Towards Participatory Air Pollution Exposure Assessment in a Goods Movement Community

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Submitted 15 September 2012; revised 10 April 2013; accepted 13 June 2013.

Abstract

Background: Air pollution from diesel truck traffic travelling to and from port facilities is a major environmental health concern in areas of Philadelphia such as the Port Richmond neighborhood. Ambient monitoring has limited capability to assess neighborhood- or personal-level exposures to this pollution.

Objectives: We sought to conduct a pilot study using a community-based participatory research (CBPR) approach to assess community environmental health concerns, and measure residents' exposure to airborne traffic-related pollutants (fine particles [$PM_{2.5}$]).

Methods: The research team established relationships with neighborhood schools and organizations, conducted 24 semistructured interviews, 2 community meetings, and 1 Photovoice exercise. Nine community researchers wore personal monitors that collected $PM_{2.5}$ in the personal breathing zone for 1 to 3 days over a 6-day period in December 2011.

Results: Air pollution and safety hazards from truck traffic, environmental hazards posed by nearby industry, related community health problems, and environmental assets were four major themes emerging from interviews and discussions. Personal monitoring revealed that smoking and smoke exposure had the most pronounced effect on $PM_{2.5}$ concentrations, and that personal $PM_{2.5}$ exposure levels were not related to ambient $PM_{2.5}$ concentrations reported from stationary monitoring stations in Philadelphia.

Conclusions: Participation in personal air pollution monitoring and Photovoice exercises helped to increase awareness of pervasive mobile- and point-source diesel emissions throughout the neighborhood and develop priorities for action. Monitoring indicated the negative effects of cigarette smoke exposure, and disconnect between ambient- and personal-level $PM_{2.5}$ concentrations that emphasized the need for more personal- and local-level monitoring. In addition, participatory methods are appropriate to involve lay persons in personal air pollution monitoring.

Keywords

Community-based participatory research, air pollution, goods movement, exposure assessment, particulate matter, photovoice, fine particles, personal exposure, ambient exposure, sources of exposure

Port-related industries provide a vital source of employment and revenues for urban communities. However, the movement of goods through ports can have significant health consequences for adjacent communities and surrounding regions. Increasingly, attention is being paid to ports for their role in local air quality problems. The Port of Philadelphia is the second largest importer of goods in the North Atlantic. Traffic of heavy-duty diesel trucks (HDDTs) to and from port facilities is a major concern; studies from other areas of the United States have shown that concentrations of ultrafine particles and gases from combustion can be highly elevated near roadways,[1,2] and exposure to these and similar pollutants has been associated with risk of asthma and respiratory infections,[3-6] lung cancer,[7,8] low birth weight and preterm birth,[3,9] and cardiopulmonary mortality.[10,11]

Individuals' exposure to air pollutants can vary widely at local and especially personal levels. Ambient monitoring, often conducted at a few scattered sites across a metropolitan region, is intended to measure background air pollution concentrations, and cannot capture variations between microenvironments.[1,12] Source-specific concentrations of particulate matter and associated pollutants can be expected to vary across space, and a person's exposure depends on their mobility patterns. Personal monitoring is necessary to assess personal exposure levels that are related to health risks, and their determinants, to inform health policy and urban planning decisions.

In addition, many have argued that community participation and residents' "local knowledge" is important for accurately defining a problem, and designing and conducting more scientifically legitimate and accountable studies.[13] CBPR methods are promoting some positive outcomes in air quality studies.[14-17] Accordingly, this work was accomplished using a CBPR approach, and represents a collaborative effort of Clean Air Council (a nonprofit advocacy organization), researchers from Drexel University and the University of Pennsylvania, and individuals who live and work in the community of Port Richmond.

The primary aim of this pilot study was to involve Port Richmond residents using a CBPR approach to assess community environmental health concerns, and measure resident exposure to traffic-related pollutants (measured as fine particulate matter). This is a pilot test of data collection protocol involving community residents in the monitoring process. As such, experiences with this pilot procedure that will help to design future studies are also included in results (e.g., examination of between-person and between-day variability in exposure is vital to design of cost-effective exposure assessment methods[18]). We also sought to evaluate challenges associated with self-monitoring of exposures, because this method has shown promise in other settings.[19] The pilot study is preliminary to a series of planned case-crossover studies of health and longitudinal studies of exposure pathways in Philadelphia.

SETTING

Poor ambient air quality is an area-wide concern in the greater Philadelphia region. According to the U.S. Environmental Protection Agency (EPA)'s 2005 National Air Toxics Assessment, Philadelphia residents face a higher than average risk of respiratory disease and cancer owing to air toxics exposure. Among criteria pollutants of the National Ambient Air Quality Standards, Philadelphia has been classified to be in moderate nonattainment for ozone (8-hour standard), and to be in nonattainment for the fine particulate standards.[20] In this study, we focus on fine particulate matter ($PM_{2.5}$) owing to the depth of existing studies and the availability of low-cost technology that allows for informed community engagement. In addition, a study conducted by the EPA in 2005[21] attributed approximately 10% of particulate matter emissions in Philadelphia to port activities, making ports the largest unregulated source of particulate pollution in the Philadelphia region. However, this estimate was made using assumptions about production, and does not link these port activities with actual nearby pollution levels.

In Philadelphia, exposure to air pollutants is an environmental justice concern. Port Richmond (pop. 38,000) is a neighborhood in northeast Philadelphia (Figure 1) adjacent to the Delaware River. Like other communities along this river, it is burdened disproportionately with environmental hazards.[22] I-95 bisects the neighborhood; south of I-95 is a primarily industrial area, and is the location of the Tioga Marine Terminal as well as other large industrial facilities. North of I-95 is primarily residential, with approximately 9,500 housing units per square mile. Port Richmond does not have a high percentage of non-White residents (37%), and more than 30% earn salaries that are at or below the federal poverty level (35%). Ten percent of residents over the age of 16 are unemployed.[23]

Figure 1 shows that port facilities in Port Richmond are in close proximity to residential areas. Big box stores such as Kmart, Petco, and Toys"R"Us are located approximately 0.5 miles north of the local port facilities and are a destination for HDDTs. Port Richmond residents are worried that air pollution from port-related traffic is linked with health issues they face. A high percentage of residents of Philadelphia (23% of children and 17% of adults), and Port Richmond in particular (26% of children and 23% of adults), suffer from asthma[24] compared with U.S. averages (9.4% of children[25] and 8.2% of adults[26]). At present, it is not possible to assert whether this elevated prevalence of asthma in Port Richmond is related to air pollution. However, in the minds of local residents, the two facts are associated.

The Clean Air Council is a nonprofit organization advocating for the public's right to breathe clean air in the greater southeastern Pennsylvania region. The council works on a range of projects toward improving air quality in the region, including a long-term engagement with Philadelphia's ports. The council established the Port Environmental Task Force, a stakeholder organization aimed at prioritizing ways for the port industry to implement pollution prevention measures. However, stakeholder participation was lacking in the task force and the council sought new ways to incorporate local knowledge into air quality improvement strategies in and around the port. The council found that Port Richmond residents desired to participate in collaborative research with local universities to address their concerns about air pollution.

METHODS

Engaging the Community in Research

Between January 2011 and April 2012, Clean Air Council staff and researchers from the University of Pennsylvania and Drexel University worked to establish relationships with community organizations and institutions acting in Port Richmond. Outreach activities included attendance at four meetings of civic organizations, one meeting among agency

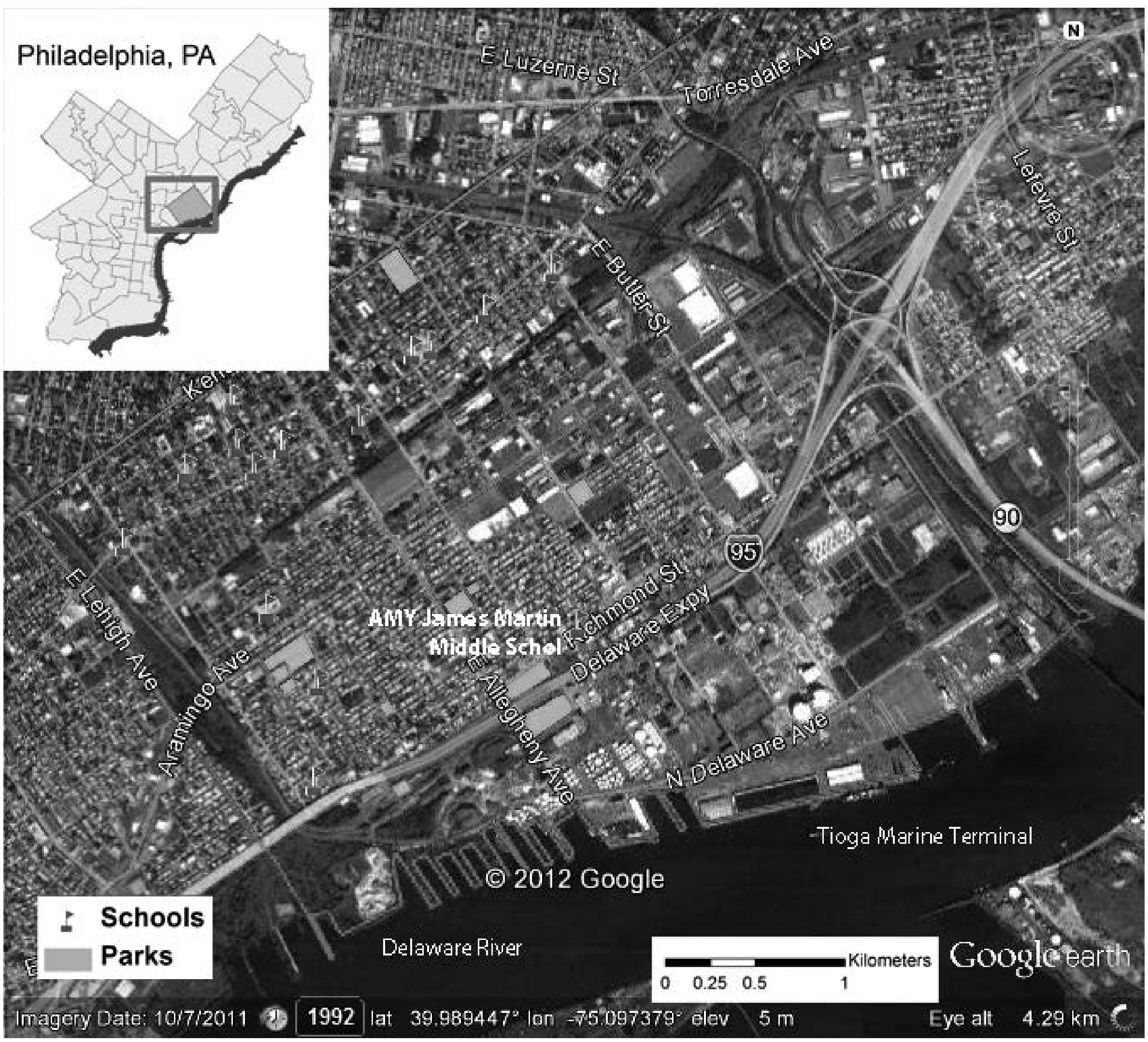

Figure 1. Map of Port Richmond Vicinity, With Schools and Parks Indicated

officials, a public meeting, and "tabling" at three community events. In addition, teachers at AMY James Martin Middle School (Figure 1) contacted the Clean Air Council regarding their concern about air pollution at the school and recruited staff to teach two full classroom days in April of 2011 about the health and environmental impacts of the goods movement system. The research team developed relationships with members from four primary organizations in the neighborhood: Port Richmond on Patrol and Civic, TownWatch, Friends of Campbell Square, and New Kensington Community Development Corporation. None of these or other community organizations (outside of the Clean Air Council) volunteered to be full partners in this endeavor; rather, they asked that we give updates at monthly meetings and connect directly with interested members. However, members and employees of these organizations were significant participants in the study components described herein.

In addition, the team (the principal investigator and three Clean Air Council staff) conducted 24 informal, unrecorded, semistructured interviews[27] with people who reside or work in Port Richmond to assess community understanding and concern about particulate matter exposure or other environmental health issues. We conducted interviews of approximately 30-minute duration in the neighborhood, at residences, in cafes, and in public spaces. Participation in interviews was unpaid, and all interviewees were conversant in English (no other demographic information was recorded). Initial contacts for interviews were obtained through the organizations and events described based on protocol approved by the University of Pennsylvania Institutional Review Board. We then used snowball sampling to identify other interview participants. At the time of the interview, researchers asked the participant if they were interested in taking part in measuring air quality. The following questions guided these interviews:

- What are your health and safety concerns?
- Are you concerned about the high volume of truck traffic in the neighborhood?
- Where do you think are the areas of highest exposure to air pollution, noise, or safety hazards from truck traffic?

All interviewers used these questions in guided interviews, and recorded responses by hand. To the extent possible, interviewees recorded specific quotes that they deemed significant. Immediately after the interview, the interviewee transcribed these notes and recorded any reflections from the process.[27] The notes and reflections were included in analyses.

Interviewees who identified an interest in participating in measuring local air quality were recruited to join the pilot research project. The new research team included nine local participants (which we refer to as "community researchers"). Some of these individuals were active members of community organizations, including Port Richmond On Patrol and Civic, and New Kensington Community Development Corporation, whereas others were not directly affiliated with a community organization. As a team, we set out to monitor personal exposures to $PM_{2.5}$. The nine community researchers and four additional residents who did not take part in personal exposure monitoring attended an initial training session on particulate matter monitoring. During the session, community researchers provided input on HDDT traffic patterns and pollution exposure, and indicated areas of concern on a large map of the area.

This study also included a Photovoice exercise.[28] Photovoice is an established photographic research technique that supports the recording of and reflecting on community resources and concerns, and promotes policy action.[28] We employed the Photovoice method to allow visual documentation of environmental health concerns, and as a tool to prompt group reflection on priorities for action. The Photovoice exercise overlapped with the air monitoring in that participants who wore monitors were asked to take photos on the same day. Owing to limited resources, not all community researchers had access to a digital camera (Canon PowerShot A2300) on each monitoring day. In total, six of the nine participants took photos on one of their monitoring days. During an initial 1-hour training session, we explained the goals of the project, namely, to photo-document environmental health hazards and community health assets. We discussed ethical guidelines approved by the institutional review board, such as sensitivity to photographing of private spaces, and no photographing of illegal activities.

The second "follow-up" meeting occurred after the monitoring concluded and preliminary data compilation and analysis had occurred. Each community researcher received a letter entailing their personal exposure levels for each monitoring day, with some background information on how to interpret these numbers (Appendix A). In addition, the research team posted photos taken by community researchers during the Photovoice exercise, and facilitated a group discussion about the photos. Together, the group brainstormed their priorities for regulatory or policy action based on group reflection on photos and their understanding of the results.

Monitoring of Personal Exposure

The research team assessed particulate matter exposure by means of personal air monitoring of nine individuals who reside or work in Port Richmond. Procedures for recruitment, consent, and participation were reviewed and approved by the Institutional Review Board at the University of Pennsylvania. Sampling occurred over a period of 6 days, and individuals participated in sampling for a period of between 1 and 3 non-consecutive days. This study used methods established in previous personal exposure assessment studies.[29-31] Community researchers wore Harvard Personal Environmental Monitors (Harvard School of Public Health, Boston, MA) to measure $PM_{2.5}$ concentration as an indicator of diesel combustion. Harvard Personal Environmental Monitors, which include an impactor to collect $PM_{2.5}$ on a 37-mm Teflon filter, were connected via sampling tube to battery-powered pumps (SidePak Model 330 and 730, TSI, Inc., Shoreview, MN; AirLite Sampler Model 110-100, SKC, Inc., Eighty Four, PA). Community researchers wore air sampling pumps and filter sampling cartridges in backpacks (with the sampler fixed to the shoulder strap)[30] at all times during the 8-hour sampling period, with the option of placing the backpack nearby during stationary activities.

Filters were weighed to assess $PM_{2.5}$ mass according to EPA protocol.[32] They were stored in a climate-controlled room for 24 hours before weighing both before and after sampling to reduce effects of humidity on weight measurements. Pumps were calibrated to 1.8 L/min the morning before deployment. Airflow was measured and recorded within 1 hour post-deployment. Filters were frozen immediately after collection to avoid loss of semivolatiles. As a standard step, we used field blanks (one per monitoring day; 5% of samples) to measure limits of detection. We ran duplicate pairs to estimate precision of each sampling method, and included blank filter analysis for comparison. The standard deviation of mass change on the field blanks was ±0.007 μg, suggesting that there was no substantial contamination of filters during handling and processing.

We recorded characteristics of the community researchers' home or workplace each sampling day. Questions documented 1) housing type (number of shared walls), 2) distance between traffic to house front, 3) presence of (and distance to) nearby industrial or point sources (such as bus depots, garages, parking lots, or gas stations), 4) energy sources for heating and cooking, 5) presence of air conditioning or humidifier, 6) presence of smokers, 7) presence of pets, 8) type of flooring, and 9) presence of upholstered furniture or curtains. In addition, community researchers received activity logs, and asked to record their activities and locations in 15-minute intervals throughout the sampling period. At the end of each sampling day, research team members reviewed activity logs and asked the participant to help complete any unclear or missing information. The goal of collecting data on these determinants of exposure was to pilot means of doing so and to alert participants to sources of interest. The study was not designed to have sufficient power to test plausible effects of these variables on air pollution, but we believe that exploratory analyses of the data were justified (to do more informed sample size calculations in the future) and, more important, were expected of us by the community.

Statistical Analysis

$PM_{2.5}$ concentrations are recorded in micrograms (μg) of particles per cubic meter (m^3) of air. We used a one-way analysis of variance method to quantify between-person and day-to-day components of exposure variability. To assess for impact of hypothesized sources of $PM_{2.5}$ on personal pollutant exposure, we used simple linear regressions that included personal pollutant exposures (in $\log_{10}$) as the dependent variable and independent variables reflecting putative sources and modifiers of exposure, such as distance from I-95, heating energy source, activity, and other factors as independent variables (Table 1). Measurements collected with and without "tobacco smoke exposure" were analyzed separately. Statistical analyses were performed using SAS software (SAS Institute, Cary, NC).

Ambient exposure measurements were obtained from Philadelphia's Air Management Services. They reflect hourly average concentrations of $PM_{2.5}$ from between two and four monitoring stations located throughout the city, with the closest being approximately 1 mile north of the study area.

RESULTS

Interviews and Community Engagement

The research team performed open-coding of transcribed notes on interviews, community meetings, and Photovoice discussion according to a methodology prescribed by Strauss and Corbin.[33] In an open-coding process, we developed a set of codes based on themes that emerged during the review of interview and meeting notes, which included patterns of truck traffic and idling as well as other point-source pollution, health effects of diesel emissions, and safety concerns from truck traffic. Community researchers helped to identify key themes at follow-up meetings and were involved in the writing and editing of this article.

Four major themes emerged from coding of these notes: Air pollution and safety hazards from truck traffic; environmental hazards from nearby industry; related community health problems; and environmental assets. Data collected in interviews and meetings primarily emphasized the first three themes—truck traffic, environmental hazards, and health concerns—whereas Photovoice photos highlighted truck traffic, health concerns, and environmental assets. Below, we describe each of these themes and supporting data.

First, truck traffic throughout the neighborhood was a major theme in interviews, meetings, and especially the Photovoice photos. In interviews, we learned that truck traffic has been a part of life in this neighborhood for decades. One participant who had lived in the neighborhood for over 60 years stated that, "We always notice trucks driving down our street. But it is certainly cleaner than when I was a kid. A train used to run right in front of my house, getting soot everywhere as it went by. Back then, I would hop on back and ride it to school!" Nevertheless, community researchers were keenly aware of their present exposure to air pollution in their neighborhood from truck traffic and idling. Wearing the monitors and recording their daily rounds in journals heightened their attention to this problem, as well as their frustration with it. For example, one community researcher, when reflecting on the monitoring and Photovoice project,

Table 1. Independent Variables

Variable	Count (n = 23)	Minimum	25th Percentile	Median	75th Percentile	Maximum
1. Time Spent Outside (%)	—	3	12	28	76	100
2. Distance From I-95 (ft)	—	359	1376	1456	2145	2533
3. Distance From Major Arterials (ft)	—	4	258	824	827	2025
4. Smoke Exposure	9	—	—	—	—	—
5. Presence of Pets	8	—	—	—	—	—
6. Number of Pets	—	0	—	—	—	3
7. Presence of Carpet	21	—	—	—	—	—
8. Presence of Candles	2	—	—	—	—	—
9. Cooking Occurrence	13	—	—	—	—	—
10. Window Opened	5	—	—	—	—	—
11. Presence of Upholstered Furniture	21	—	—	—	—	—
12. Heating Source	Gas, 14; oil, 6; electric, 3	—	—	—	—	—
13. Cooking Fuel Source	Gas, 17; electric, 6	—	—	—	—	—
14. Cleaning Occurrence	8	—	—	—	—	—

Figure 2. Photovoice Photo Showing a Truck Driving Past Park on a Neighborhood Collector Street

Figure 3. Photovoice Photo Showing a Heavy-Duty Diesel Truck (HDDT) Driving Down Allegheny Ave

Figure 4. Photo of Truck Disregarding the “No Tractor Trailers” Sign

commented that these exercises, "made me realize how many trucks there are, and how bad it smells." Community researchers also frequently noted the presence of bad smelling diesel truck fumes in their activity logs.

Although we suggested that participants take photos of any or all environmental health concerns, the majority of Photovoice photos featured outdoor scenes and showed trucks driving and idling throughout the neighborhood (Figures 2 through 4). One potential explanation is that wearing the monitors throughout their day, and writing their activity patterns, heightened their attention to outdoor sources, and trucks are the most "in your face" of these sources. Some of these photos revealed participants' annoyance with trucks driving on streets not designed for trucks. Figure 2 shows an HDDT driving past a community park on a small collector street.

Although the photos all showed outdoor scenes, in interviews and meetings, we heard that residents were also annoyed by the sight of particle pollution in their homes. One participant, during a daily follow-up interview, noted the persistent prevalence of dust buildup on her windowsills. As she slid her finger across the dirtied ledge, she said, "Look how dirty it is . . . I only let it sit for a few days, too. Just to show you how fast my windowsill gets covered in soot."

Interviews, meetings, and photos all revealed that residents felt that truck traffic is a safety hazard in the neighborhood. First, truck traffic damages curbs, sidewalks, and street surfaces. In an interview, one resident pointed to the corner of a nearby intersection, noting the crumbling curb and gaping pothole beside it that were a result of large trucks cutting corners and driving on the sidewalk. In observations, researchers frequently witnessed diesel trucks making tight turns, and at times getting stuck. Residents also expressed frustration with the frequent occurrence of trucks parking temporarily in traffic lanes while drivers run errands in stores and restaurants. In effect, trucks frequently block access for other vehicles, including emergency response vehicles. One community researcher recalled an event where a large HDDT became wedged on a nearby street, and prevented the fire department from quickly responding to a burning home only blocks away. In addition, residents find intersections with crosswalk lights to be unsafe for pedestrians, especially children. We heard multiple parents say that they would not allow their children to cross at certain heavy traffic intersections.

Figure 5. Photovoice Photo of a Man Walking With Car and Truck Traffic in Background

A second major theme, coming primarily from interviews and meetings, was a general worry about environmental hazards posed by sources other than trucks, such as point-source pollution from industrial smoke stacks to the east of I-95. Participants complained about nearby industrial plants that release large plumes of smoke, and suspected that emissions were heaviest after dark so as to go undetected. Other residents also mentioned nighttime plumes of industrial smoke in interviews and at neighborhood events. Regular topics of discussion throughout our research included the presence of abandoned industrial factories that housed potential pollutants, the prevalence of pollutants such as arsenic in the soil below a new housing developments, and the frequent "tire fires" at a large pile of used commercial tires in a lot next to I-95.

Third, we learned through interviews, focus group discussion, and photos that residents link neighborhood pollution, including air pollution, with health problems. Figure 5 shows a Photovoice photo of a man walking with arterial and highway traffic in the background. One community researcher who lives across the street from a park said that she notices children coughing more on days with heavy truck traffic or little wind. Other health concerns included the rising prevalence of autism among children in the neighborhood, and certain forms of cancer, including breast cancer, especially among women in the neighborhood.

Finally, the Photovoice exercise revealed community assets in the eyes of participants. Some photos were of family, friends, and pets, although more showed green features in the neighborhood, such as trees, park space, and planters.

At the follow-up meeting after monitoring, we shared results from the qualitative and quantitative studies with community researchers. There was general surprise about the strong effect of cigarette smoke on particle concentrations, as well as expressed desire to isolate measurement of "soot" from truck traffic in future studies. Most discussion was about the experience of wearing the monitors all day, the types of things they noticed that they had not previously noticed owing to wearing the monitors, and jokes about withstanding the loud noise from pumps. It became apparent during this discussion that community researchers toured the neighborhood, walking past what they viewed as "hot spots" to record the pollution levels at this location. In hindsight, continuous monitors would have been more beneficial for this purpose.

Finally, participants discussed their questions and priorities for regulatory or policy action. One priority for action was to advocate with the City of Philadelphia to improve enforcement of Philadelphia's anti-idling ordinance, which prohibits more than 2 minutes of idling by HDDTs. Second, community researchers wanted to see transportation signage improved (especially at the base of an exit ramp from I-95) to direct trucks away from neighborhood collector streets and toward major arterials (or to improve enforcement of designated truck routes). Third, the group wanted to be informed about how to report suspicious smoke stack emissions, for follow-up by the appropriate agency. The research team has committed to working with community researchers and regulatory agencies toward implementing these priorities.

Personal Exposure Measurements

Eight-hour integrated measurements ranged from 6 to 204 $\mu g/m^3$ (Figure 6). Average daily exposure was 65 $\mu g/m^3$, with a geometric mean (GM) of 44 $\mu g/m^3$ and a geometric standard deviation (GSD) of 2.7. The average exposure level among non-cigarette smoke-exposed (both from active and second-hand smoke) community researchers was 36 $\mu g/m^3$ (GM, 27 $\mu g/m^3$; GSD, 2.4), and 110 $\mu g/m^3$ (GM, 91 $\mu g/m^3$; GSD, 2.0) among smoke-exposed individuals. Ambient $PM_{2.5}$ concentrations were derived from between two and four stations located throughout the City of Philadelphia, with the closest station located approximately 1 mile north of Port Richmond. On monitoring days, hourly average ambient concentrations ranged from 7 to 12 $\mu g/m^3$. As seen in Figure 7, the range and variance in personal $PM_{2.5}$ exposure levels were substantially greater than the ambient concentrations. There was no correlation between personal and ambient exposure overall ($r = 0.1$) but not in the subset of personal measurements not exposed to tobacco smoke ($r = 0.1$).

Based on estimates from analysis of variance models, we found that in the full data set, day-to-day variance (in log[$PM_{2.5}$]; 0.13) was twice that for within-day (between-person) variance (0.06). This effect is even stronger when considering only non–smoke-exposed individuals ($n = 13$), for whom the day-to-day variance (0.16) is 8 times greater than within-day between-person variance (0.02).

Simple linear regressions suggested a negative association between percent of time spent outside and $PM_{2.5}$ concentration for smoke-exposed individuals, which can be interpreted as a reduction of exposure owing to leaving smoke-filled enclosed space, but the observed effect may also be just a chance finding ($p > .05$). We did not find an effect of distance from I-95 on $PM_{2.5}$ concentration or any other studied factors. However, it should be noted that the study was not powered to detect plausible effects of sources on which data were collected.

CONCLUSION

The purpose of this project was to 1) use the CBPR model to develop collaborative relationships with residents and community organizations, and involve residents in planning for and conducting air pollution research, 2) assess community concern regarding environmental health and truck traffic using interviews, meetings, and a Photovoice exercise, 3) develop and pilot a protocol to involve community residents in conducting personal measurements of $PM_{2.5}$ in the first-ever neighborhood- or personal-scale $PM_{2.5}$ monitoring project in Philadelphia, and 4) pilot a means of conveying study results to the residents and community researchers.

Data from interviews and meetings, including a Photovoice discussion, indicated that truck traffic was a major environmental health concern among residents, and a detractor from quality of life in the neighborhood. Although community researchers had prior concerns about threats to health and safety posed by truck traffic in the neighborhood, the personal monitoring and Photovoice exercise led them to greater awareness of the presence of diesel emissions, whether from mobile or point sources, throughout the neighborhood.

The first primary finding from personal monitoring was that smoking and smoke exposure has a strong effect on $PM_{2.5}$ exposure levels. Although this is not a novel finding, it did serve to remind community researchers that cigarette smoke is a form of particulate matter that has harmful health effects. Another finding was that personal $PM_{2.5}$ exposure levels were significantly different than ambient $PM_{2.5}$ concentrations in Philadelphia, which indicates that ambient monitoring should not be assumed to represent personal exposure levels for urban residents. The sample size was not large enough to determine effects of activities or proximity variables on personal exposure. Examination of patterns of variability in exposure revealed that future exposure monitoring aimed at understanding causes of air pollution should 1) focus on persons not exposed to cigarette smoke (i.e., smoking is already an established source and more research on this matter is not warranted) and 2) allocate more measurements to different days rather than persons, upon reflection that day-to-day variance in exposure dominates. The dominance of day-to-day variance in exposure also suggests that all residents experience air pollution that is determined by common factors that vary greatly in time. This should concentrate our attention on sources of exposure that match such characteristics in future studies.

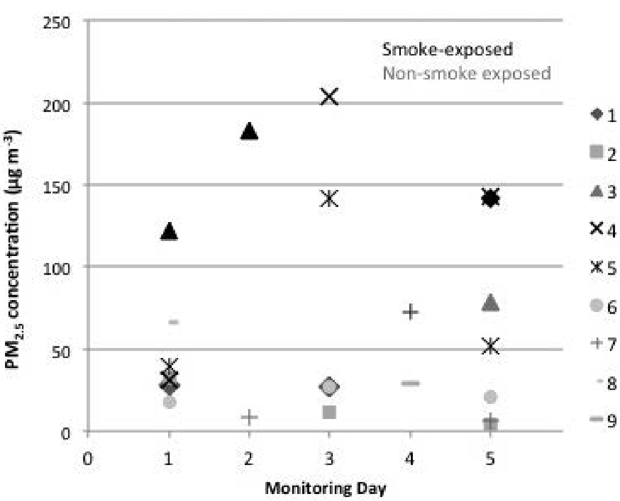

Figure 6. Participant Fine Particle ($PM_{2.5}$) Exposure (in Micrograms Per Cubic Meter) By Monitoring Day

Note. Symbols in black indicate participant smoke exposure during the monitoring day.

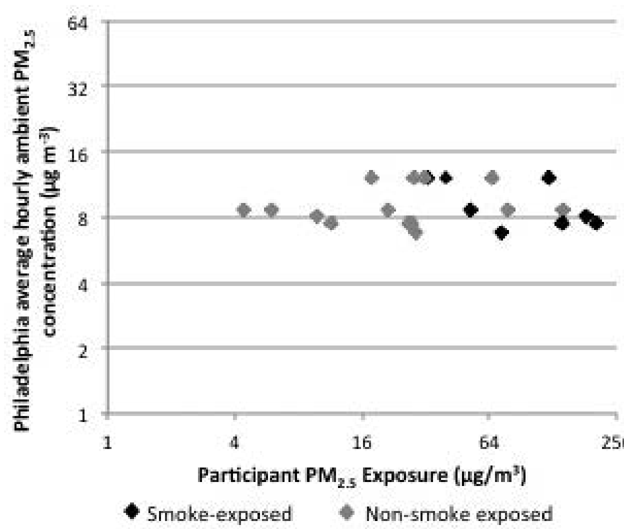

Figure 7. Participant Fine Particle ($PM_{2.5}$) Exposure Versus Philadelphia Ambient Concentration.

To use this method for a larger scale study, we would seek exposure monitors that are as quiet and unobstructive as possible, preferably continuous exposure monitors, and we would work to ensure that community researchers measure typical exposures rather than seek worst case scenarios. The community researchers are very motivated and have the necessary technical skills to wear the monitors. It may be worth considering enabling community researchers to select when they will measure exposures. This requires additional technical training and support for such activities from researchers coordinating the project, but was shown to be feasible in workplace settings.[34]

This pilot study also demonstrates that participatory methods can be used to involve lay persons in personal air pollution monitoring. Although studies are emerging that use participatory methods to collect air measurements, these have largely used stationary or mobile monitoring methods (e.g., Kinney et al.,[35] Loh et al.,[36] and Buonocore et al.[17]). With a few exceptions (e.g., Keeler et al.[37]), personal exposure studies do not typically involve open communication and collaboration with participants, or detail communication strategies if so. Our study is one of few to detail strategies, mechanics and findings of a CBPR approach for personal-level air monitoring.

The research team, including community researchers, is committed to taking action on priorities developed during this study. The main priorities developed during the follow-up meeting included improving signage for truck drivers throughout the neighborhood (especially at the base of an exit ramp from I-95) to direct trucks away from neighborhood collector streets and toward major arterials. Improving signage and enforcement of anti-idling ordinances was also a priority.

Although personal monitoring reveals exposure at the personal level, and can most accurately infer health implications, it is a more limited tool in terms of pollution source attribution (especially without continuous monitors and GPS tracking). Therefore, the research team is developing plans for a study involving fixed-site monitors (black carbon) and traffic- and marine vessel-counting throughout the neighborhood, to assess contributions of potential sources.

ACKNOWLEDGMENTS

The authors thank the Port Richmond community for partnering with us on this research endeavor. This research would not have been possible without the generous support and willingness to share instrumentation, from Dr. Hernando Perez at Drexel University and Petros Koutrakis at Harvard University. Katie Edwards was a valued participant from Clean Air Council. We are also thankful to staff at Air Management Services for their support of this project, and the use of their cleanlab for weighing of filters. This research has been made possible through funding by the United States Environmental Protection Agency (CARE 2 and Environmental Justice Small Grant to Clean Air Council), the Penn Genome Frontiers Institute and a grant with the Pennsylvania Department of Health. The Department of Health specifically disclaims responsibility for any analyses, interpretations, or conclusions.

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Appendix A. Report Back Letter

Dear _____,

Thank you for working with Clean Air Council to complete our first community air monitoring deployment. Without your work, we would not have been able to pull this off. We all feel that everything went smoothly, creating the first good data on particulate pollution in Port Richmond. The numbers you see below are the concentration of particulate matter in the air that *you* breathe for each day of the study:

- Day 1: __ μg/m^3 (where "μg/m^3" indicates micrograms per cubic meter, described below)
- Day 2: __ μg/m^3
- Day 3: __ μg/m^3

The average for all community researchers was 62 μg/m^3.

We observed that people who reported to have smoked or been near smokers had much higher particulate levels in air they breathe.

HOW TO MAKE SENSE OF THESE NUMBERS

Everyone has a single number for each of the days of the deployment. The number is the weight of particles (in micrograms) in a typical cubic meter of air you breathed on that day. Micrograms are 1 millionth of a gram, which sounds really small, but remember that only a small amount of particles can have an impact on health.

Sampling devices you wore had filters connected to pumps but a tube. These worked just like small vacuum cleaners. The filters in then collected particles and we calculated how much air was drawn through the device. The more particles that are trapped in the filter, the heavier it is at the end of each day (Figures A1 and A2).

Figure A1. The Filters

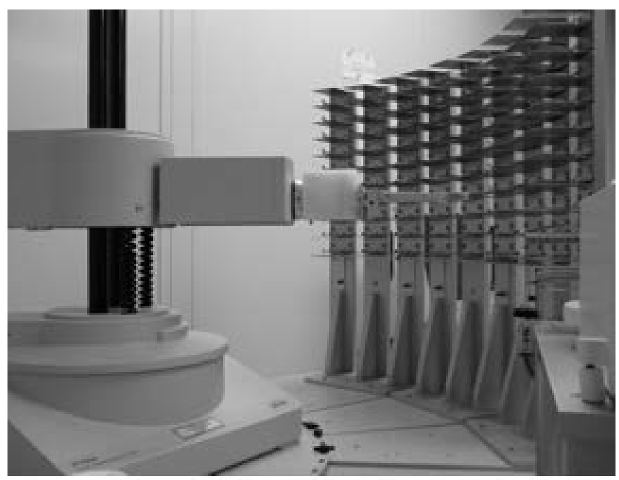

Figure A1. The Weighing Machine

TYPICAL AMOUNT OF PARTICLES IN PHILADELPHIA'S AIR

Average concentration levels of the type of particles we measured in 2010 in the City of Philadelphia at different monitoring locations was 12 to 15 μg/m^3.

WHAT DOES THIS MEAN IN TERMS OF YOUR HEALTH?

Studies have found that exposure to particulate matter is associated with asthma and respiratory disease. However, the results indicate your exposure for one day only, which is not representative of your typical daily/lifetime exposure. We cannot say what immediate or long-term health effects you will experience based on only one study.

continues

We do not know what particle levels we measured in your air mean to your health. If you are concerned about your health, you should seek advice of your doctor.

Please feel free to contact us if you have any questions or concerns.

Again, thank you for participating, and please let us know if you would like to be involved in future air quality research efforts in the neighborhood.