristbands were spiked with target pesticides prior to clean up. Mean percent recovery for these samples was 95-125%.

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Data Analysis

Descriptive statistics for demographic characteristics, pesticide detection frequencies and distributions of pesticide concentrations (ng/g) in wristbands were calculated. Poverty level was calculated as the household income divided by the number of persons in the household based on the Federal Poverty Level (U.S. Dept. of Health and Human Services, 2018). We evaluated environmental factors (e.g., building integrity, door mats present, geographic location) and behavioral practices (e.g., storage of toxic substances/chemicals, cleaning schedules, hand washing, physical activity) that may be related to pesticide exposure. We examined bivariate relationships for each potential predictor variable using Wilcoxon rank-sum tests (pesticide concentrations) for the pesticide levels found in the center-only and home/center wristbands. Kruskal-Wallis tests were conducted to compare PUR data (pounds) by county. We used Tobit multivariate regression models (separate models for each pesticide and type of wristband) with the limit of detection set as the lower bound and the $\log_{10}$-transformed pesticide concentrations as the dependent variables and environmental characteristics and behavioral practices as predictors, controlling for the other predictor variables. Lastly, we compared the wristband results among children within centers using intraclass correlations coefficients (ICC) and across settings (center-only vs. home/center) using Spearman correlations coefficients, because the pesticide concentrations were not normally distributed. STATA version 15.0 was used to conduct the analyses and $p<0.05$ was set as the significance level *apriori*.

Results

Descriptives (Table 1).

The children (N=125) were 3.0 to 5.1 years of age with the majority being female and living above the poverty level. Study participants were diverse with 30.4% Non-Hispanic White, 27.2% Hispanic/Latinx, 10.4% Black/African American, 6.4% Asian, and 13.6% identified with more than one race or ethnic category. The children lived in either the SF Bay Area (46.4%) or San Joaquin Valley (53.6%). The mean (SD) distance between children's homes and their child care centers were 3.8 (4.8) miles.

Pesticide Detection and Concentration (Table 2).

The most commonly detected pesticides (DF>20%) were bifenthrin, chlorpyrifos, cypermethrin, fipronil and cis- and trans-permethrin in the center only wristbands. Since the concentration of the pesticides had a skewed distribution due to many wristbands with non-detectable levels, the median (p50) provides the best measure of the central tendency for concentrations. Cypermethrin was the most frequently detected pesticide (50%) and it had the highest median concentration (2.3 ng/g). The distribution of the pesticide concentrations was similar for the wristbands worn in the center-only or home/center.

The amount of pesticides reported (in pounds) as PUR data were significantly different across the counties (Table 2). The PUR data showed that county #4, located in the San Joaquin Valley, had the largest amount of bifenthrin, chlorpyrifos, cypermethrin, and permethrin used compared to the other three counties. County #1 located in the SF Bay Area had the largest amount of fipronil use.

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Bivariate relationships (Table 3, 4).

Children who attended centers where they stored toxic substances onsite in their original container with SDS documentation had significantly lower levels of bifenthrin and fipronil but higher levels of cypermethrin compared to centers where substances were not stored properly (Table 3). Children who attended centers where they always washed their hands thoroughly had significantly lower concentrations of fipronil than children in centers where they did not wash their hands thoroughly. Children who attended centers where they had no cracks in the walls had significantly higher concentrations of cypermethrin than children who attended centers with cracks. Children who attended centers where the researcher observed no pests or any evidence of pests had significantly higher concentrations of bifenthrin, fipronil, and trans-permethrin than centers with pests or evidence of pests observed.

There were no significant relationships between children's level of physical activity or the presence of doormats in the classroom and pesticide concentrations detected on the wristbands.

The children who lived in homes where the floors were not cleaned daily had significantly higher concentration of fipronil than children who lived in homes where floors were cleaned daily (Table 4). Children who lived in homes with reported mold or mildew on the walls, making their home vulnerable to pest infestations, had higher concentration of chlorpyrifos than children living in homes without mold. Children living in homes with no insects observed by a parent had significantly higher concentrations of cypermethrin than children living in homes with pests. Children living in homes that used professional exterminators in the last six months had significantly higher levels of bifenthrin and chlorpyrifos but lower levels of fipronil compared to children living in homes without recent exterminators. Children living in homes near agricultural fields had significantly higher levels of bifenthrin than children not living near fields.

Tobit regression models (Table 5).

The environmental and behavioral factors that predicted the concentration of the pesticides were different for the center-only wristbands and the home/center wristbands. In the center-only wristbands, county-level agricultural, structural and commercial pesticide use (log10(PUR)) was a significant predictor of cypermethrin, fipronil, cis-permethrin and trans-permethrin. No pests or evidence of pests observed was a significant predictor of bifenthrin, cypermethrin, cis-permethrin and trans-permethrin. Storing toxic chemicals onsite in their proper container with SDS documentation was a predictor of cypermethrin, cis-permethrin and trans-permethrin. No cracks in the walls and doormats present were also significant predictors of cypermethrin.

In the home/center wristbands, county level pesticide use (log10(PUR)) was a significant predictor of bifenthrin, fipronil, cis-permethrin and trans-permethrin. In the home/center wristbands, the only significant predictor of cypermethrin was living near an agricultural field.

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Reported children's handwashing and observed children's level of physical activity were not associated with any of the six pesticides detected in the center-only wristbands. Reported daily cleaning of the floors in the house, mold in the home, home treatment by exterminators in the last six months, and the presence of doormats were also not significant predictors of any of the six pesticides detected in the home/center wristbands.

No potential exposure determinants were significantly associated with levels of chlorpyrifos found in the center-only or home/center wristbands.

Correlations (Table 6a, 6b).

The intraclass correlation coefficients indicated weak to moderate correlations for pesticide levels among children who attended the same center. Overall, the variability was similar within children in each center and between children in different centers for bifenthrin, cypermethrin, cis-permethrin and trans-permethrin, while the variability for chlorpyrifos and fipronil was higher within children in the same center than between children in different centers. These findings suggest that wristbands can accurately assess individual pesticide exposure and that it can't be assumed that exposures are similar for all children within a center. In addition, since the majority of children lived in close proximity to their child care center (~4 miles), some pesticide concentrations, such as cypermethrin, were similar between the center-only and home/center wristbands.

Children's pesticide exposures were weakly to moderately correlated across the two wristbands, center-only versus home/center. This finding may indicate that there are different sources of pesticide exposure in the home versus center.

Discussion

This study's findings showed that preschool-age children are exposed to pesticides (e.g., bifenthrin, chlorpyrifos, cypermethrin, fipronil, cis-permethrin, and trans-permethrin) in their child care centers and homes. These are all broad-spectrum insecticides designed to control a variety of insects, such as ants, cockroaches, spiders, and agricultural pests. Environmental factors associated with pesticide exposure in the child care centers were safe storage of toxic substances, cracks in the walls, pests or evidence of pests observed and geographic location (e.g., agricultural counties). Significant behavioral factors for some pesticides included children washing their hands thoroughly and doormats placed by the classroom doors. The environmental conditions associated with children's exposure to pesticides at home were having mold, insects observed, living within sight of agricultural fields and geographic location (e.g., county of residence). The behavioral factors were daily cleaning of the floors and hiring an exterminator.

Children's physical activity was not associated with pesticide levels in the wristbands and there were no significant predictors of chlorpyrifos concentrations found in the center-only or home/center wristbands.

The pesticides detected in the children's wristbands were similar to levels measured in other studies. For example, the concentration of fipronil, cypermethrin, chlorpyrifos, and cis- and trans- permethrin were similar to levels in wristbands worn by adolescents residing in an agricultural county. (Harley et al., 2019). The only pesticide detected in the adolescents' wristbands and not in the current study was dacthal, an herbicide heavily used in the agricultural region where the adolescents lived. Among child care centers in the U.S. nationally representative study of child care centers, chlorpyrifos and cis- and trans-permethrin were also detected in outside soil samples and wipes collected on indoor surfaces (Tulve et al., 2006).

Our study and others have found mixed relationships between environmental and behavioral factors and indoor pesticide exposures. For example, Harley et al., (2019) found significant relationships between the presence of doormats, carpets, and frequency of cleaning and pesticides as measured in adolescent silicone wristbands (Harley et al., 2019), yet another study found no significant relationship between housing conditions and practices and OP pesticides in urinary samples in young children (Bradman et al., 2011). A study of pesticides found that homes located near farms had higher concentration of OPs in their house dust than homes further away (Harnly et al., 2009), yet another study found cypermethrin dust concentrations were similar inside and outside in farmworker households (Trunelle et al., 2013).

Paradoxically, we found that children who attended centers where there were no pests or the evidence of pests observed had significantly higher concentrations of bifenthrin, fipronil, and trans-permethrin compared with centers where pests were observed. It may be that the centers that used pesticides eliminated all pests, allergen-inducing cockroaches and nuisance pests such as ants. These results support an approach to reducing pesticide exposures using integrated pest management (IPM). The goal of IPM is not to exterminate but reduce the number of pests using an approach of inspection, identification, monitoring, managing pest activity, and using higher risk pesticides as the last resort.

The PUR data is unique to CA and includes agricultural, structural, and commercial use of pesticides. The pyrethroid insecticides identified in the wristbands and PUR data, bifenthrin, cypermethrin, and cis- and trans-permethrin, have a low vapor pressure and tend to bind tightly to soil and dust particles and are less likely to become airborne (Johnson, Luukinen, Gervais, Buhl, & Stone, 2010; Toynton, Luukinen, Buhl, & Stone, 2009). Bifenthrin is used in both agricultural and structural pest control and is available in sprays, granules, and aerosols. In 2017, approximately 48% of the bifenthrin sold in California was for agricultural purposes. In this study, bifenthrin concentrations in the wristbands were higher when the center or home was located in the San Joaquin counties #2 and #4 indicating exposures from local agricultural fields or professional pest management companies.

Cypermethrin and permethrins are used as insecticides in agricultural applications as well as in consumer products such as commercial insect sprays. Agricultural use made up 12% of the cypermethrin and 15% of the permethrin (cis- and trans-) sold in California in 2017 (California Department of Pesticide Regulation, 2017b). Permethrin may be present in products as liquids, powders, dusts, aerosol solutions, sprays, or treated clothing (Toynton et al., 2009). Likewise, permethrin (cis- and trans-) is used in a variety of products, such as cattle ear tags and flea collars, topical flea treatments for dogs, commercial insect sprays,

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and treatments for head lice and scabies. Commercially available household insect sprays, such as ant, roach, spider, and flying insect sprays, may contain combinations of pesticide ingredients, including cypermethrin and permethrin (cis- and trans-). Cypermethrin and permethrins have been shown to have negative effects on the human's immune, reproductive and neuronal systems (Chrustek et al., 2018).

In this study, cypermethrin concentrations in the wristbands were associated with several environmental and behavioral factors in unexpected directions. Higher concentrations were associated with proper storage of chemicals in centers, no cracks in center walls, pests observed, doormats present, high county-wide use, and agricultural fields visible from the children's homes. Cis- and trans-permethrins were associated with chemical storage at the center, no pests observed, and higher county-wide use. It is difficult to differentiate the agricultural, structural and home/personal use of these pyrethroids, yet they are pervasive and concerning due to their potential effect on children's long term health (Liu & Schelar, 2012; Ma et al., 2002).

In this study, the county-wide PUR of fipronil, a phenylpyrazole, was high when children's wristband concentrations were low, indicating that the children's exposures were not related to agriculture, structural or commercial use. Fipronil is often found in topical flea treatments for pets, gel baits, or in granular products for insects found in grass (Jackson, Cornell, Luukinen, Buhl, & Stone, 2009). Only about 7% of fipronil sales in CA were used in applications reported to DPR, and most of what was reported was structural pest control by pest management professionals (California Department of Pesticide Regulation, 2017b), indicating that home-use is widespread. There were several factors related to fipronil concentrations in this study but the only factor that was significant in the regression model was lower county level use. Therefore, fipronil exposure was most likely related to individual home or center use.

Chlorpyrifos, an organophosphate pesticide, has been banned for indoor use since 2000, but was used in agriculture in California through 2020, when agricultural use was also banned (California Environmental Protection Agency (CalEPA) & California Department of Pesticide Regulation (CDPR), 2019; Drew, Holman, & Britton, 2016). Chlorpyrifos is persistent indoors, taking weeks to years for chlorpyrifos to break down (Giesy et al., 2014). Therefore, the chlorpyrifos detected in the children's wristbands may reflect drift into the young children's homes and child care centers and historical rather than recent use. Other studies showed that nearby applications of pesticides can drift indoors in child care centers or family's homes and settle in dust (Lee et al., 2011). PUR data has been associated with pesticide levels detected in homes, as measured by house dust (Gunier et al., 2011; Harnly et al., 2009). These findings and our study show that ambient pesticide levels are higher in agricultural counties than urban and suburban counties since pesticides are applied regularly in agricultural communities and drift into indoor settings.

Limitations.

Although this is the first study to use silicone wristbands as personal passive samplers to measure pesticide exposure among preschool-age children and report new findings, there are several limitations. We enrolled a convenience sample and assessed exposure data during

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a limited time period (Fall to early Winter). Information collected from family surveys were self-reported and did not include observations. There was limited information on the children's exposure to pesticides on the weekends and places outside their home. The data collection did not include dietary intake although it is known that diet contributes to pesticide exposure. There may be other, unmeasured factors that contributed to the exposure of the pesticides. Lastly, the PUR data were aggregated at the county-level and not specific to the location of the child care center or children's homes.

Clinical Implications.

This study supports the need for environmental assessments during pediatric primary care visits to determine each child's risk of exposure to pesticides. Histories taken in-person or by self-reported surveys should include information about the families' home, proximity to agricultural fields, use of pest control services and pesticide sprays, presence of pests, and pets being treated for fleas. Assessing the potential strategies under the parent's control to reduce pesticide exposure may lead to useful interventions. Washing children's hands thoroughly and daily house cleaning will reduce children's exposures to harmful pesticides. Also, cleaning with vacuum cleaners that have a HEPA filter may also increase the efficiency of removing pests and pesticides in the home. Lastly, information sheets on how to reduce the family's exposure to pesticides should be provided for all families in multiple languages.

Conclusions.

Few studies have examined pesticide exposures to young children in child care settings. Overall, these results show that preschool-age children who are at a critical stage for mental and physical development are being exposed to multiple pesticides. This study supports other evidence that pesticides applied in child care facilities and near homes expose young children to chronic, low-level toxicants that may pose long-term health risks. Interventions should be implemented to provide alternative strategies to control pests, such as integrated pest management, implemented by pediatric nurse practitioners and child care health consultants.

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Table 1.

Demographic characteristics of study population (n=125)

Characteristic	N(%)
Age 3 years	42 (33.6%)
Age 4 years	76 (60.8%)
Age 5 years+	7 (5.6%)
Male	57 (45.6%)
Female	68 (54.4%)
Non-Hispanic White	38 (30.4%)
Hispanic/Latinx	34 (27.2%)
More than one race/ethnicity	17 (13.6%)
Unknown/other	15 (12.0%)
Black/African American	13 (10.4%)
Asian	8 (6.4%)
Below poverty level	30 (24.0%)
Above poverty level	72 (57.6%)
Missing	23 (18.4%)
SF Bay Area	58 (46.4%)
San Joaquin Valley	67 (53.6%)

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Table 2.

Distributions of pesticide detection (%) and concentrations (ng/g) in wristbands and Pesticide Use Report by county

Pesticide	Detected	Concentration (ng/g)			Pesticide Use Report (PUR) by County# (pounds)*			
	(%)	Geometric Mean	95% Confidence Interval (CI)	p50	1	2	3	4
Center only (n=120)								
Bifenthrin	27.5%	3.48	2.10, 5.78	0.6	3132	15255	2708	31883
Chlorpyrifos	25.0%	0.57	0.48, 0.67	0.3	1090	27105	6561	43296
Cypermethrin	50.0%	6.49	4.46, 9.44	2.3	16	280	159	1687
Fipronil	27.5%	1.06	0.87, 1.30	0.6	2483	1027	300	691
cis-Permenthrin [a]	32.5%	1.09	0.65, 1.81	0.1	293	5421	323	9033
trans-Permethrin [a]	35.0%	2.17	1.28, 3.67	0.2				
Home/center (n=104)								
Bifenthrin	28.9%	4.61	2.51, 8.45	0.6	3132	15255	2708	31883
Chlorpyrifos	16.4%	0.58	0.45, 0.73	0.3	1090	27105	6561	43296
Cypermethrin	47.1%	6.95	4.44, 10.87	2.3	16	280	159	1687
Fipronil	23.1%	1.11	0.86, 1.44	0.6	2483	1027	300	691
cis-Permenthrin [a]	32.7%	1.22	0.68, 2.16	0.1	293	5421	323	9033
trans-Permethrin [a]	40.4%	3.87	2.05, 7.30	0.2				

[*] Kruskal-Wallis tests showed significant differences of PUR use for all of the pesticides by County at $p<.05$.

[a] PUR data reports permethrin; cis- and trans-permethrin are not reported separately

Note: LOD (pg/μL): bifenthrin 3.5; chlorpyrifos 1.8; cypermethrin 5.1; fipronil 4.4; cis-permethrin 0.7; trans-permethrin 1.3

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Table 3.

Bivariate analysis of pesticide concentrations (ng/g) in wristbands worn at child care centers only (n=120).

			Geometric Mean Concentration (ng/g)											
Characteristic		**%**	**BIF**	**p**	**CPF**	**p**	**CYP**	**p**	**FIP**	**p**	**cPRM**	**p**	**tPRM**	**p**
Chemicals stored in original container with documentation	Always	56.7%	1.7	<0.01	0.5	0.2	12.9	<0.01	0.8	<0.01	1.6	0.13	3.1	0.2
	<Always	43.3%	8.6		0.6		2.6		1.5		0.7		1.4	
Children wash hands thoroughly	Always	49.2%	1	0.1	0.7	0.3	9.8	0.1	0.6	<0.01	0.9	0.7	2	0.9
	<Always	47.5%	4.8		0.6		5.5		1.2		1.2		2.1	
Child average physical activity level > 4	Yes	24.2%	3.9	0.5	0.6	0.4	4.6	0.2	0.9	0.2	0.9	0.4	2.0	0.6
	No	74.2%	3.3		0.6		7.6		1.1		1.2		2.3	
No cracks observed in walls	Yes	55.8%	3.9	0.07	0.5	0.2	11.4	<0.01	0.9	0.3	1.5	0.06	3.0	0.2
	No	44.2%	3.0		0.6		3.2		1.3		0.7		1.4	
Pests observed or evidence of	Yes	75.8%	1.8	<0.01	0.6	0.26	7.2	0.08	0.9	0.01	0.7	0.06	1.4	0.02
	No	24.2%	27.5		0.5		4.7		1.6		4.0		9.6	
Doormat present	Yes	63.3%	2.6	0.29	0.5	0.13	4.7	0.28	1	0.26	0.8	0.10	1.5	0.17
	No	22.5%	4.5		0.8		9.8		1		3.6		7.1	
	Not Applicable	14.2%	9.2		0.7		14.6		1.5		0.6		1.6	

Notes: BIF = bifenthrin; CPF = chlorpyrifos; CYP = cypermethrin; FIP = fipronil; cPRM = cis-permethrin; tPRM = trans-permethrin

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Table 4.

Bivariate analysis of pesticide concentrations (ng/g) in wristbands worn at home and child care centers.

			Geometric Mean Concentration (ng/g)											
Characteristic (N)		**N (%)**	**BIF**	**p**	**CPF**	**p**	**CYP**	**p**	**FIP**	**p**	**cPRM**	**p**	**tPRM**	**p**
Clean floors daily (n=98)	Yes	35 (35.7%)	4.0	0.41	0.5	0.95	9.4	0.05	0.8	0.03	1.2	0.92	2.6	0.94
	No	63 (64.3%)	3.9		0.6		5.6		1.3		1.1		2.4	
Mold or mildew on walls (n=96)	Yes	15 (15.6%)	4.2	0.14	4.2	0.03	6.0	0.54	2.6	0.63	1.6	0.94	6.1	0.82
	No	81 (84.4%)	4.9		2.8		6.5		1.0		1.2		3.3	
Insects observed in home (n=104)	Yes	100 (96.2%)	4.7	0.42	0.6	0.96	6.2	0.02	1.1	0.71	1.2	0.47	3.9	0.70
	No	4 (3.9%)	3.5		0.3		125.8		0.6		1.8		2.9	
Professional exterminator last 6 mo (n=97)	Yes	43 (44.3%)	6.4	0.02	0.6	0.03	4.5	0.57	1.0	<0.01	1.5	0.40	2.6	0.76
	No	54 (55.7%)	2.9		0.5		9.1		1.1		1.0		2.3	
Agricultural fields visible from home (n=96)	Yes	19 (19.8%)	9.6	0.04	0.6	0.82	4.5	0.11	1.0	0.28	1.3	0.23	3.0	0.45
	No	77 (80.2%)	3.3		0.6		7.3		1.1		1.2		2.4	
Doormats inside and outside (n=96)	Yes	43 (44.8%)	7.9	0.09	0.7	0.24	5.1	0.26	1.0	0.78	1.3	0.95	4.5	0.63
	No	53 (55.2%)	2.8		0.5		9.6		1.3		1.2		3.1	

Notes: BIF = bifenthrin; CPF = chlorpyrifos; CYP = cypermethrin; FIP = fipronil; cPRM = cis-permethrin; tPRM = trans-permethrin

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Table 5.

Environmental and Behavioral Factors That Predict Pesticide Concentrations (ng/g) in Children's Wristbands.

	Beta Coefficient and Lower and Upper Confidence Intervals for Predictors of Pesticide Concentrations																			
Characteristic	**Bifenthrin**				**Cypermethrin**				**Fipronil**				**cis-Permethrin**				**trans-Permethrin**			
	β	**LCI**	**UCI**	**p**	**β**	**LCI**	**UCI**	**p**	**β**	**LCI**	**UCI**	**p**	**β**	**LCI**	**UCI**	**p**	**β**	**LCI**	**UCI**	**p**
Center-only Wristband (n=114)																				
Chemicals stored properly	−0.7	−2.1	0.6	0.29	1.3	0.8	1.9	<0.01	−0.37	−0.8	0.1	0.10	1.3	0.5	2.2	<0.01	1.4	0.4	2.3	<0.01
Children wash hands well	−1	−3.3	1.3	0.40	−0.5	−1.2	0.1	0.12	−4	−331.3	323.3	0.98	−0.2	−1.4	1	0.74	0.5	−0.9	1.8	0.49
No cracks in walls	0.3	−1.1	1.7	0.70	0.8	0.3	1.3	<0.01	0.01	−0.4	0.4	0.97	0.01	−0.8	0.9	0.99	−0.4	−1.4	0.6	0.41
Pests observed at center	−1.6	−3.1	−0.1	0.03	0.6	0.1	1.2	0.03	−0.1	−0.6	0.4	0.67	−0.9	−1.8	0.003	0.05	−1.4	−2.5	−0.4	0.01
Doormat in class	0.5	−0.3	1.4	0.21	0.6	0.3	0.9	<0.01	0.05	−0.2	0.3	0.72	0.3	−0.2	0.8	0.22	0.5	−0.1	1	0.10
Child physical activity level	0.7	−0.5	1.8	0.28	0.1	−0.3	0.5	0.77	−0.1	−0.4	0.3	0.69	0.2	−0.5	0.9	0.59	0.4	−0.4	1.1	0.33
PUR Log_{10}	1.6	−0.1	3.2	0.06	0.6	0.2	0.9	<0.01	−1	−1.7	−0.3	0.01	1.1	0.4	1.7	<0.01	1.2	0.5	1.9	<0.01
Overall R^2	0.12*				0.19*				0.19*				0.12*				0.12*			
Home / Center Wristband (n=104)																				
Clean floors daily	−0.2	−1.9	1.5	0.82	0.7	−0.01	1.3	0.05	−0.5	−1.2	0.2	0.19	0.03	−1.1	1.1	0.96	0.1	−1	1.3	0.82
Mold observed in home	−0.5	−2.6	1.6	0.62	0.01	−0.8	0.9	0.99	−0.5	−1.3	0.2	0.16	−0.7	−2	0.7	0.32	−1	−2.4	0.4	0.14
Insects observed in home	−0.1	−4.2	4.1	0.97	−1.3	−2.7	0.1	0.06	4.1	−443.9	452.1	0.99	−0.3	−3	2.4	0.85	0.3	−2.7	3.3	0.84
Exterminator last 6 months	0.4	−1.4	2.1	0.68	0.1	−0.6	0.8	0.76	−0.6	−1.2	0.1	0.10	0.2	−0.9	1.4	0.67	0.7	−0.5	1.9	0.26
Agricultural fields visible from home	−0.8	−2.7	1.1	0.39	1	0.2	1.9	0.02	−0.3	−1	0.4	0.41	1	−0.4	2.4	0.15	0.7	−0.7	2.2	0.33
Doormats inside and outside home	0.9	−0.7	2.5	0.27	−0.2	−0.8	0.4	0.53	−0.3	−0.9	0.3	0.32	0.3	−0.8	1.3	0.60	0.5	−0.7	1.6	0.41
PUR Log_{10}	3.2	1.1	5.3	<0.01	0.2	−0.3	0.7	0.42	−1.2	−2.4	−0.1	0.03	0.9	0.02	1.7	0.05	1.1	0.2	2.1	0.02
Overall R^2	0.08+				0.07+				0.12*				0.03				0.04			

Notes: β= beta coefficient; LCI= lower confidence interval; UCI = upper confidence interval

* p-value<0.01

+ p-value<0.05

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Table 6a.

Correlations within center and individuals

Pesticide	ICC
Bifenthrin	0.55
Chlorpyrifos	0.34
Cypermethrin	0.49
Fipronil	0.22
cisPermethrin	0.45
transPermethrin	0.46

N=120 wristbands in 33 centers

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Table 6b.

Correlation between center-only and home/center wristbands

Pesticide	Spearman
Bifenthrin	0.40
Chlorpyrifos	0.32
Cypermethrin	0.62
Fipronil	0.36
cisPermethrin	0.39
transPermethrin	0.38

* all significant p<0.001

N=99 wristbands worn by the same child