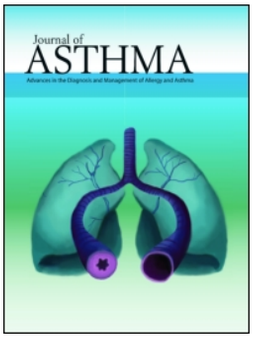

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Neighborhood air pollution and household environmental health as it relates to respiratory health and healthcare utilization among elderly persons with asthma

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ABSTRACT

Objective: The study investigated the associations between fine particulate matter ($PM_{2.5}$; $<2.5\ \mu$m in diameter), indoor environment, pulmonary function, and healthcare utilization in a vulnerable group of elderly persons with asthma. We hypothesized that environmental conditions were associated with adverse pulmonary health outcomes. *Methods*: The study involved elderly ($n = 76$; mean age 64.6 years; 48 women) vulnerable persons in Detroit, Michigan, USA, with physician-diagnosed asthma. Exposure variables included measured outdoor $PM_{2.5}$, self-rated outdoor and household environmental pollutants. Outcome variables were self-rated and measured pulmonary function, and asthma-related healthcare utilization. *Results*: Mean ambient $PM_{2.5}$ concentrations during the study was 14.14 ± (S.D. 6.36) $\mu g/m^3$ during the summer and 14.20 (6.33) during the winter ($p = 0.95$). In multiple regression analyses, adjusting for age and gender, mean 6-month concentration of $PM_{2.5}$ was related to shortness of breath (SHOB; standardized $\beta = 0.26$, $p = 0.02$) and inversely with self-rated respiratory health (SRRH; $\beta = 0.28$, $p = 0.02$). However, $PM_{2.5}$ did not predict lung function (FEV_1% predicted and FEV_1/FVC). However, $PM_{2.5}$ was related to use of asthma controller drugs ($\beta = 0.38$, $p = 0.001$). Participants' air pollution ratings predicted total healthcare utilization ($\beta = 0.33$, $p = 0.01$). *Conclusions*: In elderly persons with asthma, living near heavy industry and busy highways, objective and perceived environmental pollution relate to participants' respiratory health and healthcare utilization. Importantly, air pollution might increase use of asthma controller drugs containing corticosteroids with implication for elderly persons' risk to develop osteoporosis and cardiovascular disease.

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Introduction

Asthma in elderly persons is increasingly common, underdiagnosed, and suboptimally treated, resulting in increased utilization of healthcare resources and decreased quality of life. Elderly persons are the fastest growing group in the United States with one of the highest asthma morbidity and mortality rates [1–4]. Furthermore, asthma controller drugs contain corticosteroids, which impair older adults' immune function, and contribute to osteoporosis [5,6].

Pharmacologic therapies are typically less effective, and side effects exacerbated, in elderly persons [7–9]. Since asthma often manifests itself differently in elderly persons, e.g. fatigue is a more common presenting complaint; symptoms are commonly attributed to comorbidities [1–4,10–14]. In a recent study, 33 000 persons with asthma from 36 primary care centers were studied using electronic health data and national disease registries [15]. The study confirmed the high prevalence of comorbidities. Specifically, chronic obstructive pulmonary disease doubled the risk for asthma exacerbation. Other factors that can complicate asthma management in elderly persons include menopause, caregiver roles, and depression which is comorbid in 20% of elderly asthma patients [4,8,9,15,16]. Asthma is even more common in persons with minority status and those living under economically stressed conditions [17,18].

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Elderly persons with asthma are more susceptible to microbial and environmental culprits due to age-related changes in innate and adaptive immune responses and excessive mucous production with decreased clearance, which contributes to pathophysiological and treatment challenges [8,19–21]. Environmental factors play a major role in the etiology and exacerbation of asthma, but the actual disease pathway is less well understood in persons residing in disadvantaged neighborhoods with complex environmental exposures [22–31]. The U.S. Environmental Protection Agency's Framework for Cumulative Risk Assessment (EPA/630/P-02/001F) underscores the importance of integrating chemical and non-chemical stressors in risk assessments. This is especially critical in assessing environmental health risks among vulnerable elderly persons residing in disadvantaged communities [32]. In addition, there is limited guidance as to how evidence-based asthma guidelines should be personalized to the needs of vulnerable elderly persons. Merely focusing on pharmacological intervention does not suffice.

Elderly persons typically spend more time indoors, exercise less, and have lower intake of healthy foods which complicates the management of environmental asthma [33–36]. Despite national guidelines for asthma control, for example the widely used National Heart, Lung, and Blood Institute's (NHLBI) EPR guidelines, asthma rates among vulnerable persons are increasing, especially in polluted areas [37–39]. As many as every third person in such areas suffer from dyspnea (shortness of breath), a common warning sign of asthma [40]. Dyspnea and asthma are chronic conditions linked to altered respiratory responses to environmental stressors [41–44]. Environmental triggers include mold, chemical odors, pets, and pollen [45–48]. In addition, economic stress attenuates the body's ability to mobilize T-lymphocytes, critical for the management of environmental pollutants [49,50]. Furthermore, nonchemical environmental stressors potentiate chemical triggers [51,52]. Neighborhood exposures are compounded by indoor (household) exposures [53–57]. Access to affordable care, limited environmental awareness, noncompliance with asthma treatment plans, and limited provider awareness of environmental triggers represent significant obstacles to persons' ability to become guardian of their own respiratory well-being [58]. Asthma also interferes with a person's ability to be physically active and engage in social activities [59–62].

There is a clear association between air pollution, respiratory symptoms, and healthcare utilization [63,64]. Moreover, socioeconomically strained neighborhoods offer less access to resilience factors, e.g. green space and vulnerable older persons are less inclined to go outdoors due to neighborhood conditions, including violence and the built environment [65,66]. In addition, ongoing research, including our own, suggests that older persons are sensitive to environmental respiratory triggers [67].

The objective of this study was to determine the associations between ambient (outdoor) $PM_{2.5}$ (an asthma trigger), self-rated ambient and household environment, and measured and self-rated pulmonary function as well as healthcare utilization in a vulnerable population of elderly persons with physician-diagnosed asthma. Our overall study hypothesis was that both objective and self-rated environmental pollution are associated with decreased self-rated and measured pulmonary function and increased healthcare utilization.

Methods

This community-based participatory research project involved the community organization Arab American Community Center for Economic and Social Services (ACCESS), and a volunteer group of elderly persons with physician-diagnosed asthma. The participants were assessed twice: in the summer of 2013 and in the winter of 2013/2014.

Participants and recruitment

Eligibility criteria were 55 years of age or older with physician-diagnosed asthma. A total of 28 men with a mean age of 65.11 (SD 7.42) years and 48 females 64.23 (64.23, 7.49; p between gender = 0.62) consented. There was no loss-to-follow-up. Participants resided within a 3.2 km (2 mile) radius of the Salina Elementary School, Dearborn, Michigan, USA. The school was chosen as a reference point for accessing the neighborhood air quality. Michigan Department of Environmental Quality (MIDEQ) Air Quality Division operates an air quality monitoring station on the school grounds (identification number 26-163-00033). Information about the project was distributed through numerous channels, including ACCESS, local media, stores, churches, and mosques. Primary health care centers were informed about the study and the research team's interest to be contacted by elderly persons suffering from asthma. Once potential study participants contacted the research team, they were provided with detailed written and oral information.

We enrolled patients only after obtaining written informed consent. Participants received $40 for each of the two times they participated in the study. The Institutional review board of Wayne State University approved the study.

Interview process

At the initial meeting in the participant's home, the research assistant collected information via structured interviews using a validated survey. Upon completion of the interview, the research assistant asked the participant to undergo pulmonary function spirometry testing. The same process was repeated at the 6-month follow-up.

Self-reported survey

The survey contained 63 questions in total, including questions on gender, age, and socioeconomics. The self-rated scales are described in further detail below. They were psychometrically consistent over time.

Self-reported shortness of breath (SHOB)

In collaboration with our community partners, we adapted the validated U.K. Medical Research Council's shortness of breath/dyspnea scale [40]. The scale consists of six items, with dichotomous (yes/no) response alternatives. The questions concern whether the person had suffered from any of the following during the most recent 3 months: difficulty taking a deep breath; difficulty breathing when walking; or performing heavy work; avoiding exercising due to shortness of breath; unable to sleep through the night due to coughing or shortness of breath; and unable to catch a good, deep breath at times. Responses to the individual items were summed to generate the shortness of breath scale. Scores ranged between a low of 0 and a high of 6 with a Cronbach's alpha of 0.73.

Self-rated respiratory health (SRRH)

Self-rated respiratory health was assessed using a 1-item, 5-point Likert scale that ranges from poor (score 1) to excellent (5). The scale is analog to the well-validated scale assessing self-rated health which predicts a currently healthy person's long-term morbidity and mortality risks [68–70].

Air pollution scale

The air pollution scale consisted of five items concerning the respondent's ratings of the air quality in the neighborhood during the most recent 3 months. The questions cover: overall air quality, annoying odors, black particles, poor visibility, and health effects from air pollution. Responses were given using a Likert-type scale ranging from not at all (assigned score 1) to very concerned (3) and summed for a total score ranging between a low of 5 to a high of 15. Exploratory factor analysis supported a one-factor solution, which explained 79.2% of the total variance. The Cronbach's alpha was 0.88.

The asthma symptoms scale

The asthma symptoms scale consisted of six items with a dichotomous yes or no response scale. Questions assess asthma symptoms during the last 3 months by aggregating responses to questions regarding: wheezing with exercise; wheezing without a cold; cough that won't go away; attack of wheezing that made it difficult to breathe; tightness or heavy feeling in chest; and disturbed sleep due to wheezing, coughing, chest tightness, or shortness of breath during the last 3 months [71]. The scale ranges from a low of 0 to a high of 6. The Cronbach's alpha was 0.83.

Observer rating scale of the household environment

The research assistant (observer)-rated household environment scale aggregated responses to 12 dichotomous-response items. The scale ranges from a low of 0 and a high of 12. The Cronbach's alpha was 0.70. Trained research assistants rated the ceiling and walls, respectively, as yes/no with regard to six items: peeling paint, water stains, tiles broken or missing, plaster falling, visible mold or mildew, and other damage, adapted from a validated scale [72].

Healthcare and pharmaceutical utilization

The survey inquired about the frequency of use of asthma drugs during the preceding 3 months, including rescue inhalers without corticosteroids, and controller inhalers with corticosteroids. Information was also collected about the number of times the participant had visited the emergency department, their own physician, and whether or not they had been hospitalized for asthma symptoms during the last 3 months.

Lung function testing

Pulmonary function testing was done using the KoKo-USB handheld spirometer (item number 25-31-605), marketed by Nightingale-Alan Medical Equipment Services, LLC, Cincinnati, Ohio, USA. The spirometer's software package (PUL313105SN) allowed data processing using a portable computer. The spirometer was calibrated daily prior to initiating any home visits, using the 3 l volume KoKo calibration syringe (PUL510000) and the 3 l volume KoKo multiflow calibration syringe (PUL520000). Spirometry testing was done in the participant's own home following the interview, with the person sitting comfortably in a chair. The participant received instructions about the testing process. Then the interviewer demonstrated the procedure. Finally, the participant was asked to blow into the spirometer after taking a deep breath and using full expiratory effort. Predicted forced expiratory volume during 1 s (FEV_1%), based on age and sex, and forced expiratory volume during 1 s/forced vital capacity (FEV_1/FVC) were used as pulmonary function outcome [73].

Rationale for seasonal sampling

The interviewer visited subjects' homes during two different times: (1) during the winter, with a modelled mean ambient $PM_{2.5}$ concentration of around 10 μg/m^3 in Detroit in 2010, and (2) during the summer with a mean ambient $PM_{2.5}$ concentration of 14 μg/m^3 in 2010 [74]. By following the participants over time, we were able to test the validity of our predictive model linking, for example, air pollution to future lung function.

Air pollution assessment

Neighborhood ambient $PM_{2.5}$ was monitored using a tapered element oscillating microbalance (TEOM 1400ab; Rupprecht & Patashnick, Albany, New York, USA) operated by MIDEQ. Continuous $PM_{2.5}$ data from the Dearborn site were used to quantify exposures to ambient $PM_{2.5}$ in the epicenter of the study from which we recruited participants. Mean 6-month $PM_{2.5}$ concentration was determined by calculating the average of all daily measures for the stipulated time period, e.g. 180 days. Outdoor temperature was monitored using an R.M. Young thermometer. The summer data collection extended from June 20, 2013 to September 14, 2013, with the mean monitoring date being July 28, 2013, and the standard deviation being 24 days. The winter sampling took place from December 10, 2013 to April 24, 2014, with a mean date of February 21, 2014, and a standard deviation of 31 days.

Statistics

Chi-square and Student's *t*-test were used for statistical testing of discrete and continuous variables, respectively. Seasonal changes in pulmonary function, self-rated respiratory health, and environmental conditions were assessed using paired sample Student's *t*-test. Associations between changes in self-rated and objective pulmonary function outcome were determined using multiple linear regression. In the first step, age and gender were entered. In the second step, mean $PM_{2.5}$ exposure was entered. In the third step, participants' rating of household environment was entered. In the fourth and final step, frequency of use of asthma controller drug was entered. Table 3 depicts variables entered at each step. That is, we present stepwise results of the association between (step 1) mean exposure to $PM_{2.5}$ and lung function (FEV_1%). In step 2, ratings of the household environment are added. β represents the standardized regression coefficient between the variable entered at that specific step and the outcome variable—in this case lung function. A negative β denotes that with increasing levels of this variable, i.e. $PM_{2.5}$, lung function decreases. With positive β higher scores on the exposure variable is associated with higher scores on the outcome variables.

In models predicting FEV_1%, age and gender were not entered into the model because these variables are already taken into account when calculating predicted lung volume. Participants' air pollution ratings were added in the third step of the model when total healthcare utilization was the outcome. Standardized βs with 95% confidence intervals for unstandardized betas are reported. Statistical significance was set to a two-tailed p values of <0.05. Exact, two-sided p values are reported. Data were analyzed using IBM SPSS statistics, version 24, 2016.

Results

A total of 76 adults with a mean age of 64.59 years (SD 7.46) and a range of 55–89 years were evaluated twice; during the summer of 2013 and 6 months later, during the 2013/2014 winter. Nine out of ten (88.0%) had health insurance, predominantly Medicaid (82.7%). Among the participants, 81.3% reported that at least one more person residing in their home had

been diagnosed with asthma. 6.7% of the participants reported being a current cigarette smoker (1.3% waterpipe/hookah), 13.3% were former cigarette smokers (2.7% waterpipe/hookah), and 18.7% reported that someone else in the home smoked tobacco products.

Air pollution ratings

Table 1 depicts self-rated and measured air pollution and pulmonary function. Significantly more people were concerned about health effects from air pollution in the summer. Participants' ratings on the air pollution scale improved between the summer and winter assessments. The mean difference between seasons was 0.85 (95% confidence interval 0.36–1.34, $t_{75} = 3.46$, $p = 0.001$).

Household inspections

Table 1 reports results of the inspection by the trained interviewers of the physical state of the ceilings and walls of the participants' household environment. There were no significant differences across seasons.

Ambient $PM_{2.5}$ concentration

Table 1 depicts that there were no significant changes in ambient $PM_{2.5}$ between baseline and the 6-month follow-up. The mean number of days between the baseline and the follow-up evaluation was 212 days (SD = 20.94), with a range of 122–259 days. This variation in days between follow-up allowed us to calculate the estimated mean personal exposure to $PM_{2.5}$ by adding up the mean daily $PM_{2.5}$ concentration and divide by the number of days between the person's two assessments. The mean ambient air pollution concentration of $PM_{2.5}$ between the first and second assessment was 12.08 $\mu g/m^3$ (SD = 0.16), with a range of 11.52–12.42.

Asthma symptoms

There were significant seasonal-associated differences in participants' asthma symptoms, with more symptoms in the summer (Table 1). The mean decrease in asthma symptoms between the summer and winter was 0.56 (SD 1.62; $t_{73} = 2.64$, $p = 0.01$). In response to a global question whether their asthma had changed over time, there were no significant seasonally associated differences. At the summer assessment, 27.0% reported it having gotten worse over time versus 21.6% in the winter.

Self-rated respiratory health (SRRH)

Table 1 depicts that there were no significant differences in respondents' self-rated respiratory health between the summer and winter.

Table 1. Descriptive statistics of participants' physical environment, respiratory health and healthcare utilization in summer versus winter ($n = 76$).

	Summer (2013)	Winter (2014)	*p* value
Environment			
Air pollution ratings			
Perceived health effects, %	85.3	64.0	**0.002**
Overall air pollution ratings, mean (SD)	11.39 (1.43)	10.53 (1.93)	**0.001**
Household inspections			
Physical state of ceilings and walls, mean (SD)	0.67 (1.67)	0.76 (1.66)	0.71
Air Particulate concentration ($\mu g/m^3$)			
$PM_{2.5}$, mean (SD)	14.14 (6.36)	14.20 (6.33)	0.95
Respiratory health, mean (SD)			
Asthma symptoms	5.36 (2.02)	4.81 (2.13)	**0.01**
Shortness of breath (SHOB)	4.81 (1.44)	4.60 (1.39)	0.24
Self-rated respiratory health (SRRH)	2.04 (0.64)	2.09 (0.72)	0.65
Pulmonary function			
FEV_1%[a]	0.90 (0.23)	0.86 (0.24)	0.14
FEV_1/FVC[b]	0.83 (0.12)	0.78 (0.16)	**0.005**
Healthcare utilization			
Medical visits			
No of unplanned visits for asthma, mean (SD)	1.27 (1.49)	1.41 (1.27)	0.42
ED visits due to asthma, mean (SD)	0.67 (0.99)	0.19 (0.59)	**<0.001**
Asthma related hospitalization, %	34.7	22.7	**0.049**
Total healthcare utilization, mean (SD)	1.92 (2.35)	1.61 (1.67)	0.183
Pharmacological utilization			
Asthma drugs, %	93.3	89.3	0.37
Rescue inhaler without corticosteroids, mean (SD)	1.43 (1.14)	1.71 (1.41)	**0.047**
Inhalers with corticosteroids, mean (SD)	1.23 (1.16)	0.89 (1.30)	**<0.001**

Bold indicates significant *p*-value.
[a]Forced expiratory volume during 1 s of predicted %.
[b]Forced expiratory volume during 1 s/forced vital capacity.

Table 2. Correlation between changes over time in: lung volume (FEV_1%[a] and FEV_1/FVC[b]), shortness of breath (SHOB), and self-rated respiratory health (SRRH; $n = 76$).

	FEV_{1s}%	FEV_{1w}%	FEV_1/FVC_s	FEV_1/FVC_w	FEV_{1w}% − FEV_{1s}%	FEV_1/FVC_w − FEV_1/FVC_s	$SHOB_w$ − $SHOB_s$	$SRRH_w$ − $SRRH_s$
FEV_{1s}%	1							
FEV_{1w}%	0.53***	1						
FEV_1/FVC_s	0.55***	0.25*	1					
FEV_1/FVC_w	0.12	0.65***	0.33**	1				
FEV_{1w}% − FEV_{1s}%	−0.46***	0.51***	−0.30*	0.56***	1			
FEV_1/FVC_w − FEV_1/FVC_s	−0.29*	0.44***	−0.42***	0.72***	0.76***	1		
$SHOB_w$ − $SHOB_s$	−0.01	0.15	−0.14	0.24*	0.16	0.33**	1	
$SRRH_w$ − $SRRH_s$	−0.07	0.06	0.18	0.18	0.13	0.04	−0.28*	1

[a]Forced expiratory volume during 1 s of predicted %.
[b]Forced expiratory volume during 1 s/forced vital capacity; w: winter; s: summer.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Pulmonary functioning

FEV_1% did not decrease significantly from summer to winter. FEV_1/FVC decreased a mean of 0.05 (SD = 0.16; 95% confidence interval 0.02–0.09), $t_{76} = 2.87$, $p = 0.005$; Table 1).

Healthcare and pharmacological utilization

Although there were no season-related differences in unplanned total healthcare visits, the number of visits to an emergency department due to asthma was significantly higher in the summer. Mean difference = 0.48; 95% confidence interval, 0.25–0.71; $t_{72} = 4.09$, $p < 0.001$; Table 1). During the summer, a third of the patients had been hospitalized for asthma during the last three months, as compared to 1 in 5 in the winter ($p = 0.049$). The mean *annualized* overall healthcare utilization was 7.68 (SD 10.15) visits. As reported in Table 1, the majority of the participants reported regular use of asthma drugs in general during the most recent 3 months, with no seasonal variation. Participants reported less frequent use of rescue inhaler without corticosteroids in the summer than in the winter. In contrast, they used more controller inhalers with corticosteroids in the summer versus the winter.

Correlations between self-rated and measured lung function between the summer and winter

Table 2 shows that FEV_1% in the summer was significantly associated with FEV_1% in winter ($r = 0.53$, $p < 0.001$). The association between FEV1/FVC in summer and winter was also significant ($r = 0.33$, $p = 0.003$). FEV_1% was correlated with FEV_1/FVC, in the summer ($r = 0.55$, $p < 0.001$) and the winter ($r = 0.65$, $p < 0.001$), respectively. Changes in FEV_1% between the summer and the winter were significantly related to changes in FEV_1/FVC between seasons ($r = 0.76$, $p < 0.001$) (Table 2). Changes in measured pulmonary function (FEV_1/FVC) over the 6 months study period were associated with changes in shortness of breath. Furthermore, changes in shortness of breath over time were inversely associated with changes in self-rated respiratory health.

Linear regression model of associations between environmental exposures and health outcomes Table 3 depicts results for a series of multiple linear regression analyses of the associations between environmental factors, on the one hand, and healthcare utilization, lung function, asthma symptoms, shortness of breath, and self-rated respiratory health, on the other hand. In the following, we discuss the key findings reported in the table.

The first regression presented in Table 3 shows that mean levels of outdoor $PM_{2.5}$ was not significantly associated with FEV_1%. However, in the final step 3, the model show that more frequent use of asthma inhalers with corticosteroids was associated with better FEV_1% (β in step 3 = 0.27).

The second model presented in Table 3 demonstrates that use of controller inhalers with corticosteroids was associated with better lung function as measured by FEV_1/FVC (β in step 4 = 0.45), controlling for possible effects from age and gender. The model has four steps since we controlled for age and gender in step 1.

The third model presented in Table 3 shows that increasing age is associated with more healthcare utilization (β in step 1 = 0.28). Step 3 of the model shows that age remains a significant factor. In addition, participants' air pollution ratings are associated with healthcare utilization (β in step 3 = 0.33). In step 4, use of asthma controller drugs enters as being significantly associated with healthcare utilization along with age. However, once asthma controller drug use has been entered, air pollution ratings no longer remains significantly associated with healthcare utilization.

In the subsequent model, $PM_{2.5}$ is significantly associated with use of asthma controller inhalers (β in

Table 3. Separate multiple linear regression models predicting: lung function; healthcare utilization, drug use, asthma symptoms; shortness of breath (SHOB), and self-rated respiratory health (SRRH; $n = 76$).

Variable	β[a] (95% CI[b])	p[c]	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
			Lung function (FEV1%[d])					
Step 1: Mean exposure to $PM_{2.5}$	−0.05 (−0.47, 0.31)	0.68	−0.05 (−0.48, 0.31)	0.41	−0.15 (−0.67, 0.17)	0.22		
Step 2: Rating of household envt.			−0.09 (−0.05, 0.02)	0.48	−0.04 (−0.04, 0.03)	0.78		
Step 3: Asthma controller drug use					**0.27 (0.001, 0.10)**	**0.04**		
R^2		0.002		0.010		0.069		
			Lung function (FEV_1/FVC[e])					
Step 1: Age	0.12 (−0.01, 0.01)	0.32	0.12 (−0.01, 0.01)	0.32	0.12 (−0.01, 0.01)	0.32	0.08 (−0.01, 0.01)	0.51
Gender (Ref: male)	0.03 (−0.07, 0.09)	0.83	0.02 (−0.07, 0.09)	0.85	0.03 (−0.07, 0.09)	0.83	0.01 (−0.07, 0.08)	0.99
Step 2: Mean exposure to $PM_{2.5}$			0.02 (−0.24, 0.27)	0.89	0.02 (−0.24, 0.27)	0.89	−0.16 (−0.45, 0.07)	0.21
Step 3: Rating of household envt.					−0.03 (−0.03, 0.02)	0.81	0.05 (−0.02, 0.03)	0.66
Step 4: Asthma controller drug use							**0.45 (0.01, 0.08)**	**0.001**
R^2		0.015		0.015		0.016		0.182
			Total healthcare utilization					
Step 1: Age	**0.28 (0.01, 0.14)**	**0.03**	**0.27 (0.01, 0.14)**	**0.03**	**0.23 (0.01, 0.12)**	**0.04**	**0.22 (0.00, 0.12)**	**0.04**
Gender (Ref: male)	−0.08 (−1.29, 0.64)	0.50	−0.10 (−1.35, 0.54)	0.40	−0.06 (−1.17, 0.66)	0.57	−0.10 (−1.28, 0.45)	0.35
Step 2: Mean exposure to $PM_{2.5}$			0.23 (0.00, 6.09)	0.05	0.10 (−1.94, 4.50)	0.43	0.003 (−3.10, 3.18)	0.98
Step 3: Rating of household envt.					−0.05 (−0.34, −0.22)	0.66	0.000 (−0.26, 0.26)	0.99
Air pollution ratings					**0.33 (0.08, 0.60)**	**0.01**	0.16 (−0.11, 0.44)	0.23
Step 4: Asthma controller drug use							**0.40 (0.20, 0.98)**	**0.004**
R^2		0.088		0.142		0.238		0.337
			Asthma controller drug use in last 3 months					
Step 1: Age	0.10 (−0.03, 0.06)	0.43	0.09 (−0.02, 0.06)	0.41	0.10 (−0.02, 0.06)	0.36		
Gender (Ref: male)	0.08 (−0.45, 0.88)	0.52	0.04 (−0.50, 0.74)	0.70	0.06 (−0.46, 0.77)	0.62		
Step 2: Mean exposure to $PM_{2.5}$			**0.38 (1.37, 5.31)**	**0.001**	**0.38 (1.37, 5.26)**	**0.001**		
Step 3: Rating of household envt.					−0.18 (−0.32, 0.03)	0.11		
R^2		0.014		0.159		0.192		
			Asthma symptoms					
Step 1: Age	0.12 (−0.04, 0.11)	0.32	0.11 (−0.04, 0.10)	0.36	0.12 (−0.03, 0.10)	0.32	0.05 (−0.04, 0.07)	0.61
Gender (Ref: male)	0.05 (−0.85, 1.29)	0.68	0.04 (−0.89. 1.19)	0.77	0.05 (−0.83, 1.25)	0.69	0.02 (−0.78, 0.95)	0.84
Step 2: Mean exposure to $PM_{2.5}$			**0.27 (0.39, 7.13)**	**0.03**	**0.27 (0.42, 7.14)**	**0.03**	0.07 (−2.07, 3.92)	0.54
Step 3: Rating of household envt.					−0.14 (−0.48, 0.12)	0.24	−0.04 (−0.30, 0.20)	0.69
Step 4: Asthma controller drug use							**0.58 (0.58, 1.27)**	**<0.001**
R^2		0.016		0.087		0.107		0.391
			SHOB					
Step 1: Age	0.23 (−0.01,0.09)	0.06	0.23 (−0.00, 0.09)	0.05	**0.24 (0.01,0.09)**	**0.04**	0.20 (−0.01,0.08)	0.06
Gender (Ref: male)	**0.25 (0.03, 1.36)**	**0.04**	0.22 (−0.18, 1.28)	0.06	**0.24 (0.04, 1.31)**	**0.04**	**0.22 (0.02, 1.20)**	**0.04**
Step 2: Mean exposure to $PM_{2.5}$			**0.26 (0.30, 4.40)**	**0.03**	**0.26 (0.31, 4.33)**	**0.02**	0.11 (−1.04, 3.01)	0.33
Step 3: Rating of household envt.					−0.21 (−0.36, 0.01)	0.06	−0.14 (−0.29, 0.06)	0.19
Step 4: Asthma controller drug use							**0.39 (0.17, 0.64)**	**0.001**
R^2		0.097		0.163		0.207		0.328
			SRRH					
Step 1: Age	−0.22 (−0.05, 0.00)	0.07	−0.22 (−0.04, 0.00)	0.07	−0.22 (−0.05, 0.00)	0.07	−0.18 (−0.04, 0.00)	0.11
Gender (Ref: male)	0.03 (−0.31, 0.41)	0.78	0.06 (−0.26, 0.44)	0.61	0.06 (−0.27, 0.44)	0.63	0.08 (−0.22, 0.45)	0.49
Step 2: Mean exposure to $PM_{2.5}$			**−0.28 (−2.45, −0.25)**	**0.02**	**−0.28 (−2.45, −0.24)**	**0.02**	−0.15 (−1.83, 0.44)	0.23
Step 3: Rating of household envt.					0.04 (−0.09, 0.12)	0.76	−0.03 (−0.11, 0.09)	0.80
Step 4: Asthma controller drug use							**−0.36 (−0.33, −0.06)**	**0.005**
R^2		0.052		0.131		0.132		0.234

[a]Standardized beta; bold indicates significant beta.
[b]95% confidence interval for unstandardized beta; bold indicates significant confidence interval.
[c]p value; bold indicates significant p-value.
[d]Forced expiratory volume during 1 s of predicted %.
[e]Forced expiratory volume during 1 s/forced vital capacity.

step 2 = 0.38). $PM_{2.5}$ remained the only significant factor also in step 3 when the research assistants' ratings of the household environment were entered and found to be non-significant.

$PM_{2.5}$ was significantly associated with asthma symptoms (β in step 2 = 0.27). It remained a significant factor in step 3, when ratings of the household environment were added. However, in step 4, when use of asthma controller drugs was entered, the latter was significant while $PM_{2.5}$ no longer remained significantly associated with asthma symptoms.

Similar findings held true for exposures associated with shortness of breath. That is, apart from both age and female sex being risk factors, step 2 indicates that $PM_{2.5}$ was significantly associated with shortness of breath. However, in the final step 4, when asthma controller drug use was found to be significantly associated with shortness of breath, $PM_{2.5}$ was no longer significantly associated with shortness of breath.

$PM_{2.5}$ was inversely associated with self-reported respiratory health in both step 2 and 3 ($\beta = 0.26$). However, when use of asthma controller drugs was entered in step 4, $PM_{2.5}$ no longer remained

significantly associated with self-reported respiratory health.

Discussion

This study concerns environmental risk factors for the exacerbation of asthma in elderly persons with physician-diagnosed asthma that reside in a heavily polluted and resource restrained neighborhood in southeast Detroit. This is a group of persons that have been subject to limited prospective studies regarding the living conditions' impact on pulmonary function [25,75]. In agreement with several other studies, we did not find any consistent relationship between measured air pollution and pulmonary function; FEV_1% and FEV_1/FVC [76–78]. However, our results suggest that neighborhood concentration of $PM_{2.5}$ relates to use of controller inhalers with corticosteroids. Use of asthma controllers is probably a reliable indicator of a person's perceived pulmonary function, and thus a more direct indicator of adverse effects from air pollution than measured pulmonary function. Moreover, $PM_{2.5}$ promote inflammation of the respiratory system, which is counteracted by controller drugs containing corticosteroids [78,79]. If our findings are confirmed in a larger-scale study, air pollution-driven use of asthma controller drugs might increase the risk of osteoporosis and heart failure in already high-risk elderly persons [80–83]. Shortness of breath is a recognized prodromal of worsening asthma [84,85] $PM_{2.5}$ was predictive of a worsening in shortness of breath ratings. Thus, both health behavior in terms of asthma controller drug use, and self-ratings of shortness of breath appear to be sensitive to neighborhood air pollution. Importantly, in the step before the model took use of asthma controller drugs into consideration, $PM_{2.5}$ levels were significantly associated with asthma symptoms, shortness of breath, and self-reported respiratory health. In all three cases, when use of asthma controller inhalers was entered in step 4, the significant effects of $PM_{2.5}$ disappeared. This is likely due to the fact that use of asthma controller inhalers is significantly associated with $PM_{2.5}$. Thus, that relationship might "steal" most of the explained variance between $PM_{2.5}$ and self-reported lung function. Further support for this conclusion is the fact that use of asthma controller drugs is significantly associated with asthma symptoms, shortness of breath, healthcare utilization, and self-reported respiratory health. Persons with worse perceived lung function and higher healthcare utilization are likely also more frequent user of asthma controller drugs—not least if symptoms are due self-reported or measured adverse environmental exposures.

These findings support our overall hypothesis that environmental pollutants in elderly persons' neighborhood adversely impact pulmonary health. However, measured air pollution, using $PM_{2.5}$ as a marker of particulates in the air, does not directly predict measured pulmonary function. Rather, $PM_{2.5}$ predicts use of asthma controller drugs with corticosteroids, which have strong anti-inflammatory properties. This relationship makes sense from a pathophysiological point of view since fine particulate matters initiate systemic inflammation [86–89]. Further in support of our overall hypothesis is the findings that $PM_{2.5}$ predicts shortness of breath as well as worse self-rated respiratory health. Both of these relationships disappear once we control in the model for the use of asthma controller drugs.

We explored the utility of a proposed new scale, self-rated respiratory health. The validity of the scale is supported by the findings that $PM_{2.5}$ is related with lower self-rated respiratory health. Furthermore, the validated MRC shortness of breath scale correlated inversely with self-rated respiratory health. However, although changes in shortness of breath correlated with changes in objective pulmonary function, self-rated respiratory health did not. These findings are promising, but further research is needed to determine whether self-rated respiratory health adds substantially to the assessment of a person's perceived pulmonary health status, beyond that explained by shortness of breath ratings.

There were wide concerns among the respondents about health effects from air pollution in their community. Of special concern is the fact that over 80% of participants stated that poor air quality had adversely affected their health, or someone else's health in their household.

There was no significant difference across seasons in ambient $PM_{2.5}$ concentrations. This is in agreement with an older study using more detailed, but short-term, spatiotemporally-related measurements of air pollutants, including $PM_{2.5}$ in Detroit [74,90]. The latter study, the Geospatial Determinants of Health Outcomes Consortium (GeoDHOC), used 50 active air samplers distributed throughout Detroit and Windsor. However, the data were only collected during a two-week period in September 2008 and May and June 2009, compared to this study that measured particulates on a daily basis over a 6-month period.

Utilization of rescue inhalers was more common in the winter versus use of controller inhalers with corticosteroids during the summer. Other studies have

reported findings of more asthma symptoms and higher use of rescue inhalers during the winter, during which exercise and cold induced bronchoconstriction is more common [91–93]. However, in our cohort of elderly persons 70% reported that they were not physically active. Hospitalization and visits to the emergency department due to asthma were more common in the summer.

This is a small pilot study that is affected by several strengths and weaknesses. It is noteworthy that there was no loss-to-follow-up among the participants. Community-based cohort studies of disadvantaged persons typically have a substantial loss-to-follow-up. Our high retention rate translates into high internal validity as to the associations between environmental exposures, asthma symptoms, and health care utilization over time.

There are some limitations to the generalizability of the study. The study is small, and we lack ongoing measures of exposures to $PM_{2.5}$. The study involves elderly persons living in a geographically and socioeconomically disadvantaged area. However, in contrast to prior work, we focused on vulnerable elderly persons and were able to study all participants during two different time intervals, without any loss to follow-up. Our pulmonary function quality measures also suggest that we were able to administer the test with high reliability.

Conclusions

This prospective study demonstrates the high burden of asthma in an elderly vulnerable population residing in a disadvantaged and heavily polluted neighborhood. Environmental pollution indicators were related to several objective and self-rated measures of lung function. Importantly, fine particulate matters appear to promote use of asthma controller drugs that contain corticosteroids with a number of adverse health effects in vulnerable elderly persons. The study provides some evidence as to the potential of using self-rated respiratory health as a complementary and user friendly measure of pulmonary health.

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