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Respiratory health, pulmonary function and local engagement in urban communities near oil development

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A R T I C L E I N F O

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A B S T R A C T

Background: Modern oil development frequently occurs in close proximity to human populations. Los Angeles, California is home to the largest urban oil field in the country with thousands of active oil and gas wells in very close proximity to homes, schools and parks, yet few studies have investigated potential health impacts. The neighborhoods along the Las Cienagas oil fields are situated in South LA, densely populated by predominantly low-income Black and Latinx families, many of whom are primarily Spanish-speakers.
Methods: A cross-sectional community-based study was conducted between January 2017 and August 2019 among residents living <1000 m from two oil wells (one active, one idle) in the Las Cienagas oil field. We collected self-reported acute health symptoms and measured FEV1 (forced expiratory volume in the first second of exhalation) and FVC (forced vital capacity). We related lung function measures to distance and direction from an oil and gas development site using generalized linear models adjusted for covariates.
Results: A total of 961 residents from two neighborhoods participated, the majority of whom identify as Latinx. Participants near active oil development reported significantly higher prevalence of wheezing, eye and nose irritation, sore throat and dizziness in the past 2 weeks. Among 747 valid spirometry tests, we observe that living near (less than 200 m) of oil operations was associated with, on average, −112 mL lower FEV1 (95% CI: −213, −10) and −128 mL lower FVC (95% CI: −252, −5) compared to residents living more than 200 m from the sites after adjustments for covariates, including age, sex, height, proximity to freeway, asthma status and smoking status. When accounting for predominant wind direction and proximity, we observe that residents living downwind and less than 200 m from oil operations have, on average, −414 mL lower FEV1 (95% CI: −636, −191) and −400 mL lower FVC (95% CI: −652, −147) compared to residents living upwind and more than 200 m from the wells.
Conclusions: Living nearby and downwind of urban oil and gas development sites is associated with lower lung function among residents, which may contribute to environmental health disparities.

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1. Introduction

Modern oil development frequently occurs in close proximity to human populations. Globally, there are approximately 40,000 oil fields (Mead, 1993) that have the potential to effect over 600 million people living nearby (O'Callaghan-Gordo et al., 2016). Over the past decade, oil production in the United States (US) has nearly doubled while natural gas production rose 50% reversing a longstanding decline in production (Energy Information Administration, 2018). An estimated 8.6 million

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people live less than 1600 m from an active oil extraction site in the US. (Czolowski et al., 2017) California (CA), together with Texas, North Dakota, and Alaska account for ~60% of all oil produced domestically. Public health concern has accompanied this rapid growth in oil production (Cotton and Charnley-Parry, 2018).

As oil and gas development is becoming more common near where people live, work and play, there is an increasing potential for human exposure to contaminants associated with drilling and fossil fuel extraction (Adgate et al., 2014; Finkel et al., 2013). Recent research demonstrates multiple health-hazardous air pollutants associated with petroleum extraction, including particulate matter (PM), nitric oxides (NOx), polyaromatic hydrocarbons, benzene, naphthalene, xylenes, toluene, ethylbenzene, formaldehyde, and sulfuric acid (Field et al., 2014). Documented health effects from exposure to such chemicals include symptomatic acute physical and respiratory effects, dizziness, headaches, and fatigue along with respiratory system irritation, such as difficulty breathing and impaired lung function (ATSDR., 1999; Bolden et al., 2015).

While there are few epidemiological studies related to upstream oil extraction, results from three recent health surveys near natural gas extraction and hydraulic fracturing sites reported symptoms of throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds and stress (Steinzor et al., 2013; Rabinowitz et al., 2015; Ferrar et al., 2013). These symptoms were more common in individuals living nearby gas facilities compared to those farther away. Elevated incidence of pediatric asthma hospitalization has been observed among nonurban areas with the highest levels of gas drilling activity (Willis et al., 2018, 2020; Rasmussen et al., 2016). Survey-based studies documented higher rates of headaches, dizziness, and eyes, nose, throat and skin irritation among residents near oil development compared to people living farther away (San Sebastián et al., 2001; Kponee et al., 2015). Recent studies in CA and Texas identified adverse birth outcomes associated with oil extraction activities(Cushing et al., 2020; Gonzalez et al., 2020; Tran et al., 2020).

Los Angeles (LA) County, CA, is home to one of the most petroleum-dense basins in the world, with thousands of oil and gas extraction wells spread across multiple oil fields in 70 different communities (Fig. 1a) (Chilingar and Endres, 2005; Gamache and Frost, 2003). Approximately 1/3rd of the 10 million LA County residents live <1 mile of an active oil drilling site, and over 500,000 residents live <¼ mile (~400 m) (Sadd and Shamasunder, 2015). Some live as close as 60 feet from active oil operations (Fig. 1b) (Elkind, 2012). Such a dense, diverse population living in close proximity to oil is unmatched across the US (Elkind, 2012).

The neighborhoods atop the Las Cienagas oil fields are situated in South LA, populated by predominantly low-income Black and Latinx families. Over 90% of residents are people of color (self-identify as Latinx/Hispanic, Black, Asian and/or as a race other than White) and approximately three-quarters of households live below 200% of the federal poverty line (Shamasunder et al., 2018a). According to CalEnviroScreen, CA's environmental justice screening tool to identify highly vulnerable communities, this area is among the top 10% most disproportionately-environmentally burdened in the state (Office of Environmental H, 2017). These neighborhoods, when compared to the state, fall into the bottom 20% for educational attainment and among the top 15% for poverty based on CalEnviroScreen metrics. After an upswing in oil production in Las Cienagas oil field, nearby residents began to report adverse acute health symptoms, such as nosebleeds and headaches, ailments that have been described in other areas with oil and gas production (Lohah, 2014). Subsequently, one oil and gas development (OGD) site (which consists of multiple production wells) was shuttered by the city of Los Angeles, and is the "idle" site in this study as it was not actively producing oil or gas during the study period. Other sites, including the "active" study site, continued to extract oil from this field. We used community-driven methodology to assess respiratory health among community residents living in two neighborhoods in the Las Cienagas oil field which were within 1000 m of either active or idle OGD sites.

2. Methods

To examine the possible chronic deleterious effects of oil drilling operations in close proximity to neighborhoods in urban Los Angeles, we analyzed the relationship between OGD sites' proximity with self-reported acute symptoms and pulmonary function test results among diverse residents. A cross-sectional community-based study was conducted between January 2017 and August 2019 near two oil sites in the Las Cienagas oil field in South Los Angeles, CA. One OGD well site (in the North University Park neighborhood) housed 21 wells which were idle, that is, not actively producing any oil or gas, during the study period. The second OGD well site (in the Jefferson Park neighborhood) had 28 wells at the time of the study and was actively producing oil during the entire study period. The academic research team and Esperanza Community Housing collaborated to train *Promotores de Salud* (community health workers) in recruitment and research methods. A *Promotor de Salud* is a community member who is uniquely linked to the cultural and regional connections in the neighborhood and this local, networked approach offers an innovative model that provides culturally accessible

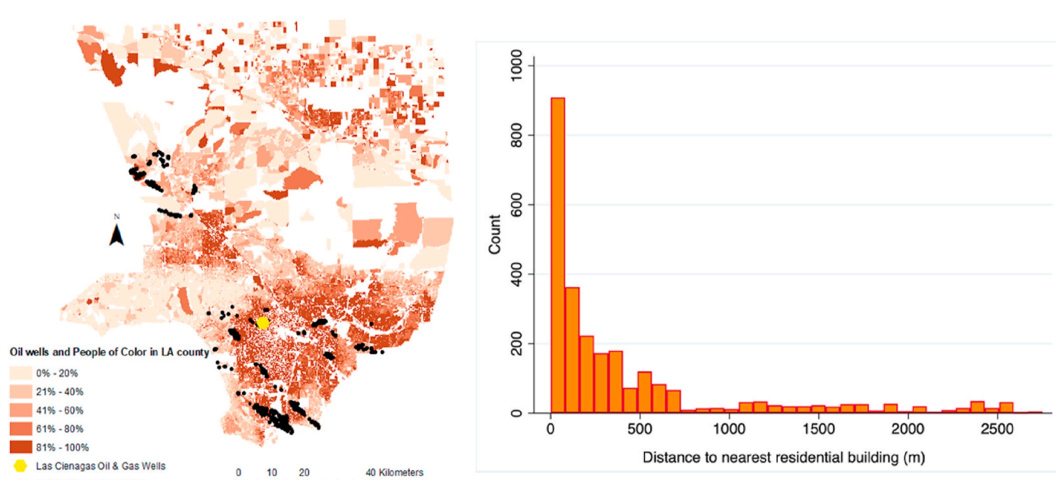

Fig. 1. a) Location of active oil wells and people of color (according to 2010 US Census block data) in Los Angeles County. Las Cienagas oil field is shown by the yellow dot. b) Proximity of active oil wells to residential homes in Los Angeles County (graph on right). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

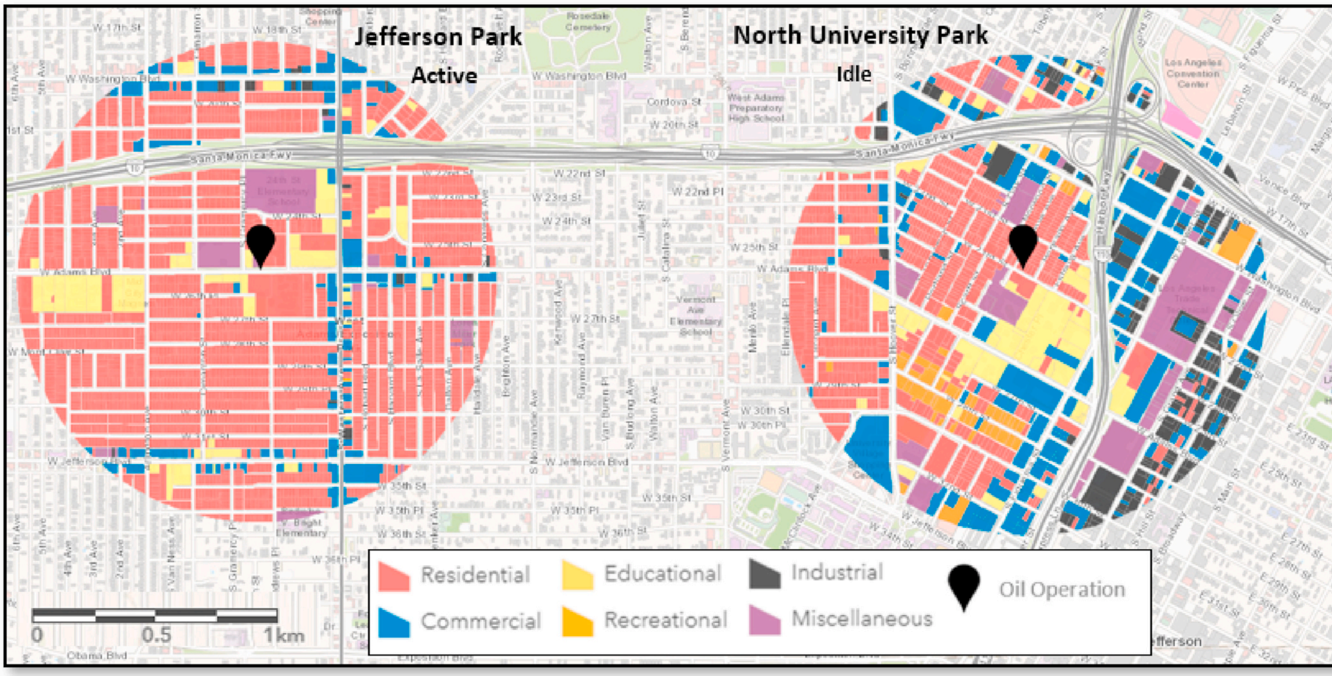

Fig. 2. Oil operation locations and land-use around the two neighborhoods in South Los Angeles, California.

health education for low-income communities of color and supports changes for improved health (Rhodes et al., 2007; Dominguez et al., 2015; Ingram et al., 2014; Pérez and Martinez, 2008). We partnered with skilled community *promotores* for recruitment in this neighborhood-based study. University of Southern California (USC) researchers and community partners went to local elementary schools, churches and door to door to distribute recruitment flyers, answer questions and invite residents to participate in the study. Flyers were posted in apartment buildings and distributed to school children when permission was granted. To be eligible, participants were at least 6 years old, spoke English, Spanish or Korean, and lived within 1000 m of one of the OGD sites of interest for at least two years. Multiple participants per household were eligible to participate if they met the inclusion criteria. Among the potential eligible participants that spoke to a community *promotor*, 74% agreed to participate in the study. Written informed consent was obtained from all participants 18 years of age or older, assent and parental consent were obtained from all participants younger than 18 years. All protocols, consent forms, and survey materials were approved by the University of Southern California Institutional Review Board. Participants who provided written consent completed a baseline demographic and health questionnaire, reported acute symptoms over the past two weeks, and provided physiological measurements.

2.1. Health questionnaire

If participants were under the age of 13, the parent/guardian completed the questionnaire. The questions were based on validated questionnaires from a Southern CA respiratory health study (Peters et al., 1999a) and adapted for accessibility and cultural relevance based on input from the *promotores* and Esperanza. The questionnaire was administered in the participant's preferred language (Spanish, English or Korean) and asked sociodemographic information, race/ethnicity, sex, age, tobacco exposure (e.g. smoking history, current smoking practices, presence of indoor environmental tobacco smoke), occupation and residential history. We collected information about disease history, including if the participant ever had a doctor-diagnosis of asthma. The participant was considered to have allergic rhinitis if answered affirmative to the question "Have you ever had hay fever?".

2.2. Acute symptoms survey

We asked questions regarding acute irritant and physical symptoms experienced during the previous two weeks, leveraging survey tools developed in partnerships with communities living near nuisance industries (Tajik et al., 2008; Schinasi et al., 2011). We considered the following acute symptoms: respiratory (wheezing or whistling of the chest, coughing every morning, sleep disturbed by wheezing, sore throat, chest tightness, or runny nose), mucous-membrane irritation (burning, tearing, or irritated eyes, burning or irritated nose), neurological (dizziness, headache, fatigue, ringing of the ears, seizure), gastrointestinal (nausea or vomiting, diarrhea), and as well as others (nosebleeds, backache, rash). Some symptoms that we considered to be unrelated to airborne OGD emissions (e.g. backache, vomiting, diarrhea, cold/flu) were included to address the possibility that residents might report excessive symptoms due to possible negative feelings about the well sites. These questions were collected on a scale with 4 categories within the past two weeks ("not at all", "once or twice", "a few times per week"or "daily"). We dichotomized the response into any symptom (Yes) or not at all (No) categories for interpretability and analysis purposes.

2.3. Lung function measurements

Lung function was assessed using a commercially available spirometer (ndd Easy-On PC, Andover MA) by trained study staff. Maximal-effort spirometry was overseen by trained personnel following American Thoracic Society criteria. Three to 7 blows were performed by each participant to establish consistency, representativeness, and performance credibility. Multiple variables were automatically collected and logged using the ndd software; FEV1 (forced expiratory volume in the first second of exhalation), FVC (forced vital capacity), and MMEF (maximal mid-expiratory flow). We focused on FEV1 and FVC as both measures are established as strong and independent predictors of respiratory disease, cardiovascular mortality and all-cause mortality (Baughman et al., 2012; Beaty et al., 1982; Mannino et al., 2003; Schünemann et al., 2000). Each participant's height (to nearest 0.1 cm) and weight (0.1 lbs) was also measured. Finally, each participant was asked if they had cold or flu symptoms within the past 72 h (defined as the presence of cough, fever, sore throat, and/or runny or stuffy nose).

2.4. Statistical analysis

We evaluated participant characteristics by neighborhood and variable distributions. We found the continuous spirometry data to approximate a normal distribution and proceeded with untransformed variables for subsequent analyses. Various representations of oil-well related exposures were then constructed. We assessed differences based on neighborhood (Model 1) and then distance from the oil well using a binary indicator of whether the participants' home was near (<200 m) versus farther (200–1000 m) from an oil well (Model 2). The selection of 200 m for the main analysis was chosen based on a changing relationship observed between distance and lung function among study participants (Figure S1). Then, we constructed a 4-level categorical exposure variable accounting for predominant wind direction and distance from the well site: living upwind and more than 200 m from OGD wells (reference); living upwind and within 200 m; living downwind and more than 200 m; and living downwind and within 200 m (Model 3). In addition, we considered models with distance modeled as a continuous variable using a lognormal transformation (Model 4). Predominant wind direction in the LA basin is from the west to the east which we confirmed using 5 years (Jan 2015–Jan 2020) of wind speed and direction data from a nearby meteorological station (see Fig. 3). Prior studies have observed high pollution concentrations and gradients on the east side of freeways (Zhu et al., 2002, 2006) and downwind (east) of the OGD facilities (Garcia-Gonzales et al., 2019a). Sensitivity analysis for lung function outcomes was also assessed at 150 m and 400 m.

A list of potential confounders was determined a priori from the available survey variables based on previous literature and biological plausibility (Peters et al., 1999b). Logistic models for the presence of acute respiratory symptoms were adjusted for sex (male/female), age group (<18, 18–60, >60), race/ethnicity (Hispanic/Latinx, Black or Asian), dichotomized residential distance to freeway (<200 m), season (winter, spring, summer or fall), baseline asthma status (yes/no), ever smoker (yes/no), reported indoor environmental tobacco smoke (yes/no) and recent flu or cold symptoms (yes/no). A random effect for household (based on address) was included to account for multiple participants from the same residential address. Using generalized linear models, we examined the relationship between lung function and proximity to oil wells adjusted for age (polynomial spline with 3 degrees of freedom), sex (male/female), race/ethnicity, baseline asthma status (yes/no), ever smoker (yes/no), reported indoor environmental tobacco smoke (yes/no), recent flu or cold symptoms (yes/no), dichotomized residential distance to freeway (<200 m), height (m), weight (lbs) spirometry technician and interactions between age and height, and age and sex. We further examined the effect of distance and direction from the oil well site (using the 4-level categorical exposure variable) on measured FEV1 and FVC in a model stratified by neighborhood.

Finally, we conducted a subgroup analysis based on age groups, sex, race/ethnicity and asthma status. All analyses assumed a 2-sided alternative hypothesis at a 0.05 level of significance. All statistical analyses were conducted using R statistical computing language (R Core Team, 2020) version 3.6.2.

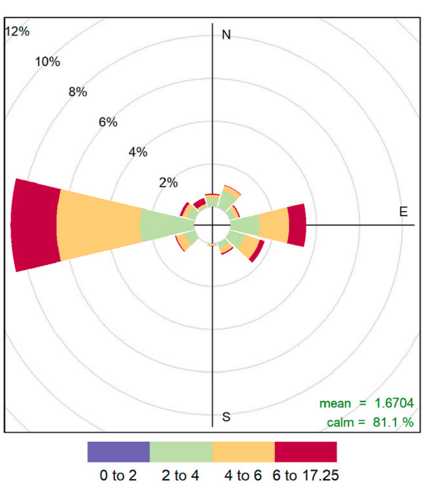

Fig. 3. Wind rose showing wind direction and speed based on 5 years of data (Jan 2015–Jan 2020) from a meteorological station located at the USC University Park Campus, <5 km from the study sites. Direction was reported when wind speeds were >0 mph.

3. Results

3.1. Characteristics of the study population

A total of 972 residents participated in this study to measure lung function and self-reported acute mental and physical health symptoms from 488 distinct addresses (Table 1). 11 participants were subsequently excluded for living outside of the study area after subsequent confirmation of residential address. The mean age of the participants was 39 years with 29% of the participants being children (<18 years) and 22% over the age of 60. The majority (62%) were female and 100% identified as people of color including 792 Hispanic/Latinx, 115 Black/African Americans, and 54 Asians/Asian Americans (51 identified as Korean and 3 as South Asian). On average, participants had lived in the neighborhood for 19 years. 68% of the participants completed the survey in Spanish. Overall, 15% of participants reported a doctor diagnosis of asthma. 21% of participants were ever smokers and 6% reported environmental tobacco smoke inside of the home. More than 70% of participants were nonworkers (e.g. student, homemaker, retiree or unemployed). The median distance from the respective well sites to residences was 291 m. Participants living near the neighborhood with the active drill site were, on average, slightly older and more diverse in terms of race/ethnicity as well as more likely to have ever smoked cigarettes. A total of 288 people lived near (<200 m) an oil well site.

3.2. Self reported acute symptoms

Participants living in the neighborhood with the active OGD wells reported significantly higher prevalence of recent wheeze, daily morning cough, eye irritation, dizziness, fatigue, backache and rash in the past 2 weeks (Table 2) compared to participants living near the idle OGD wells (n = 960). However, we did not observe differences in respiratory symptoms based on proximity to wells, with the exception of sneezing/running nose. Other symptoms unlikely to be related to oil drilling, showed no difference (e.g. trouble hearing, diarrhea) or higher prevalence among the neighborhood with the idle site (e.g. flu or cold symptoms).

In multivariable logistic regression models, we observe that the participants living in the neighborhood with active oil production wells have 2.6 times higher odds (OR 2.58; 95% CI: 1.19, 5.59) of reporting wheezing in the past two weeks compared to participants living in the neighborhood with idle wells. Living near compared to farther from an oil drill site was not statistically significant (OR 1.20; 95% CI 0.69, 2.13) in the model, although living near and downwind was associated with higher odds of recent wheeze (OR 2.26; 95% CI: 1.14, 4.49, Fig. 4, Table S1). In the multivariable models we did not observe consistent significant differences by neighborhood or distance for morning cough (Table S2). We did observe that participants living downwind of the well sites had higher odds of reporting sleep disturbance due to wheezing over the past two weeks (downwind and <200 m: OR 2.91, 95% CI 1.20, 7.06, Table S3).

Table 1
Characteristics of participants by neighborhood and well proximity.

	North University Park (idle)	Jefferson Park (active)	Near Well (<200 m)	Farther from Well (>200–1000 m)
	N = 441	N = 520	N = 288	N = 673
Age categories, N (%):				
9 - 18	138 (31.3%)	136 (26.1%)	56 (19.4%)	218 (32.4%)
18-60	243 (55.1%)	212 (40.8%)	133 (46.2%)	322 (47.8%)
60 <	60 (13.6%)	172 (33.1%)	99 (34.4%)	133 (19.8%)
Gender, N (%):				
Female	286 (64.9%)	310 (59.5%)	180 (62.5%)	416 (61.8%)
Male	155 (35.1%)	210 (40.5%)	108 (37.5%)	257 (38.2%)
Race/Ethnicity, N (%):				
Asian/Asian American	2 (0.4%)	52 (10.0%)	48 (16.7%)	6 (0.9%)
Black/African American	6 (1.4%)	109 (21.0%)	40 (13.9%)	75 (11.1%)
Hispanic or Latinx	433 (98.2%)	359 (69.0%)	200 (69.4%)	592 (88.0%)
Employed, N (%)	132 (29.9%)	144 (27.7%)	74 (25.7%)	202 (30.0%)
Duration (years) of residence in the neighborhood, Median [25th; 75th]	10.0 [5.0; 17.0]	24.5 [12.0; 40.0]	14.0 [7.0; 27.0]	14.0 [7.0; 33.0]
Ever smoker, N (%)	70 (15.9%)	138 (26.5%)	74 (25.7%)	134 (19.9%)
Current smoker, N (%)	19 (4.3%)	35 (6.7%)	16 (5.6%)	38 (5.6%)
Exposed to environmental tobacco smoke, N (%)	38 (8.6%)	21 (4.0%)	17 (5.9%)	42 (6.2%)
Allergic rhinitis/Hay fever, N (%)	71 (16.1%)	132 (25.4%)	78 (27.1%)	125 (18.6%)
Doctor diagnosis of asthma, N (%)	57 (12.9%)	85 (16.3%)	50 (17.4%)	92 (13.7%)
Distance to the closest freeway, N (%):				
≥200 m–1000 m	235 (53.3%)	480 (92.3%)	228 (79.2%)	487 (72.4%)
<200 m	206 (46.7%)	40 (7.7%)	60 (20.8%)	186 (27.6%)
Distance from well, m, Mean (SD)	308 (224)	380 (238)	162 (42)	396 (156)
Distance from well, categorial, N (%)				
≥200 m–1000 m	268 (60.8%)	405 (77.9%)	–	673 (100%)
<200 m	173 (39.2%)	115 (22.1%)	288 (100%)	–
Direction from well, N (%)				
Upwind	174 (39.5%)	175 (33.7%)	55 (19.1%)	294 (43.7%)
Downwind	267 (60.5%)	345 (66.3%)	233 (80.9%)	379 (56.3%)
Households, N	205	283	163	325

Table 2
Self-reported acute symptoms among participants by neighborhood and well proximity.

	North University Park (idle)	**Jefferson Park (active)**	**Near Well (<200 m)**	**Farther from Well (>200–1000m)**
	N = 442	***N = 518***	***N = 288***	***N = 672***
Wheeze & Bronchitic Symptoms				
Wheezing/ whistling in the chest	57 (12.9%)	95 (18.3%) *	50 (17.4%)	102 (15.2%)
Morning cough, every day	110 (24.9%)	105 (20.3%)*	67 (23.2%)	148 (22.0%)
Sleep disturbed by wheeze	43 (9.7%)	69 (13.3%)	39 (13.5%)	73 (10.9%)
Other Respiratory Symptoms				
Sore throat	157 (35.5%)	181 (34.9%)	91 (31.6%)	247 (36.8%)
Chest tightness	76 (17.2%)	112 (21.6%)	56 (19.4%)	132 (19.6%)
Sneezing or runny nose	175 (40.0%)	207 (40.0%)	132 (45.8%)	250 (37.2%)*
Recent cold or flu symptoms during spirometry	151 (34.2%)	98 (18.9%) *	79 (27.4%)	170 (25.2%)
Mucous-membrane irritation				
Irritation of the eyes	184 (41.6%)	276 (53.3%)*	144 (50.0%)	316 (47.0%)
Irritation of the nose	168 (38.0%)	213 (41.1%)	117 (40.6%)	264 (39.3%)
Neurological				
Dizziness	114 (25.8%)	176 (34.0%)*	91 (31.6%)	199 (29.6%)
Headache	222 (50.2%)	242 (47.1%)	130 (45.1%)	334 (49.7%)
Fatigue	177 (40.0%)	241 (46.7%)*	144 (50.0%)	274 (40.1%)*
Ringing of the ears	125 (26.5%)	156 (30.1%)	87 (30.2%)	194 (28.9%)
Seizure	8 (1.8%)	6 (1.2%)	4 (1.4%)	10 (1.4%)
Gastrointestinal				
Diarrhea	43 (9.7%)	78 (15.1%) *	39 (13.5%)	82 (12.2%)
Nausea or Vomiting	40 (9.0%)	53 (10.2%)	19 (6.6%)	61 (9.1%)
Other				
Nosebleeds	45 (10.2%)	67 (12.9%)	22 (7.6%)	90 (13.4%)*
Backache	188 (42.5%)	251 (48.5%)*	144 (50.0%)	295 (43.8%)
Rash	47 (10.6%)	84 (16.2%) *	43 (14.9%)	88 (13.1%)

* chi-square test, $p < 0.05$.

Among other symptoms analyzed with the adjusted logistic models, we identify significantly higher odds of sore throat (OR 2.04; 95% CI 1.19, 3.51), chest tightness (OR 3.16; 95% CI 1.54, 6.48), irritation of the eyes (OR 3.08; 95% CI 1.775.30), irritation of the nose (OR 2.23; 95% CI 1.31, 3.82), dizziness (OR 3.01; 95% CI 1.53, 5.90) and ringing of the ears (OR 1.74, 95% CI 1.05, 2.88) among residents in the neighborhood with the active drill site. The other symptoms were not statistically significant for neighborhood site in multivariable models, including symptoms thought to be unrelated to the well activity (e.g. backache and trouble hearing) (Table S4). We do not observe proximity alone to be a significant predictor of self-reported acute symptoms after adjusting for other covariates.

3.3. Pulmonary function results

Of the study participants, 919 performed at least one spirometry test. 172 participants were excluded because of restrictions in age (included only participants ages 10 to 85, n = 26) or due to invalid/outlier

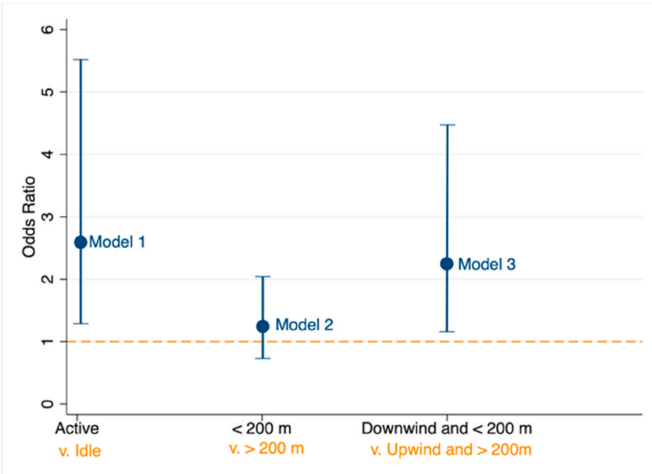

Fig. 4. The odds ratio and 95% confidence interval for recent wheeze for Model 1) participants living in the neighborhood with the active compared to the idle OGD well sites; Model 2) participants living near (<200 m) the OGD well sites compared to those living farther away (200–1000 m); and Model 3) participants living both near (<200 m) and downwind of an OGD well site compared to those living farther (200–1000 m) and upwind. All models are adjusted for age, sex, race/ethnicity, asthma diagnosis, recent flu/cold, season, ever smoker, recent exposure to environmental tobacco smoke and living near a freeway. Models include a random effect for residential household.

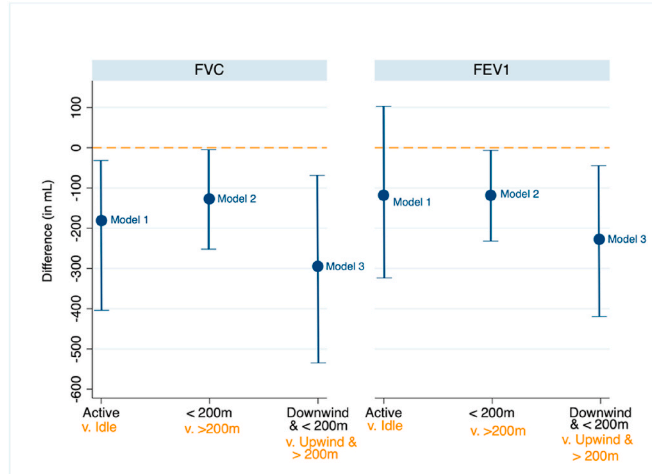

Fig. 5. The difference in average FEV1 and FVC (in mL) and 95% confidence interval for Model 1) participants living near the neighborhood with the active compared to the idle OGD sites; Model 2) participants living near (<200 m) the OGD sites compared to those living farther away (200–1000 m); and Model 3) participants living both near (<200 m) and downwind of an OGD site compared to those living farther (200–1000 m) and upwind. All models are adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, ever smoker, indoor exposure to environmental tobacco smoke, living near a freeway, season, spirometry technician and a random effect for residential household.

pulmonary function measurements that did not meet the ATS criteria (n = 146). Mean FEV1 and FVC for males were 2773 mL and 3654 mL, respectively, and the corresponding means for females were 2220 mL and 2875 mL.

In multivariable linear models, participants living near the active oil wells had, on average, a −188 mL FVC (95% CI: −405, −28) and −110 mL FEV1 (95% CI: −286, 66) difference compared to the idle site suggesting significantly lower FVC values among residents near the active site. After considering proximity, we observe that residents living near (<200 m) oil well sites had, on average, −128 mL lower FVC (95% CI: −282, −5) and −112 mL lower FEV1 (95% CI: −213, −10) compared to residents living more than 200 m from the wells (Fig. 4). When accounting for predominant wind direction and proximity, we observe that residents living downwind and less than 200 m from oil operations had, on average, −296 mL lower FVC (95% CI: −525, −67) and −236 mL lower FEV1 (95% CI: −425, −48) compared to residents living upwind and more than 200 m from the wells (Fig. 5, Table S6). Participants living downwind 200–1000 m from the site also had, on average, significantly lower FVC (β = −253 mL, 95% CI: −384, −123) and FEV1 (β = −207 mL, 95% CI:− 314, −100) than those upwind and farther away. Further, living upwind and close (<200 m) from the well sites was also associated with a significantly reduced FEV1 and FVC lung function measurements (Table S6). Examining distance from the well site using a continuous log transformed metric per 100 m, we find that a twofold increase in the distance away from the site improves FVC by 92 mL (β = 133 95% CI: 30.3, 236.2); FEV1 values are positively associated with an increase in the distance from the OGD site but not statistically significant (β = 72; 95% CI: −13.9, 157.1) (Table S7).

Among the multivariable linear regression models stratified by neighborhood, we found that living within 200 m of the active wells (Jefferson Park, Table S8) was associated with significantly lower mean FVC (β = −278 mL, 95% CI: −502, −55) and FEV1 (β = −240 mL, 95% CI: −439, −42) compared to more than 200 m away from the wells. A similar pattern was observed when examining downwind participants, where those living downwind and near (<200 m) the active oil wells had significantly lower mean FVC (β = −399 mL, 95% CI: −652, −147) and FEV1 (β = −414 mL, 95% CI: −636, −191) compared to living upwind and more than 200 m away from the wells after adjusting for covariates (Fig. 6). The pattern largely persistent among participants in the neighborhood with the idle wells (Fig. 6, Table S9). Among participants in the neighborhood near the idle wells, which is impacted by multiple freeways, we found that residents living downwind and close to the idle wells was associated with lower lung function (FVC: β = −297 mL, 95% CI: −577, −18; FEV1: β = −284 mL, 95% CI: −490, −76).

3.4. *Sensitivity analyses*

We assessed lung function using two additional proximity distances: 150 m and 400 m. The associations observed with lung function persists in similar direction (Table S10 and S11). The difference in FEV1 among participants living <150 m from the well site are similar (β = −187 mL, 95% CI: 332, −42) when compared to the results using the <200 m distance. We observe the difference attenuate for FEV1 at the 400 m distance (β = −21 mL, 95% CI: 119, 82). Across both analyses, a significantly lower lung function was observed among those living nearby and downwind of the oil well facilities.

In addition, significant effects with respect to distance and direction from oil operations and lung function were seen across subgroups (Table 3), including among participants without asthma. In an analysis restricted to participants without asthma, the difference in the effect of living near and downwind of an OGD well site was similar to that of the entire study population (−271 mL lower FEV1 and -326 mL lower FVC on average). We observed the effects of oil and gas wells on FEV1 lung function, on average, to be significant among adults, Latinx residents and participants over 60 if living downwind and <200 m from a well site.

4. Discussion

Although petroleum extraction is increasingly common in urbanized areas, few studies exist on the health consequences for nearby residents (Colborn et al., 2011; McKenzie et al., 2012; Werner et al., 2015). In this community-driven epidemiological study, we report both self-reported acute symptoms and pulmonary function measurements of a diverse cohort of residents living near both an active and idle drill site that draw

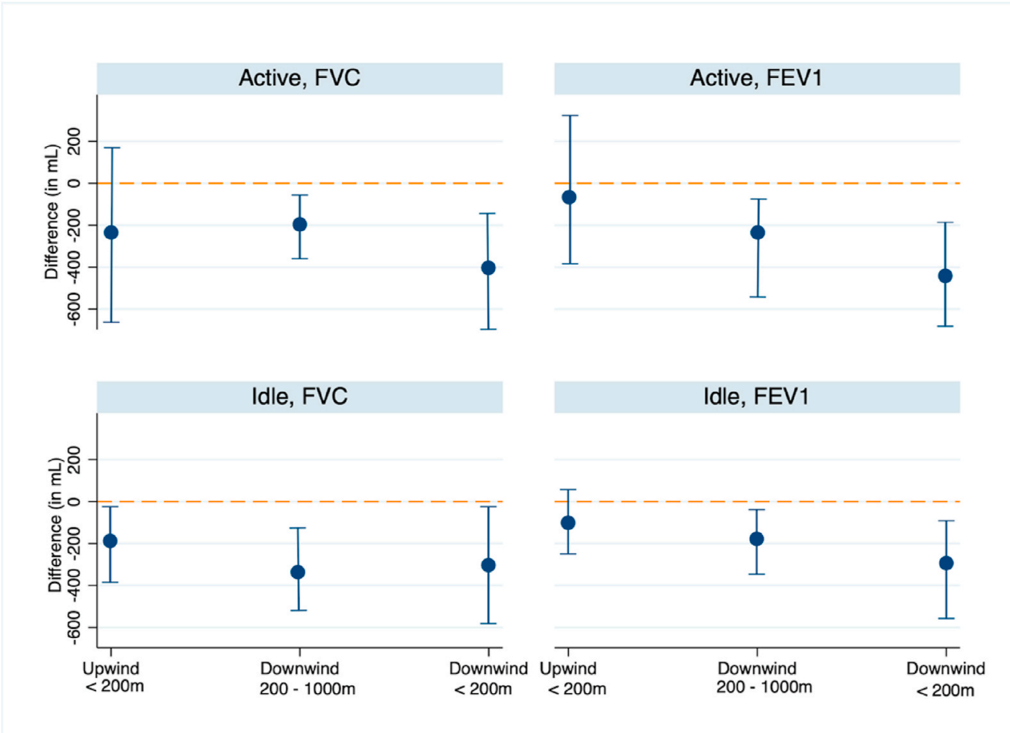

Fig. 6. Average difference in FEV1 (left) and FVC (right) in mL compared to participants living upwind and 200–1000 m from the OGD site stratified by neighborhood. Top row show results for participants living near the active OGD site (Jefferson Park neighborhood) and bottom row is among participants living near the idle OGD site (North University Park). The reference category is living upwind and more than 200 m from an OGD site. Models are adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, ever smoker, indoor exposure to environmental tobacco smoke, living near a freeway, season, spirometry technician and a random effect for residential household.

Table 3
Multivariate subgroup analyses of oil site distance and direction effects ond differences in FEV_1 and FVC (reported in mL).

	FVC[a]			FEV_1[a]		
Subgroups	Downwind <200 m	Downwind 200–1000 m	Upwind <200 m	Downwind <200 m	Downwind 200–1000 m	Upwind <200 m
Age						
9- <18	−234 (−495, 37)	**−292 (−495, −89)**	−8 (−396, 379)	−163 (−378, 51)	**−180 (−347, −13)**	−51 (−369, 266)
18-60	**−225 (−419, −32)**	−157 (−334, 20)	−251 (−566, 63)	**−290 (-570, -8)**	**−169 (−327, −12)**	**−219 −394, −45)**
>60	−303 (−669, 62)	−339 (−734, 55)	−275 (−806, 256)	**−303 (−266, −40)**	**−284 (−569, −0.5)**	−170 (−552, 212)
Sex						
Female	−158 (−335, 19)	**−158 (−335, −46)**	−162 (−449, 114)	**−194 −332, −55)**	**−161 (−283, −39)**	−170 (−390, 50)
Male	**−435 (−863, −7)**	−276 (−393, 3)	**−313 (−589, −37)**	−236 (−603, 131)	**−224 (−457, −32)**	−160 (−395, 75)
Race/Ethnicity						
Latinx	**−298 (−544, −54)**	**−271 (−412, −125)**	**−208 (−373, −42)**	**−264 (−459, −69)**	**−205 (−319, −91)**	**−176 (−308, −44)**
Black	−305 (−717, 108)	−476 (−1015, 61)	367 (−823,1557)	−330 (−681, 20)	−397 (−854, 61)	438 (−574,1450)
Asthma status						
Yes	−263 (−591, 72)	−69 (−378, 239)	−122 (−591, 346)	**−380 (−662, −99)**	−276 (−558, 5)	77 (−350, 504)
No	**−326 (−601, −52)**	**−271 (−420, −123)**	**−232 (−401, −63)**	**−271 (−498, −46)**	**−191 (−313, −69)**	**−171 (−331, −32)**

[a] Models were adjusted for age, height, age-height interaction, sex, race/ethnicity, weight, asthma diagnosis, recent flu/cold, smoking, exposure to indoor environmental tobacco smoke, site, living near a freeway, season and spirometry technician. A random effect was included for residential household. Stratifying variables were excluded from their respective model runs.

from Las Cienagas oil field in urban South Los Angeles. We identify that residents living near the active drill site report more acute symptoms, including wheezing, sore throat, chest tightness, dizziness and eye or nose irritation compared to their counterparts living near the idle wells. Furthermore, residents living closer to the OGD operations have, on average, lower lung function compared to the residents farther away. While this pattern is more pronounced near the actively producing site, we see persistent effects in both neighborhoods. The impacts on lung function were further observed among non-asthmatic participants, indicating that oil-related activity may have adverse effects on otherwise healthy people. This study provides evidences of potential adverse relationship between respiratory health and oil drilling activities in an urban context.

Our findings in this study in an urban context suggest that resident self-reported health symptoms are similar to those reported through surveys nearby natural gas and hydraulic fracturing sites in more rural settings. Results from three recent health surveys in the US observed symptoms of throat and nasal irritation, eye burning, sinus problems, headaches, skin problems, loss of smell, cough, nosebleeds and stress as more common among individual living closer to extraction sites compared to those living farther away (Steinzor et al., 2013; Rabinowitz et al., 2015; Ferrar et al., 2013). Survey-based studies documented higher rates of headaches, dizziness, and eyes, nose, throat and skin irritation among residents in oil producing regions compared to people living farther away in Ecuador (San Sebastián et al., 2001) and Nigeria (Kponee et al., 2015). Elevated incidence of pediatric asthma hospitalization has also been observed in nonurban areas with the highest levels of drilling activity, suggesting an association between extraction activity and respiratory health (Willis et al., 2018).

A single well typically operates for decades (often more than 60 years in CA) with neighbors facing impacts from construction, production, processing and transportation. Such operations produce a complex mixtures of pollutants including carcinogens, mutagens, reproductive, developmental toxins and endocrine disruptors (Garcia-Gonzales et al., 2019b; Johnston et al., 2019; Colborn et al., 2014; Macey et al., 2014). Hazardous compounds can be volatilized or aerosolized during extraction via active evaporating pits, flares, surface spills, processing, and transportation (Colborn et al., 2014). Research near Las Cienagas oil field identified both combusted (e.g. traffic) and volatilized hydrocarbons were affecting air quality throughout the community and revealed episodic peaks of methane and VOCs likely attributable to local oil and gas operations (Collier-Oxandale et al., 2020). Studies of acute inhalation exposures to petroleum hydrocarbons in occupational settings as well as among residents living near refineries, oil spills or gas stations have found increased risks of eye irritation and headaches (Kim et al., 2009; Tunsaringkarn et al., 2013) and asthma symptoms (White et al., 2009; Rovira et al., 2014; Wichmann et al., 2009). In additional reviews of non-occupational exposures to ambient levels of benzene and other petroleum hydrocarbons found adverse impacts to the respiratory health of children (Ferrero et al., 2014) and respiratory dysfunction and endocrine disruption among adults (Bolden et al., 2015).

Occupational exposure in the petroleum industry is associated with a higher prevalence of respiratory and nasal symptoms, and lung function impairment (Stoleski et al., 2011). Decrease in lung function has been documented among children living near petrochemical industries (Rusconi et al., 2011) and among children living near gas-flares and oil spills (Aweto et al., 2019) compared to those in a reference communities. In a community-based study across five states, multiple volatile organic compounds (VOCs) were measured at concentrations exceeding a chronic risk level threshold (Macey et al., 2014). Evidence suggests that exposure to VOCs may adversely affect pulmonary function (Elliott et al., 2006; Yoon et al., 2010; Cakmak et al., 2014). Stagnant air patterns have also been associated with health impacts in regions with unconventional natural gas development (Brown et al., 2015). While the mechanisms of VOC toxicity are still being understood, some research indicates oxidative stress having a role (Garçon et al., 2006; Coleman et al., 2003; Röder-Stolinski et al., 2008). Reduced lung function has been associated with subsequent increased risk of overall mortality including coronary artery disease and respiratory disease (Islam et al., 2007; Knuiman et al., 1999; Sin et al., 2005). A small study in rural Colorado found preliminary evidence of adverse cardiovascular impacts, including higher augmentation index and blood pressure, among adults near the most drilling activity in this cross-sectional community study (McKenzie et al., 2019).

Los Angeles houses a dense, diverse population living in close proximity to oil extraction (Elkind, 2012). Nonetheless, oil extraction in LA has long been obfuscated from public view even as extraction sites operate within residential zones, hidden by tall walls or landscaped hedges (Elkind, 2012). In recent years, as oil production increased, low-income neighborhoods have raised health concerns. The City of LA requires no buffers or setbacks between oil extraction and homes, and approximately 75% of active oil or gas wells are located within a 500 m distance from "sensitive land uses", such as a home, school, childcare facility, park, or senior residential facility. Recent research leveraging a community air monitoring network in South Los Angeles identified ambient methane concentrations were higher within 500 m of the OGD sites (Okorn et al., 2021). Such elevated concentrations were present at the idle well suggesting fugitive emissions occur even when oil production has ceased (Okorn et al., 2021). There are ~970 active oil or gas wells within 200 m of a residential property in LA County as of 2019 (Fig. 1b). Nonetheless, a prior door to door survey in the Las Cienagas neighborhoods found that 63% of residents would not know how to contact local regulatory authorities in case of a pollution or health concern (Shamasunder et al., 2018b). 45% of respondents in this same survey were unaware of the oil and gas operations in the neighborhood (Shamasunder et al., 2018b).

To our knowledge, this is the first study to examine the relationship between lung function in urban communities and oil well sites. To date the limited health research on oil and gas development in the US is based in rural and majority non-Hispanic White communities. Our study involves a predominantly low-income community of color living in an historically underserved and environmental justice community. Very limited data is available on the impacts of oil drilling in an urban environment (Garcia-Gonzales et al., 2019a; Shamasunder et al., 2018b). In this study we identify proximity to urban oil drilling sites as a factor associated with reduced lung function among nearby residents. To date, researchers have largely relied on assessing health impacts near oil and gas development, such as birth outcomes or hospitalization, using secondary data (Johnston and Cushing, 2020). While limited by a cross-sectional design, our study contributes novel pulmonary function measurements to the epidemiology on health effects of urban oil drilling. However, this analysis faces several limitations. We cannot rule out potential confounding by unmeasured covariates or differential participation rates based on concerns about neighborhood health or environmental quality. We cannot account for lifetime residential history, individual household characteristics nor occupational exposures. Self-reported household income data was not reliable (30% of the data was missing or reported as "I don't know"); therefore this information was not considered in the analysis. Multiple participants per household were allowed as long as they met the inclusion criteria and our modeling only accounted for such differences based on a random effect by residential address. As we only collected address information, and as multiple families often live in one household (or one common address), we could not distinguish unique families. Wind direction and proximity is used as a proxy for exposure to pollution associated with the well sites and may not represent true oil-related exposure. Future work will include assessing neighborhood scale air pollution to better understand potential spatiotemporal patterns of regional, freeway and oil drilling related exposures.

5. Conclusions

Together, our findings suggest that living near urban oil drilling sites is significantly associated with reduced lung function in South Los Angeles. This community-academic research improves understanding of impacts from living nearby drilling operations on the health and welfare of this community, which is critical to inform public health relevant strategies to address community concerns. We observe a similar pattern among those living near the active and idle sites suggesting potential chronic impacts of exposures. As a community of predominantly low-income residents of color, these impacts raise environmental justice concerns about the effects of urban oil drilling. Reducing emissions, increasing the distance between oil operations and residents, and investments in renewable energy and energy efficiency measures that reduce reliance on fossil fuels overall—could protect the lung health of residents near oil wells.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.111088.

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