A Section 508–conformant HTML version of this article
is available at https://doi.org/10.1289/EHP8831.

Changes in Latina Women's Exposure to Cleaning Chemicals Associated with Switching from Conventional to "Green" Household Cleaning Products: The LUCIR Intervention Study

Kim G. Harley,[1] Lucia Calderon,[1] James E.S. Nolan,[1] Randy Maddalena,[2] Marion Russell,[2] Katherine Roman,[3] Stephanie Mayo-Burgos,[3] Jessica Cabrera,[3] Norma Morga,[4] and Asa Bradman[1]

[1]Center for Environmental Research and Children's Health (CERCH), School of Public Health, University of California, Berkeley, Berkeley, California, USA
[2]Lawrence Berkeley National Laboratory, Berkeley, California, USA
[3]CHAMACOS Youth Council, Salinas, California, USA
[4]Clinica de Salud del Valle de Salinas, Salinas, California, USA

Background: Household cleaning products may be a significant source of chemical exposures, including carcinogens and suspected endocrine disruptors.

Objectives: We characterized exposures during routine household cleaning and tested an intervention to reduce exposures to cleaning product chemicals.

Methods: The Lifting Up Communities with Interventions and Research (LUCIR) Study is a youth-led, community-based intervention project. Youth researchers conducted personal air monitoring with 50 Latina women while they cleaned their homes with their regular cleaning products (preintervention visit) and then 1 week later while they used "green" cleaning products provided by the study (postintervention visit). Air samples were analyzed for volatile and semivolatile organic compounds using gas chromatography–mass spectrometry and high-performance liquid chromatography. We compared pre- and postintervention air concentrations of 47 chemicals of concern, selected because they were on California's Proposition 65 list of carcinogens or reproductive/developmental toxicants or were suspected endocrine disruptors. Youth researchers were integrally involved in the study design, data collection, interpretation, and dissemination of findings.

Results: We observed statistically significant decreases in air concentrations of 17 chemicals of concern when participants switched to green cleaning products, including decreases in geometric mean concentrations of 1,4-dioxane (−46.4%), chloroform (−86.7%), benzene (−24.8%), naphthalene (−40.3%), toluene (−24.2%), and hexane (−35.5%). We observed significant increases in air concentrations of three fragrance compounds: the plant-derived terpene, beta-myrcene (221.5%), and the synthetic musks celestolide (31.0%) and galaxolide (79.6%). Almost all participants (98%) said the replacement products worked as well as their original products, and 90% said that they would consider buying the replacement products in the future.

Discussion: This study demonstrates that choosing cleaning products that are marketed as green may reduce exposure to several carcinogens and endocrine disruptors. Future studies should determine whether use of unscented green products would further reduce exposure to terpenes and musks. https://doi.org/10.1289/EHP8831

Introduction

Household cleaning products can expose consumers to multiple chemicals, including volatile organic compounds (VOCs) that may affect human health. Multiple studies have shown associations of cleaning products with increased risk of asthma (Folletti et al. 2017; Zock et al. 2007) and respiratory irritation (Folletti et al. 2017; Medina-Ramón et al. 2006; Zock et al. 2007) in professional cleaners, but few have examined how housecleaning may affect women's cancer risk or reproductive health (Dodson et al. 2012; Zota et al. 2010). Suspected or known carcinogens found in cleaning products include chloroform, which was found to be released by products containing bleach (Odabasi 2008); 1,4-dioxane, a contaminant found in dish soaps, laundry detergents, and other foaming products (Tahara et al. 2013; Tanabe and Kawata 2008); and benzene derivatives, found in certain carpet cleaners and detergents (Agency for Toxic Substances and Disease Registry 2007). Suspected endocrine disruptors found in household cleaning products include low molecular weight phthalates, which are used as fragrance carriers (Harris et al. 1997); synthetic musks, used as fragrances (Bitsch et al. 2002); and cyclosiloxanes, used as solvents and carriers in household cleaners (McKim et al. 2001).

Latina women may be at particular risk of exposure to cleaning product chemicals. In California, 81% of maids and house cleaners in the formal sector are Latina (California Breast Cancer Research Program n.d.), and this proportion may be even higher when informal workers are considered (Wolfe et al. 2020). Research also suggests that Latinas clean their homes more frequently and use more products than individuals of other races and ethnicities (Moran et al. 2012).

Inhalation is a primary route of human exposure to cleaning product chemicals because many products emit VOCs or semivolatile organic compounds (SVOCs) (Bello et al. 2009). These chemicals may persist for several hours in a home, extending exposure beyond the time of active cleaning (Nazaroff and Weschler 2004). Bello et al. showed increases in concentrations of total VOCs emitted during 10-min bathroom cleaning sessions of a sink, mirror, and toilet, as measured using personal monitors (Bello et al. 2010). In chamber studies, use of household cleaners resulted in measurable concentrations of glycol ethers, formaldehyde, terpenes, and other chemicals (Nørgaard et al. 2014; Singer et al. 2006). Although these studies demonstrate that volatile cleaning chemicals can be detected in air during cleaning activities, the studies analyzed only a small number of compounds and were performed in simulated environments that may not accurately characterize real-life exposure. Additionally, none of these studies examined interventions to reduce an individual's exposures.

The purpose of our study was to *a*) characterize air concentrations of multiple suspected carcinogens and endocrine-disrupting chemicals in the breathing zone of Latina women while they

Address correspondence to Kim G. Harley, School of Public Health, University of California, Berkeley, 2121 Berkeley Way #6128, Berkeley, CA 94720-7360 USA. Email: kharley@berkeley.edu

Supplemental Material is available online (https://doi.org/10.1289/EHP8831).

The authors declare they have no actual or potential competing financial interests.

Received 16 December 2020; Revised 18 June 2021; Accepted 13 July 2021; Published 1 September 2021.

Note to readers with disabilities: *EHP* strives to ensure that all journal content is accessible to all readers. However, some figures and Supplemental Material published in *EHP* articles may not conform to 508 standards due to the complexity of the information being presented. If you need assistance accessing journal content, please contact ehponline@niehs.nih.gov. Our staff will work with you to assess and meet your accessibility needs within 3 working days.

cleaned their homes in real-world conditions using their own regular household cleaning products and *b*) determine whether women could reduce their exposures by switching to using cleaning products marketed as lower chemical. Because there is a wide range of terminology and there are no official standards for lower chemical products, we generically refer to these as "green" cleaning products. This study was a community-based participatory research project with an additional goal of engaging and empowering youth in environmental health research to benefit their community.

Methods

The Lifting Up Communities with Interventions and Research (LUCIR) Study is a youth empowerment intervention study examining strategies to reduce cleaning product chemical exposure to Latina women. The Spanish word *lucir* means "to shine," reflecting the housecleaning focus of the study. The study was designed in collaboration with the Center for the Health Assessment of Mothers and Children of Salinas (CHAMACOS) Youth Council, a group of Latino high school students engaged in environmental justice, health literacy, and research in Salinas, California, a predominantly low-income agricultural community.

Youth Participatory Action Research Approach

The CHAMACOS Youth Council is a volunteer group that meets bimonthly with a youth coordinator (J.E.S.N.) to learn about environmental health, equity, and justice, and to plan and implement community-based research projects. Youth Council members generally range in age from 14 to 19 y old. An important function of the Youth Council is to identify environmental health topics of importance to their community and to help researchers frame grant proposals to obtain funding to collaborate with them on this work. Our model and method for engaging youth researchers and integrating their experiential expertise into study design, implementation, and dissemination has been described elsewhere in the context of similar studies (Madrigal et al. 2014, 2016; Nolan et al. 2021).

In early meetings, Youth Council members identified exposure to cleaning product chemicals as an important environmental health concern because of the large number of Latina women working as cleaners and because of the cultural importance of housecleaning in their families and community. In 2018, funding was received from the California Breast Cancer Research Program to conduct this research as a community research collaboration integrally involving the Youth Council.

Beginning in spring 2019, in their bimonthly meetings Youth Council members began learning about health concerns related to cleaning chemicals, conducting hands-on exercises in personal and ambient air monitoring, inventorying cleaning products in their own homes, trying out green cleaning products, pilot testing and providing feedback on study questionnaires and protocols, and developing a name and logo for the study. During the summer of 2019, 10 Youth Council members were hired as paid youth research assistants who were responsible for conducting all key aspects of the research study under the supervision of adult staff members. The youth research assistants recruited participants from their community, tracked study activities, calibrated air monitoring equipment, developed educational materials, and conducted home visits with participants, including interviewing participants in English or Spanish, observing cleaning activities and products used, and collecting air samples. During the summer of 2020, Youth Council members were hired again to take the lead in returning study results to the participants and the community at large, including developing a newsletter that described the study findings. Although the original intent was for the youth to report the study findings at an in-person meeting for participants, this meeting was not possible because of the COVID-19 pandemic. Instead, the youth research assistants worked with a local professional arts group to learn storyboarding, voice acting, and animation skills to develop an animated miniseries (https://cerch.berkeley.edu/research-programs/lucir-study) explaining the study findings, techniques for how to choose safer products while in the store, and safer use of cleaning products in the home. Youth research assistants have presented the study findings virtually at a scientific conference, community meetings, a graduate-level public health class, and high school classrooms. Three Youth Council members (K.R., S.M.-R., J.C.) contributed as paper authors.

Study Intervention

Participants in the LUCIR Intervention Study were 50 women living in Salinas, California, who were recruited by the youth researchers through flyers, word of mouth, and personal networks. Women were eligible for the study if they were at least 18 y old; lived in the Salinas area; self-identified as Latina, Hispanic, or Mexican; and spoke English or Spanish. Women received $50 USD in incentive coupons and a selection of green cleaning products for their participation. Data collection took place from June through August 2019. The Committee for the Protection of Human Subjects at University of California, Berkeley approved this study, and written informed consent was obtained from each participant.

Participants completed two home-based data collection visits spaced 1 wk apart. Participants were asked not to clean their homes on the day of the visit before the study staff arrived. At the preintervention visit, women were asked to clean their kitchen and bathroom for 30 min total, using their regular cleaning products while wearing a small backpack containing personal air monitoring equipment. Study participants were not told which cleaning tasks to perform but were asked to conduct their usual cleaning routines. For logistical reasons, cleaning was limited to the kitchen and bathroom to ensure that all participants were engaged in similar cleaning activities. The kitchen and bathroom were chosen because multiple cleaning products are typically used in these rooms. After the participant finished 30 min of cleaning, one youth research assistant removed the backpack and processed the air samples, and another youth research assistant talked to the participant about chemicals in household cleaning products, provided her with educational materials, and gave her green replacement cleaning products to use for the next week and at the postintervention visit.

One week later, staff returned for the postintervention visit to monitor the participant while she cleaned for 30 min using only the green replacement products. Again, participants were not told what to do but were asked to engage in their regular routines. Participants were free to choose which of the green products to use in their cleaning.

Green Replacement Products

The replacement products were national brands that marketed themselves as being green or lower in harmful chemicals. There is no official standard definition of green products, so all potential replacement products were screened using product labeling [e.g., U.S. Environmental Protection Agency Safer Choice label (U.S. Environmental Protection Agency n.d.)], consumer databases [e.g., Environmental Working Group's Guide to Healthy Cleaning (Environmental Working Group n.d.)], and label review to confirm that they did not list ingredients of concern. The youth researchers took a lead role in selecting the green replacement products, including photographing cleaning supply aisles at local stores to identify the array of locally available products and inventorying cleaning supplies in their own homes to determine the categories of products to include (e.g., all-purpose spray, floor-cleaning liquid, powder cleanser). Study staff purchased a variety of green cleaning products that were locally available and relatively low cost (less than $4 USD each) and partitioned the products into unmarked containers. The youth researchers tested out the products at home, made observations on standardized forms they had developed, discussed their opinions, and voted on the products that best fit the anticipated needs of study participants, considering factors such as effectiveness and fragrance.

All participants received the same green replacement products: two all-purpose cleaners (one in a spray bottle, one in a pour bottle), toilet bowl cleaner, powder cleanser, disposable wipes, and dish soap. Participants were also provided with a homemade glass cleaner made of water, white vinegar, and the dish soap, as well as a new toilet cleaning brush, a sponge, and a mop to reduce cross contamination. The replacement products used in the intervention are listed in Table S1. Four of the seven replacement products (the all-purpose cleaners, toilet bowl cleaner, and disposable wipes) contained fragrance. Although unscented products would have been preferable, it was difficult to find unscented products in the community, and for sustainability reasons, locally available, affordable scented products were chosen. The replacement products were manufactured by four different companies to give participants exposure to multiple brands.

Data Collection

At the preintervention visit, youth research assistants administered a structured questionnaire to collect information about family demographics, income, smokers in the home, and usual household cleaning habits, including what types of products were used and how often.

At both the pre- and postintervention visits, youth research assistants observed and recorded factors that might have changed between visits, including current ventilation (e.g., fans, air conditioning, and number of open doors and windows in the kitchen, bathroom, and main living area), whether the home smelled of smoke, and use of air fresheners. The participant was also asked about use of scented products that day, including questions about air fresheners, scented candles, and laundry products, and was asked to complete a checklist of which personal care products she had used that day. At each visit, youth research assistants observed the participant while she cleaned, noting the products used, cleaning activities conducted, and the location and timing of each activity. Youth researchers also monitored compliance and noted whether a participant accidentally used one of her regular products instead of the green replacement products at the postintervention visit.

At the end of the postintervention visit, the participant was asked about her experience with the intervention, including whether she would continue to use green products and whether being in the study had influenced her housecleaning attitudes and behaviors. The original intention was to recontact participants 8–9 months after the completion of the study to determine whether the study had any long-term impacts on cleaning practices. Unfortunately, the participant follow-up was disrupted by the COVID-19 pandemic. Because of restrictions on research activities as well as changes in cleaning recommendations early in the pandemic, follow-up was halted in early 2020 and did not resume until early 2021. Due to difficulties caused by the pandemic, follow-up data is available for 36 (72%) of the 50 participants, 20 of whom provided data in early 2020 and 16 in early 2021. In all cases, the follow-up survey was conducted before the participant had been informed of the study findings.

Personal Air Monitoring

Personal air monitoring was conducted using a small backpack worn by the participant that contained two air pumps (SKC, PCXR8 Universal Sample Pump) connected by flexible tubing to sampling media positioned on the shoulder straps of the backpack near the participant's breathing zone. Three types of sampling media were used: *a*) multibed thermal desorption tubes (28286-U; Supelco) custom packed with primary bed of Carbopack™ B sorbent (4 mm) backed with a 2-mm section of Carbopack™ X for measurement of VOCs; *b*) silica gel cartridges coated with 2,4-dinitrophenylhydrazine (DNPH) (XPoSure Aldehyde Sampler P/N WAT047205; Waters Corporation) with ozone scrubbers installed upstream (P/N WAT054420) for measurement of volatile carbonyls including formaldehyde and acetaldehyde; and *c*) Tenax TA thermal desorption tubes (Supelco) for measurement of SVOCs such as musks and high-molecular-weight phthalates. Prior to use, the Carbopack™ and Tenax thermal desorption tubes were conditioned at 345°C and 280°C, respectively, for 30 min with a helium purge (30 mL/min) then sealed in Teflon capped TDS3 storage containers (P/N 25045-U; Sigma). Air flow during sampling was set to 100 mL/min for the thermal desorption tubes and 1 L/min for the DNHP-coated cartridges using dedicated sampling media. Actual sampling flow rates were recorded for each pump and sample line prior to and after each sampling event using DryCal® flow meters (Defender model 510; Mesa Labs). Start and stop times were recorded, and sampling was conducted for 30 min. Sampling media were stored at −30°C after use and shipped weekly to Lawrence Berkeley National Laboratory for analysis.

Laboratory Methods

Before VOC analysis, a gas-phase internal standard (120 ng of 1-bromo-4-fluorobenzene) was injected into each Carbopack™ sorbent tube with a helium purge (30 mL/min) at room temperature for 4 min. Once prepared, the sorbent tubes were analyzed by thermal desorption coupled gas chromatography–mass spectrometry (GC-MS) using a ThermoDesorption Autosampler (Model TDSA2; Gerstel), a thermal desorption oven (Model TDS3), and a cryogenically cooled injection system (Model CIS4). The cooled injection system contained a Tenax® TA–packed glass injection liner (P/N 013247-005-00; Gerstel). The samples were desorbed at 50 cc/min (splitless) with initial temperature at 25°C (0.5 min delay), followed by a 60°C/min ramp to 330°C with a 1 min hold time. The cooled inlet was held at 1°C and then heated after 0.1 min to 300°C at a rate of 12°C/s, followed by a 2 min hold time. The GC was operated in solvent vent mode with a splitless injection. Compounds were resolved on a GC (Series 6890 Plus; Agilent Technologies) equipped with a 30 m by 0.25 mm diameter Restek™ Rxi™-624Sil MS capillary column (P/N 13868) with 1.4-μm film thickness. The initial oven temperature was 1°C, held for 2 min, then increased to 100°C at 5°C/min (hold 2 min), then increased again to 140°C at 3°C/min, then to 300°C at 10°C/min and held for 10 min. The helium flow through the column was held constant at 1.2 mL/min (initial pressure 47 kPa, 39 cm/s). The resolved analytes were detected using electron impact MS (5973; Agilent Technologies) operated in total ion current (TIC) mode with target and qualifier ions specified for each target compound. The MS temperature settings were 240°C, 230°C, and 150°C for the transfer line, MS source, and MS quad, respectively. The MS was operated in scan mode with a range of 34 *m/z* to 450 *m/z*. Multipoint calibrations were prepared from pure standards for all target VOCs. The response for each analyte was normalized to the internal standard response.

The DNPH-coated cartridges were extracted with 2 mL of high-purity acetonitrile (P/N 018-4; Burdick & Jackson™) and analyzed by high-performance liquid chromatography (HPLC; 1200 Series; Agilent Technologies). Target analytes were resolved on a 200 mm by 3.2 mm Allure AK column (P/N 9159523-700; Restek™) and run with 60:40 acetonitrile:water mobile phase at 0.5 mL/min with UV detection at 360 nm. Multipoint calibration curves were prepared from certified standard hydrazone derivatives of all target analytes (CRM47651; Sigma-Aldrich).

The SVOC method was based on that described by Ramírez et al. (2010). Before the analysis, an internal standard (250 pg of xylene-musk-D9) in methanol was injected into each Tenax sorbent tube followed by a helium purge (30 cc/min) at room temperature for 4 min. Once prepared, the sorbent tubes were analyzed by thermal desorption coupled GC-MS as described above for VOCs. The samples were desorbed in splitless mode with initial temperature at 25°C (0.5 min delay) followed by a 60°C/min ramp to 320°C with a 10-min hold time. The cooled inlet was held at 1°C and then heated after 0.1 min to 320°C at a rate of 12°C/s, followed by a 3-min hold time. The GC was operated in solvent vent mode with a splitless injection. Compounds were resolved on a GC (Series 7890A; Agilent Technologies) equipped with a 30 m by 0.25 mm diameter Agilent DB-UI 8,270 D ultra-inert capillary column (P/N 122-9732) with 0.25-μm film thickness. The initial oven temperature was 100°C, held for 3 min, then increased to 170°C at 30°C/min (no hold time), increased to 198°C at 5°C/min (hold 2 min), then to 310°C at 30°C/min and held for 3 min. The helium flow through the column was held constant at 1.2 mL/min (initial pressure 89.149 kPa, 40.853 cm/s). The resolved analytes were detected using electron impact high efficiency source MS (5977B; Agilent Technologies) operated in selected ion monitoring (SIM) mode with target and qualifier ions specified for each target compound. The MS temperature settings were 300°C, 200°C, and 150°C for the transfer line, MS source, and MS quad, respectively. The MS was operated in scan mode with a range of 34 *m/z* to 1,000 *m/z*. Multipoint calibrations were prepared from pure standards for all target VOCs. The response for each analyte was normalized to the internal standard response.

These methods quantified 110 unique VOCs and SVOCs; however, to reduce the number of comparisons, we limited our statistical analysis to 47 target analytes of concern that were selected *a priori* because they are suspected carcinogens, reproductive toxicants, or endocrine disruptors. Chemicals were included if they were identified by the State of California as carcinogens or reproductive and developmental toxicants according to Proposition 65 (Office of Environmental Health Hazard Assessment 2020) or if they were listed as potential endocrine disruptors on The Endocrine Disruption Exchange (TEDX) (The Endocrine Disruption Exchange 2018).

Air concentrations of VOCs, including aldehydes, are reported in micrograms per cubic meter. Air concentrations of SVOC are reported in nanograms per cubic meter. We obtained complete preintervention air concentration data for all participants ($N = 50$). However, one Carbopack™ sorbent tube was damaged in the field following the postintervention home visit, resulting in a sample size of 49 for some postintervention VOC analytes.

Data Analysis

Of the 47 target analytes of interest, we limited our statistical analyses to the 40 (85.1%) that were detected in at least 60% of samples. [A complete list of all 47 analytes, their detection frequencies, and method detection level (MDL) are presented in Table S2.] Concentrations below the MDL were assigned the machine-read concentration if available or imputed with a random value <MDL based on the log-normal distribution (Lubin et al. 2004).

We examined pre- and postintervention differences in air concentrations by comparing geometric mean (GM) concentrations at each visit. For analytes detected in >90% of samples at both visits, we used mixed effects models to obtain average within-individual percent change in geometric mean air concentrations before and after the intervention. For analytes detected in 60%–90% of samples at either visit, Tobit regression models were used to obtain within-person percent change in geometric means between visits. All models adjusted for ventilation (yes/no, defined as youth researcher's observation of open windows and doors or use of fans, air conditioning, and exhaust hoods at time of visit), use of air fresheners (yes/no, defined as participant's reported use of any of eight different types of air fresheners that day or youth researcher's observation of air freshener use at time of visit), and smell of smoke in the household (yes/no, defined as youth researcher's observation). Air concentrations were log-normally distributed and were log10 transformed for analysis.

Established health benchmarks exist for eight of the chemicals of interest (benzene, m/p-xylene, o-xylene, chloroform, carbon tetrachloride, formaldehyde, acetaldehyde, and naphthalene). We calculated the percent of participants with air concentrations exceeding the acute Reference Exposure Level (REL) set by the California Office of Environmental Health Hazard (Office of Environmental Health Hazard Assessment 2019) for these analytes at the pre- and postintervention visits. For those participants exceeding the REL, we calculated their hazard quotient as the ratio of their levels to the REL.

All analyses were conducted using Stata (version 15; StataCorp). Statistical significance was considered at $\alpha = 0.05$.

Results

The characteristics of the 50 women enrolled in the study are shown in Table 1. Most participants were born in Mexico (78%) and completed the questionnaire in Spanish (64%). Almost half of the participants had less than a high school education (48%), and 40% lived in households with an annual income at or below the U.S. federal poverty threshold (U.S. Census Bureau 2019). Many participants reported personally using cleaning products in their homes every day to clean surfaces (38%), floors (20%), or toilets (22%). Almost all participants reported using cleaning products in their homes at least once per week, ranging from 72% using products to clean glass to 96% using cleaning products to clean surfaces. Participants tended to be the primary housecleaners in their homes: 48% reported that they conducted all of the household cleaning, and an additional 32% reported that they conducted most of the household cleaning. Twenty women (40%) reported also using cleaning products at work, but only one participant was a professional housecleaner.

The cleaning activities performed at each visit are shown in Table 2. The most common activities were cleaning toilets and wiping surfaces such as counters, cabinets, and appliances, which were performed by more than 90% of women at each visit. Seventy percent of women mopped their floors at both visits, and more than half handwashed their dishes, cleaned their bathtubs or showers, and cleaned glass. At both visits, the median number of cleaning activities done was five and the maximum was eight. Although women were asked to perform their "usual" cleaning routine at both visits, there were often small differences in the activities conducted. Only 14 women (28%) performed exactly the same tasks at both visits. Differences in activities appeared random rather than systematic between visits.

In total, 205 different conventional cleaning products were used in the preintervention visit, including different formulations or scents of widely available national brands. The most commonly used conventional products are shown in Table S3. Although seven

Table 1. Characteristics of study population ($N = 50$), LUCIR Study, Salinas, California, 2019.

Characteristic	n (%)
Age (y)	
18–24	6 (12.0)
25–34	8 (16.0)
35–44	16 (32.0)
45–54	12 (24.0)
55–64	7 (14.0)
65+	1 (2.0)
Language of survey	
Spanish	32 (64.0)
English	18 (36.0)
Country of birth	
United States	11 (22.0)
Mexico	39 (78.0)
Ethnicity	
Mexican[a]	49 (98.0)
Other Latina	1 (2.0)
Highest education attained	
Less than 6th grade	14 (28.0)
Some middle or high school	10 (20.0)
High school graduate/General Educational Development (GED)	10 (20.0)
More than high school	16 (32.0)
Poverty level[b]	
At or below poverty	20 (46.5)
Above poverty	23 (53.5)
Missing	7
Person who typically conducts household cleaning	
Only participant	24 (48.0)
Mostly participant	16 (32.0)
Equally split with someone else	4 (8.0)
Mostly someone else	6 (12.0)
Uses cleaning products at work	
Yes	20 (40.0)
No	30 (60.0)
Frequency of home cleaning product use for...	
Cleaning surfaces	
Every day	19 (38.0)
Few times a week	24 (48.0)
Once a week	5 (10.0)
Few times a month	1 (2.0)
Once a month	0 (0.0)
Rarely or never	1 (2.0)
Cleaning mirrors, windows, or other glass	
Every day	5 (10.4)
Few times a week	19 (39.6)
Once a week	12 (25.0)
Few times a month	8 (16.7)
Once a month	1 (2.1)
Rarely or never	3 (6.25)
Missing	2
Cleaning the toilet	
Every day	11 (22.9)
Few times a week	18 (37.5)
Once a week	17 (35.4)
Few times a month	2 (4.2)
Once a month	0 (0.0)
Rarely or never	0 (0.0)
Missing	2
Cleaning the tub or shower	
Every day	5 (10.4)
Few times a week	21 (43.8)
Once a week	16 (33.3)
Few times a month	5 (10.4)
Once a month	1 (2.1)
Rarely or never	0 (0.0)
Missing	2
Cleaning the floor	
Every day	10 (20.8)
Few times a week	21 (43.8)
Once a week	11 (22.9)
Few times a month	2 (4.2)
Once a month	3 (6.3)
Rarely or never	1 (2.1)
Missing	2

[a]Includes responses Mexican, Mexican American, and Indigenous Mexican.
[b]Poverty defined as an annual household income at or below the U.S. federal poverty threshold (U.S. Census Bureau 2019).

green replacement products were given, not all women chose to use all the products at the postintervention visit. The most commonly used replacement products were the toilet bowl cleaner (used by 90% of women) and the two all-purpose cleaners (used by 86% and 82%, respectively) (see Table S1). There were problems with compliance for five participants during the postintervention visit: two participants accidentally used their regular dish soap and three participants used bleach at the postintervention visit.

Pre- and postintervention GM air concentrations are shown in Table 3, and the percent change in air concentrations between visits is shown in Table 3 and Figure 1. Concentrations of most halogenated hydrocarbons, benzene derivatives, aldehydes, and alkanes decreased after switching to the green replacement cleaning products. The largest change was in chloroform concentrations, which decreased 86.7% between the pre- and postintervention visit, after adjustment for ventilation, use of air fresheners, and smell of smoke in the home (GM: $2.43\ \mu g/m^3$ preintervention vs. $0.32\ \mu g/m^3$ postintervention). Carbon tetrachloride concentrations decreased by 59.2% (GM: 1.85 vs. $0.77\ \mu g/m^3$), 1,4-dioxane by 46.4% (GM: 0.57 vs. $0.31\ \mu g/m^3$), and naphthalene by 40.3% (GM: 0.13 vs. $0.08\ \mu g/m^3$) between the pre- and postintervention visits. We observed statistically significant decreases in 7 of the 10 benzene derivatives examined, including benzene (GM: 0.77 vs. $0.58\ \mu g/m^3$; 24.8% decrease), styrene (GM: 0.92 vs. $0.54\ \mu g/m^3$; 41.6% decrease), m/p-xylene (GM: 1.13 vs. $0.72\ \mu g/m^3$; 36.6% decrease), and phenol (GM: 1.08 vs. $0.51\ \mu g/m^3$; 52.5% decrease). Of the aldehydes, we observed a 37.7% decrease in acetaldehyde (GM: 16.36 vs. $10.16\ \mu g/m^3$), a 40.7% decrease in benzaldehyde (GM: 3.39 vs. $2.04\ \mu g/m^3$), and a 51.4% decrease in hexaldehyde (GM: 16.97 vs. $8.23\ \mu g/m^3$). We observed no difference in air concentrations of glycol ethers, siloxanes, phthalates, or nitro musks.

In contrast, we saw statistically significant increases in air concentrations of three fragrance compounds when participants switched to the green replacement cleaning products (Table 3).

Table 2. Summary of cleaning activities in preintervention ($N = 50$) and postintervention ($N = 50$) visits, LUCIR Study, Salinas, California, 2019.

	Preintervention	Postintervention
	n (%)	n (%)
Participant cleaned...		
Surfaces[a]	47 (94)	47 (94)
Mirrors, windows, or other glass	28 (56)	33 (66)
Toilet	47 (94)	49 (98)
Tub or shower	28 (56)	28 (56)
Floor	35 (70)	35 (70)
Handwash dishes	30 (60)	32 (64)
Researchers observed...		
Use of ventilation[b]	38 (74)	40 (80)
Use of air fresheners[c]	47 (94)	45 (90)
Smell of smoke[d]	1 (2)	1 (2)

[a]Surfaces include counters, cabinets, tables, chairs, doors, doorknobs, shelves, walls, and appliance surfaces.
[b]Defined as open windows/doors or use of fans/air conditioning/exhaust hood at time of visit.
[c]Defined as participant report of use of any of eight different types of air fresheners on day of visit or researcher's observation of air freshener use at time of visit.
[d]Defined as discernible smell of tobacco or marijuana smoke at time of visit.

Table 3. Personal air concentrations of select VOCs (micrograms per cubic meter) and SVOCs (nanograms per cubic meter) among women using regular cleaning products (preintervention visit) and "green" cleaning products (postintervention visit), LUCIR Study, Salinas, California, 2019 ($N = 49–50$).

Chemical	N	Preintervention Visit DF (%)	Preintervention Visit GM (GSD)	Postintervention Visit DF (%)	Postintervention Visit GM (GSD)	Percent change (95% CI) in GM
Volatile organic compounds ($\mu g/m^3$):						
Halogenated hydrocarbons						
Chloroform[a,c]	49	49 (100)	2.43 (8.72)	49 (100)	0.32 (4.08)	−86.7 (−92.6, −76.0)
Carbon tetrachloride[a,c]	49	49 (100)	1.85 (3.26)	46 (93.9)	0.77 (1.68)	−59.2 (−71.3, −42.0)
Dichloromethanea[a,c]	49	47 (95.9)	0.29 (1.65)	44 (89.8)	0.27 (1.70)	−9.2 (−22.6, 6.6)
Tetrachloroethylene[a,c]	49	46 (93.9)	0.05 (3.21)	43 (87.8)	0.03 (3.07)	−31.9 (−51.8, −3.9)
1,2-Dichloroethane[a]	49	48 (98.0)	0.33 (3.30)	39 (79.6)	0.26 (5.09)	−3.8 (−32.5, 36.9)
Other						
1,4-Dioxane[a]	49	49 (100)	0.57 (3.60)	47 (95.9)	0.31 (3.07)	−46.4 (−63.3, −21.8)
Naphthalene[a,c]	49	49 (100)	0.13 (2.68)	47 (95.9)	0.08 (3.14)	−40.3 (−56.0, −19.0)
2-Ethylhexanol[c]	49	49 (100)	2.33 (3.72)	46 (93.9)	1.41 (4.78)	−40.2 (−59.9, −10.6)
TXIB/Kodaflex[c]	49	46 (93.9)	0.58 (4.18)	45 (91.8)	0.55 (4.38)	−6.8 (−38.6, 41.4)
Benzene derivatives						
Benzene[a,b,c]	49	49 (100)	0.77 (2.11)	49 (100)	0.58 (2.08)	−24.8 (−39.5, −6.6)
Toluene[b,c]	49	49 (100)	2.15 (3.29)	49 (100)	1.67 (4.08)	−24.2 (−46.8, 8.0)
Ethylbenzene[a,c]	49	49 (100)	0.43 (3.55)	46 (93.9)	0.29 (3.58)	−31.2 (−50.0, −5.3)
m/p-Xylene[c]	49	49 (100)	1.13 (3.90)	47 (95.9)	0.72 (5.34)	−36.6 (−58.3, −3.6)
o-Xylene[c]	49	49 (100)	0.40 (3.97)	46 (93.9)	0.29 (3.77)	−28.6 (−47.6, −2.9)
Styrene[a,c]	49	49 (100)	0.92 (2.40)	47 (95.9)	0.54 (3.51)	−41.6 (−56.0, −22.3)
Phenol[c]	49	47 (95.9)	1.08 (3.99)	40 (81.6)	0.51 (4.57)	−52.5 (−67.1, −31.3)
Butylbenzene[c]	49	47 (95.9)	0.05 (2.82)	40 (81.6)	0.04 (3.46)	−9.8 (−36.2, 27.4)
Nitrobenzene[a,b,c]	49	38 (77.6)	0.06 (8.67)	43 (87.8)	0.08 (6.18)	10.8 (−38.2, 98.4)
1,4-Dichlorobenzene[a]	49	46 (93.9)	0.07 (8.71)	39 (79.6)	0.03 (11.66)	−43.6 (−60.6, −19.3)
Aldehydes						
Formaldehyde[a,c]	50	50 (100)	15.63 (1.87)	50 (100)	13.22 (1.80)	−14.0 (−27.5, 1.9)
Acetaldehyde[a,c]	50	50 (100)	16.36 (2.41)	49 (98)	10.16 (2.11)	−37.7 (−51.6, −20.0)
Benzaldehyde[c]	49	48 (98.0)	3.39 (2.48)	46 (93.9)	2.04 (3.23)	−40.7 (−55.8, −20.4)
Hexaldehyde[c]	49	49 (100)	16.97 (2.68)	46 (93.9)	8.23 (3.56)	−51.4 (−68.0, −26.2)
Alkanes						
Hexane[b,c]	49	49 (100)	0.63 (4.86)	47 (95.9)	0.41 (4.13)	−35.5 (−55.7, −6.0)
Heptane[c]	49	49 (100)	0.42 (3.40)	47 (95.9)	0.38 (3.46)	−8.1 (−33.4, 26.9)
Glycol ethers						
Ethylene glycol monobutyl ether (EGBE)[c]	49	29 (59.2)	0.12 (41.09)	31 (63.3)	0.10 (13.64)	−36.1 (−80.0, 104.4)
Diethylene glycol monobutyl ether (DGBE)[c]	49	32 (65.3)	0.17 (21.82)	36 (73.5)	0.15 (36.39)	2.6 (−67.4, 222.3)
Siloxanes						
Octamethylcyclotetrasiloxane (D4)[c]	49	49 (100)	1.50 (6.18)	49 (100)	1.67 (9.83)	8.2 (−45.5, 114.8)
Decamethylcyclopentasiloxane (D5)[c]	49	49 (100)	13.09 (7.00)	48 (98)	12.51 (14.63)	−6.0 (−60.8, 125.5)
Terpenes						
b-Myrcene[a]	49	49 (100)	1.67 (5.01)	47 (96)	5.47 (6.78)	221.5 (74.5, 492.4)
Semivolatile organic compounds (ng/m^3):						
Phthalates						
Diethyl phthalate[c]	50	50 (100)	173.40 (2.46)	50 (100)	164.90 (2.24)	−3.8 (−21.3, 17.7)
Dibutyl phthalate[b,c]	50	50 (100)	79.28 (1.55)	50 (100)	77.44 (1.46)	−2.6 (−15.6, 12.3)
Diisobutyl phthalate[c]	50	50 (100)	124.99 (2.35)	50 (100)	114.25 (2.15)	−8.2 (−23.7, 10.4)
Nitro musks						
Musk xylene[c]	50	49 (98.0)	0.97 (3.53)	50 (100)	0.70 (1.68)	−26.2 (−48.0, 4.6)
Musk ketone[c]	50	50 (100)	2.39 (3.47)	50 (100)	2.36 (3.47)	−1.0 (−18.0, 19.6)
Polycyclic musk						
Cashmeran (DPMI)[c]	50	47 (94.0)	11.91 (6.69)	49 (98)	13.57 (3.64)	49.1 (−23.8, 191.9)
Celestolide (ADBI)[c]	50	50 (100)	3.07 (2.88)	50 (100)	3.97 (2.65)	31.0 (5.2, 63.1)
Phantolide (AHMI)[c]	50	49 (98.0)	0.89 (3.19)	50 (100)	1.05 (3.25)	22.4 (−5.5, 58.6)
Galaxolide (HHCB)[c]	50	50 (100)	514.33 (4.14)	50 (100)	924.05 (2.25)	79.6 (27.0, 154.1)
Tonalide (AHTN)[c]	50	49 (98.0)	47.92 (2.72)	49 (98)	48.95 (2.62)	2.9 (−20.9, 33.8)

Note: Percent change estimates are adjusted for household ventilation, use of air fresheners, and smell of smoke in the household. Percent change estimates are from mixed effects models, except for tetrachlorethylene, 1,2,-dichloroethane, phenol, butylbenzene, nitrobenzene, 1,4,-dichlorobenzene, EGBE, and DGBE, which were detected in <90% of samples at any time point and were calculated using Tobit regression models. CI, confidence interval; DF, detection frequency; GM, geometric mean; GSD, geometric standard deviation; SVOC, semivolatile organic compound; VOC, volatile organic compound.

[a]California Proposition 65 Carcinogen.

[b]California Proposition 65 Reproductive/Developmental Toxicant.

[c]Suspected endocrine-disrupting chemical according to The Endocrine Disruption Exchange (TEDX) list.

Beta-myrcene, a naturally occurring terpene, increased by 221.5% (GM: 1.7 vs. 5.5 $\mu g/m^3$), and the polycyclic musks celestolide and galaxolide increased by 31.0% (3.1 vs. 4.0 ng/m^3) and 79.6% (514.3 vs. 924.1 ng/m^3), respectively, with use of the replacement products.

For three of the eight chemicals with health-based exposure benchmarks, a small number of participants experienced exposures that exceeded the acute REL set by the State of California (Table 4) (Office of Environmental Health Hazard Assessment 2019). At the preintervention visit, one participant (2%) exceeded the REL for acetaldehyde (hazard quotient: 1.30), two (4%) for formaldehyde (hazard quotients: 1.13, 1.38), and one (2%) for chloroform (hazard quotient: 2.65). At the postintervention visit, no participants exceeded the RELs for acetaldehyde or formaldehyde. The same participant that exceeded the REL for chloroform at the preintervention visit also exceeded the REL for chloroform in the

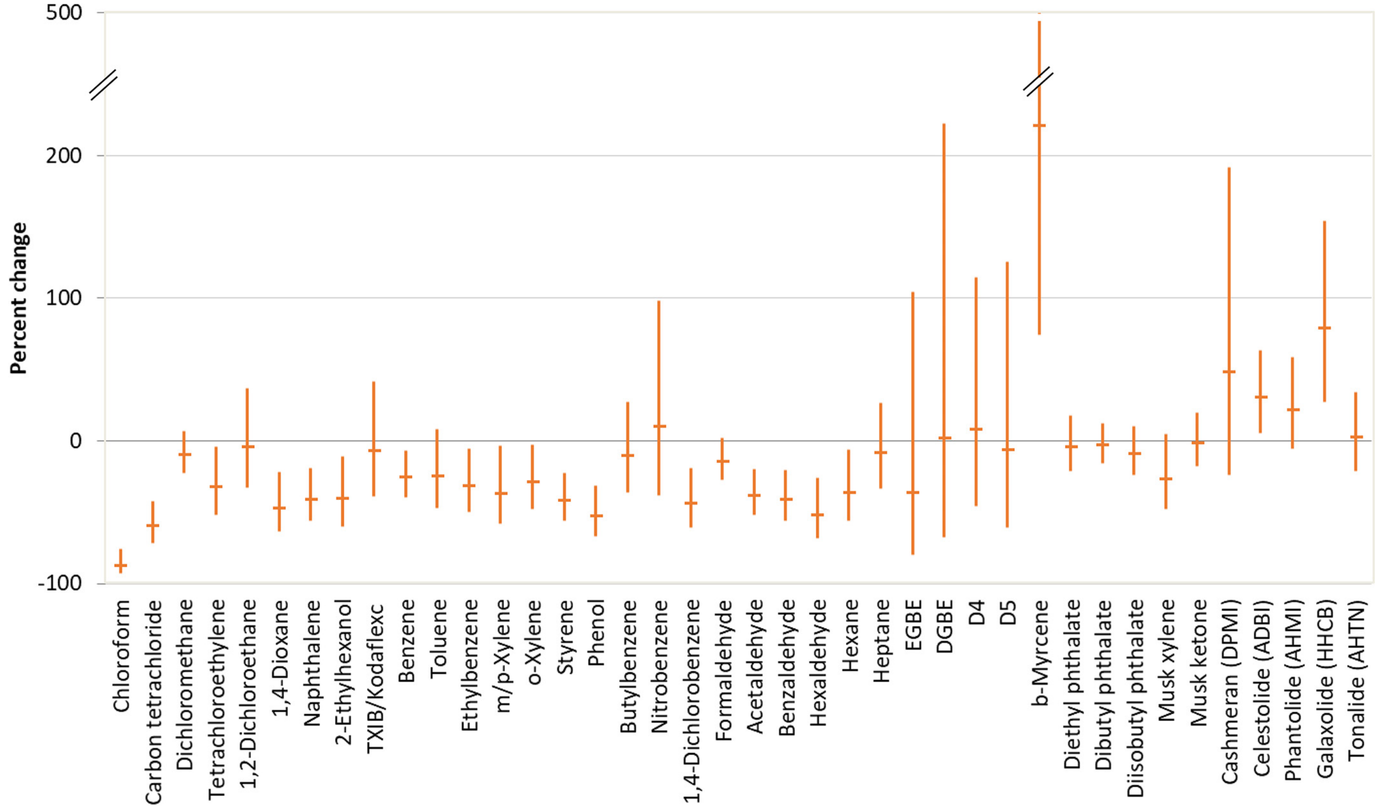

Figure 1. Percent change in geometric mean personal air concentrations of select VOCs and SVOCs comparing postintervention visit ("green" cleaning products) to preintervention visit (conventional products), LUCIR Study, Salinas, California, 2019 ($N = 49–50$). Percent change is adjusted for household ventilation, use of air fresheners, and smell of smoke in the household. Percent change estimates are from mixed effects models, except for tetrachlorethylene, 1,2,-dichloroethane, butylbenzene, nitrobenzene, 1,4,-dichlorobenzene, phenol, EGBE, and DGBE, which were detected in <90% of samples at any time point and were calculated using Tobit regression models. Note: D4, octamethylcyclotetrasiloxane; D5, decamethylcyclopentasiloxane; DGBE, diethylene glycol monobutyl ether; EGBE, ethylene glycol monobutyl ether; SVOC, semivolatile organic compound; VOC, volatile organic compound.

postintervention visit (hazard quotient: 1.07); however, this participant was one of the women who accidentally used bleach during the postintervention visit, which potentially affected these results.

At the end of the postintervention visit, 46% of women said they were very concerned about how cleaning chemicals may affect their health (Table 5). Almost all women stated that being in the study would change the way they chose cleaning products (92%), that the green replacement products worked as well as their original products (98%), and that they would consider using or buying the replacement products again in the future (90%). At follow-up between 8 and 20 months later, 92% of the 36 women who were surveyed reported that they were using green cleaning products more often than they did before the study, with 55% reporting use of green cleaning products "always" or "most of the time" while cleaning their homes. The main reasons given for not using more green cleaning products were that "The stores where I shop do not sell them" (37%) and "They are too expensive" (27%). However, these findings should be interpreted with caution because only 72% of the original population could be contacted.

Discussion

We observed that air concentrations of multiple VOCs collected from the breathing zone of Latina women while they were cleaning their own homes decreased significantly when they switched from their regular cleaning products to green cleaning products but that concentrations of three fragrance chemicals increased. Switching to green cleaning products was associated with reductions in suspected carcinogens, developmental toxicants, and endocrine disruptors, including chloroform, benzene, acetaldehyde,

Table 4. Number of participants exceeding the California office of environmental health hazard assessment (OEHHA) acute reference exposure level (REL), LUCIR Study, Salinas, California, 2019.

			Exceeding acute REL	
	Acute REL	Maximum observed	Preintervention ($N = 50$)	Postintervention ($N = 49–50$)
Chemical	($\mu g/m^3$)	($\mu g/m^3$)	*n* (%)	*n* (%)
Chloroform[a,b,c]	150	398.0	1 (2)	1 (2)[d]
Formaldehyde[a,c]	55	76.0	2 (4)	0 (0)[e]
Acetaldehyde[a,c]	470	613.1	1 (2)	0 (0)[e]

Note: REL, reference exposure level.
[a]California Proposition 65 Carcinogen.
[b]California Proposition 65 Reproductive/Developmental Toxicant.
[c]Suspected Endocrine Disrupting Chemical.
[d]This participant forgot intervention instructions and accidentally used bleach in her cleaning.
[e]$N = 50$.

Table 5. Participant reactions postintervention and 8–20 months later, LUCIR Study, Salinas, California, 2019–2021.

Participant feedback	n (%)
At postintervention visit ($N = 50$):	
Do you think the products we gave you worked as well as your usual products?	
No	1 (2)
Yes	49 (98)
Would you consider buying and using any of the products we gave you again in the future?	
No	1 (2)
Maybe	4 (8)
Yes	45 (90)
Do you think being in this study will change the way you choose cleaning products for your home?	
No	0 (0)
Maybe	4 (8)
Yes	46 (92)
How concerned are you about how cleaning chemicals may affect your health?	
Not concerned	3 (6)
A little concerned	7 (14)
Somewhat concerned	17 (34)
Very concerned	23 (46)
8–20 months after intervention ($N = 36$):	
Do you use green cleaning products more now than you did before the study?[a]	
No	2 (6)
Yes	33 (92)
How often do you use green cleaning products?	
Never	0 (0)
Sometimes	13 (36)
About half the time	3 (8)
Most of the time	16 (44)
Always	4 (11)
Why don't you use more green cleaning products?[b]	
Not really worried about cleaning products	0 (0)
They are too expensive	8 (27)
The stores where I shop don't sell them	11 (37)
They don't work as well	1 (3)
I don't like the smell	4 (13)
I want to but I just haven't gotten around to it	2 (7)
COVID-19 pandemic	3 (8)

[a]One participant did not answer this question ($n = 35$).
[b]Only asked of participants who did not respond "Always" to question, "How often do you use green cleaning products," and two participants did not answer this question ($n = 30$).

and 1,4-dioxane. However, the green products were associated with increases in two polycyclic musks, celestolide and galaxolide, that are suspected endocrine disruptors (The Endocrine Disruption Exchange 2018) and one terpene, β-myrcene, that is a potential carcinogen (Office of Environmental Health Hazard Assessment 2020), suggesting that switching to use of green cleaning products was not completely successful in eliminating exposure.

The three compounds that increased during the intervention are often used as fragrances in consumer products (Magnano et al. 2009; Wolkoff 2020). Only two of the replacement products provided to participants were explicitly fragrance-free: the dishwashing soap and the homemade glass cleaner. Our preliminary research for this study found that unscented cleaning products were harder to find and that many youth council members preferred scented cleaning products. As a result, most of the green products we provided had discernable fragrances, including the two all-purpose cleaners, one of which was lavender scented and the other lemon scented. It is not clear which replacement product or products were the source of the increased air concentrations of celestolide, galaxolide, and β-myrcene. Our future steps include analyzing the specific composition of chemical emissions from the green cleaning products used by participants in this study to target the specific sources of these increases.

An important aspect of this study was reporting back the findings to the community, including nuanced messaging to explain the results. On one hand, it is helpful to be able to tell community members that switching to green cleaning products decreased concentrations of 17 chemicals of concern in the breathing zone. However, we have also had to report that a small number of chemicals increased and that these chemicals are likely associated with fragrance. We have had to explain that not all "natural fragrances" are innocuous. For example, β-myrcene—which increased by more than 200% in this study—is a naturally occurring plant oil but is also a suspected carcinogen (Office of Environmental Health Hazard Assessment 2020). Part of the educational message to community members has been to encourage them to try to choose unscented products or make homemade products with greener ingredients when possible and improve ventilation as much as feasible.

To our knowledge, this is the first study to characterize Latina women's exposure to cleaning chemicals and to document a simple method to decrease many, but not all, exposures. Participants in the study were receptive to switching their cleaning products and reported that the green replacement products generally worked as well as their regular products. Several months after the end of the study, the majority of participants reported that they were continuing to use green products more frequently than they had before the study. However, this study had considerable loss-to-follow-up due to delays related to COVID-19. Additionally, although we assured participants that they should be honest, social desirability bias may have influenced participants to say they used green cleaning products more frequently than they truly did.

Although this community-based intervention of 50 women is considerably larger than previous laboratory-based studies, the sample size is still relatively small. Our study may have lacked power to identify changes in some compounds, such as formaldehyde and toluene, that showed decreases that were not statistically significant. Additionally, we were limited in our ability to compare women's observed exposures to recommended risk thresholds because health-based benchmarks do not exist for most of these compounds, even though toxicology or epidemiologic research raises concerns about their impacts on health. There were some problems with compliance, with five women using a conventional product at the postintervention visit. To be conservative, we analyzed the data in an intent-to-treat manner and included noncompliant women in the analysis.

This study encouraged women to clean their homes in their usual way, providing real-world insight that might not be available from highly controlled laboratory studies. However, we constrained the cleaning activities to the kitchen and bathroom, so some sources of exposure, such as laundry detergent and cleaning activities in other parts of the house, were not examined. Additionally, because women were limited to cleaning for only 30 min, not all participants may have had adequate time to complete all their regular cleaning tasks. For example, only 66% of participants cleaned their tubs and showers during the observation period, suggesting that many participants may have skipped the tasks that are more infrequent or time consuming, limiting our ability to make inferences about these tasks.

A strength of this study was its engagement of local youths in community-based participatory research. The youths were integrally involved in key aspects of the planning and implementation of the study, which ensured that the replacement products were locally available and acceptable to the study participants. Most of the interviews were conducted by the youth researchers in Spanish, and many of the participants were community members known to the youth research assistants. The youth researchers have also been involved in the interpretation of the results and deeply engaged in multimedia communication of the findings to the study participants and community.

This study demonstrates that changes in cleaning products can reduce exposure to multiple chemicals of concern. However, it also found increases in some chemicals with the use of green products, highlighting the difficulty for consumers who wish to reduce their chemical exposures from cleaning products. Unfortunately, although many cleaning products are marketed under a variety of labels, including "green," "eco-friendly," and "nontoxic," there is no standard definition or designation to help consumers choose products without chemicals of concern. It can also be difficult for consumers to find products that are unscented or fragrance-free. We prioritized unscented items in our comprehensive search for replacement products but were not able to find any locally available, affordable, all-purpose cleaners that did not have fragrance. Although study participants indicated they were concerned about the effects of cleaning products on their health, that they liked the alternative products, and that they wanted to use green cleaning products, access to these products continues to be a problem, particularly in low-income communities. The two main reasons that participants stated they did not use more green cleaning products were related to cost and availability. Simple homemade cleaning products, using greener ingredients, are one option for reducing costs, although some consumers may prefer to use conventional, name-brand products.

In summary, we demonstrated that exposure to several known or suspected carcinogens, reproductive toxicants, and endocrine disruptors decreased when women switched from their regular cleaning products to green products but that levels of certain fragrance compounds of concern increased. Future studies should determine whether use of unscented green cleaning products is associated with a more comprehensive reduction in exposure.

References

Agency for Toxic Substances and Disease Registry. 2007. Toxicological Profile for Benzene. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Bello A, Quinn MM, Perry MJ, Milton DK. 2009. Characterization of occupational exposures to cleaning products used for common cleaning tasks-a pilot study of hospital cleaners. Environ Health 8:11, PMID: 19327131, https://doi.org/10.1186/1476-069X-8-11.

Bello A, Quinn MM, Perry MJ, Milton DK. 2010. Quantitative assessment of airborne exposures generated during common cleaning tasks: a pilot study. Environ Health 9:76, PMID: 21118559, https://doi.org/10.1186/1476-069X-9-76.

Bitsch N, Dudas C, Körner W, Failing K, Biselli S, Rimkus G, et al. 2002. Estrogenic activity of musk fragrances detected by the E-screen assay using human mcf-7 cells. Arch Environ Contam Toxicol 43(3):257–264, PMID: 12202919, https://doi.org/10.1007/s00244-002-1192-5.

California Breast Cancer Research Program. N.d. Exploring chemical exposures for California's women workers. https://www.cbcrp.org/worker-exposure/#occupation=4230 [accessed 10 September 2020].

Dodson RE, Nishioka M, Standley LJ, Perovich LJ, Brody JG, Rudel RA. 2012. Endocrine disruptors and asthma-associated chemicals in consumer products. Environ Health Perspect 120(7):935–943, PMID: 22398195, https://doi.org/10.1289/ehp.1104052.

Environmental Working Group. N.d. Guide to Healthy Cleaning. https://www.ewg.org/guides/cleaners/ [accessed 10 September 2020].

Folletti I, Siracusa A, Paolocci G. 2017. Update on asthma and cleaning agents. Curr Opin Allergy Clin Immunol 17(2):90–95, PMID: 28141626, https://doi.org/10.1097/ACI.0000000000000349.

Harris CA, Henttu P, Parker MG, Sumpter JP. 1997. The estrogenic activity of phthalate esters *in vitro*. Environ Health Perspect 105(8):802–811, PMID: 9347895, https://doi.org/10.1289/ehp.97105802.

Lubin JH, Colt JS, Camann D, Davis S, Cerhan JR, Severson RK, et al. 2004. Epidemiologic evaluation of measurement data in the presence of detection limits. Environ Health Perspect 112(17):1691–1696, PMID: 15579415, https://doi.org/10.1289/ehp.7199.

Madrigal DS, Minkler M, Parra KL, Mundo C, Gonzalez JE, Jimenez R, et al. 2016. Improving Latino youths' environmental health literacy and leadership skills through participatory research on chemical exposures in cosmetics: the HERMOSA Study. Int Q Community Health Educ 36(4):231–240, PMID: 27431602, https://doi.org/10.1177/0272684X16657734.

Madrigal D, Salvatore A, Casillas G, Casillas C, Vera I, Eskenazi B, et al. 2014. Health in my community: conducting and evaluating photovoice as a tool to promote environmental health and leadership among Latino/a youth. Prog Community Health Partnersh 8(3):317–329, PMID: 25435558, https://doi.org/10.1353/cpr.2014.0034.

Magnano M, Silvani S, Vincenzi C, Nino M, Tosti A. 2009. Contact allergens and irritants in household washing and cleaning products. Contact Dermatitis 61(6):337–341, PMID: 20059494, https://doi.org/10.1111/j.1600-0536.2009.01647.x.

McKim JM Jr., Wilga PC, Breslin WJ, Plotzke KP, Gallavan RH, Meeks RG. 2001. Potential estrogenic and antiestrogenic activity of the cyclic siloxane octamethylcyclotetrasiloxane (D4) and the linear siloxane hexamethyldisiloxane (HMDS) in immature rats using the uterotrophic assay. Toxicol Sci 63(1):37–46, PMID: 11509742, https://doi.org/10.1093/toxsci/63.1.37.

Medina-Ramón M, Zock JP, Kogevinas M, Sunyer J, Basagaña X, Schwartz J, et al. 2006. Short-term respiratory effects of cleaning exposures in female domestic cleaners. Eur Respir J 27(6):1196–1203, PMID: 16510456, https://doi.org/10.1183/09031936.06.00085405.

Moran RE, Bennett DH, Tancredi DJ, Wu X(M), Ritz B, Hertz-Picciotto I. 2012. Frequency and longitudinal trends of household care product use. Atmos Environ 55:417–424, https://doi.org/10.1016/j.atmosenv.2012.03.021.

Nazaroff WW, Weschler CJ. 2004. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmos Environ 38(18):2841–2865, https://doi.org/10.1016/j.atmosenv.2004.02.040.

Nolan JES, Coker ES, Ward BR, Williamson YA, Harley KG. 2021. "Freedom to breathe": youth participatory action research (YPAR) to investigate air pollution inequities in Richmond, CA. Int J Environ Res Public Health 18(2):554, PMID: 33440892, https://doi.org/10.3390/ijerph18020554.

Nørgaard A, Kudal J, Kofoed-Sørensen V, Koponen I, Wolkoff P. 2014. Ozone-initiated VOC and particle emissions from a cleaning agent and an air freshener: risk assessment of acute airway effects. Environ Int 68:209–218, PMID: 24769411, https://doi.org/10.1016/j.envint.2014.03.029.

Odabasi M. 2008. Halogenated volatile organic compounds from the use of chlorine-bleach-containing household products. Environ Sci Technol 42(5):1445–1451, PMID: 18441786, https://doi.org/10.1021/es702355u.

Office of Environmental Health Hazard Assessment. 2019. OEHHA Acute, 8-Hour and Chronic Reference Exposure Level (REL) Summary. https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary [accessed 6 August 2021].

Office of Environmental Health Hazard Assessment. 2020. The Proposition 65 List. https://oehha.ca.gov/proposition-65/proposition-65-list [accessed 15 March 2021].

Ramírez N, Marcé R, Borrull F. 2010. Development of a thermal desorption-gas chromatography–mass spectrometry method for determining personal care products in air. J Chromatogr A 1217(26):4430–4438, PMID: 20483421, https://doi.org/10.1016/j.chroma.2010.04.049.

Singer BC, Destaillats H, Hodgson AT, Nazaroff WW. 2006. Cleaning products and air fresheners: emissions and resulting concentrations of glycol ethers and terpenoids. Indoor Air 16(3):179–191, PMID: 16683937, https://doi.org/10.1111/j.1600-0668.2005.00414.x.

Tahara M, Obama T, Ikarashi Y. 2013. Development of analytical method for determination of 1,4-dioxane in cleansing products. Int J Cosmet Sci 35(6):575–580, PMID: 23859116, https://doi.org/10.1111/ics.12079.

Tanabe A, Kawata K. 2008. Determination of 1,4-dioxane in household detergents and cleaners. J AOAC Int 91(2):439–444, PMID: 18476359, https://doi.org/10.1093/jaoac/91.2.439.

The Endocrine Disruption Exchange. 2018. Search the TEDX List. https://endocrinedisruption.org/interactive-tools/tedx-list-of-potential-endocrine-disruptors/search-the-tedx-list [accessed 6 August 2021].

U.S. Environmental Protection Agency. N.d. Safer Choice Program. https://www.epa.gov/saferchoice/products [accessed 10 September 2020].

U.S. Census Bureau. 2019. Poverty Thresholds by Size of Family and Number of Children. https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html [accessed 6 August 2021].

Wolfe J, Kandra J, Engdahl L, Shierhotz H. 2020. *Domestic Workers Chartbook*. Washington, DC: Economic Policy Institute.

Wolkoff P. 2020. Indoor air chemistry: terpene reaction products and airway effects. Int J Hyg Environ Health 225:113439, PMID: 32044535, https://doi.org/10.1016/j.ijheh.2019.113439.

Zock J-P, Plana E, Jarvis D, Antó JM, Kromhout H, Kennedy SM, et al. 2007. The use of household cleaning sprays and adult asthma: an international longitudinal study. Am J Respir Crit Care Med 176(8):735–741, PMID: 17585104, https://doi.org/10.1164/rccm.200612-1793OC.

Zota AR, Aschengrau A, Rudel RA, Brody JG. 2010. Self-reported chemicals exposure, beliefs about disease causation, and risk of breast cancer in the Cape Cod Breast Cancer and Environment Study: a case-control study. Environ Health 9:40, PMID: 20646273, https://doi.org/10.1186/1476-069X-9-40.