Published in final edited form as:
Environ Res. 2021 November ; 202: 111704. doi:10.1016/j.envres.2021.111704.

Association of neighborhood deprivation with pulmonary function measures among participants in the Gulf Long-Term Follow-up Study

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Abstract

Introduction: Individual-level socioeconomic status (SES) has been shown to be an important determinant of lung function. Neighborhood level SES factors may increase psychological and physiologic stress and may also reflect other exposures that can adversely affect lung function, but few studies have considered neighborhood factors.

Objective: Our aim was to assess the association between neighborhood-level SES and lung function.

Methods: We cross-sectionally analyzed 6,168 spirometry test results from participants in the Gulf long-term Follow-up Study, a large cohort of adults enrolled following the largest maritime oil spill in US history. Outcomes of interest included the forced expiratory volume in one second (FEV_1; mL), the forced vital capacity (FVC; mL), and the FEV_1/FVC ratio (%). Neighborhood deprivation was measured by linking participant home addresses to an existing Area Deprivation Index (ADI) and categorized into quartiles. Individual-level SES measures were collected at enrollment using a structured questionnaire and included income, educational attainment, and financial strain. We used multilevel regression to estimate associations between ADI quartiles and each lung function measure.

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Author Contributions: DPS collected the data for this study. KGL and DPS conceptualized and designed the study. KGL conducted the statistical analysis and drafted the manuscript. KGL, with input from DPS interpreted the findings. KGL, DPS, EJW provided scientific review and intellectual content for the final draft of the manuscript.

Conflicts of Interest: None declared

Data: The data are not available on-line for replication, but requests for study data to be shared under individualized Data Sharing Agreements may be made through the GuLF Study management site (see instructions at https://gulfstudy.nih.gov/en/forresearchers.html).

Declaration of interests
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.

Results: Greater neighborhood deprivation was associated with lower FEV_1: β_{Q2vsQ1}: −30 mL (95% CI: −97, 36), β_{Q3vsQ1}: −70 mL (95% CI: −135, −4) and β_{Q4vsQ1}: −104 mL (95% CI: −171, −36). FVC showed similar patterns of associations with neighborhood deprivation. No associations with the FEV_1/FVC ratio were observed.

Conclusion: Neighborhood deprivation, a measure incorporating economic and other stressors, was associated with lower FEV_1 and FVC, with magnitudes of associations reaching clinically meaningful levels. The impact of this neighborhood SES measure persisted even after adjustment for individual-level SES factors.

INTRODUCTION

Low socioeconomic status (SES) is a well-established risk factor for chronic disease outcomes [1–5]. SES is a composite measure of social and economic standing and can be characterized at both the individual and neighborhood levels. Evidence suggests that both individual- and neighborhood- level SES are important determinants of health. At the individual-level, lower SES is associated with increased risk for poor respiratory health outcomes. For example in a 10-year longitudinal study, Hedlund et al. showed that low SES was associated with increased incidence of asthma, symptoms of asthma, and chronic productive cough [6]. Other researchers have found increased risk of chronic obstructive pulmonary disorder [7, 8] and respiratory infections [9]. Lung function measures, including the forced expiratory volume in 1 second (FEV_1), have also been seen to have an inverse association with individual-level SES measures [1, 8].

Some research has evaluated the link between neighborhood SES and respiratory health [10–14]. Living in a neighborhood with socioeconomic disadvantaged is associated with lack of access to food, safety, education, health services and poor health behaviors [15, 16]. Residents living in disadvantaged neighborhoods also face physical and social disorder that can lead to chronic stress [17]. Such neighborhoods may also be more likely to have proximity to sources of adverse environmental exposures. Little is known about the impact of neighborhood SES factors on objective measures of lung function.

FEV_1 is an important measure of general health and an independent predictor of mortality [18, 19]. Risk factors for reduced FEV_1 include poor health behaviors like smoking[20]. Reduced FEV_1 has also been linked with poor nutrition[21] and obesity[22]. Poor health behaviors including smoking and obesity, have also been linked to living in a socioeconomically disadvantaged neighborhood, suggesting that neighborhood may have an impact on respiratory health.

Neighborhood SES factors have been well-established as important risk factors for poor health, including adverse respiratory outcomes[23]. However, many of the studies have been conducted in children[24] and those among adults have typically focused on special populations such as adults with asthma [25, 26] and those hospitalized for specific conditions such as respiratory syncytial virus[27]. Further, these studies have relied on neighborhood measures at the census tract level or larger, which may introduce exposure misclassification of neighborhood traits that occur at the block-group level, a geospatial unit with greater spatial resolution. We sought to assess the link between neighborhood SES and respiratory health among a more diverse cohort. Thus, the objective of this study was to determine association between neighborhood SES characterized as deprivation at the census block-group level and lung function measures among a large group of adults ≥21 years of age. Secondary analyses also assessed individual-level SES measures including income, highest educational attainment, and financial strain in relation to lung function.

METHODS

Study Design

We used cross-sectional data from the Gulf Long-Term Follow-up Study (GuLF Study), a prospective cohort of adults (n=32,608) who participated in response and cleanup activities following the 2010 *Deepwater Horizon (DWH)* oil spill, and others who received safety training but were not hired. Enrolled participants completed telephone questionnaires between March 2011 and March 2013. Participants who were English- or Spanish- speaking residents of Alabama, Florida, Louisiana, Mississippi, or Texas (n=25,304) were eligible for a home exam. 11,193 eligible participants completed a home visit exam (May 2011–May 2013) and of these 10,040 completed spirometry testing. We analyzed spirometry data from participants with lung function measurements obtained from spirometry tests meeting American Thoracic Society/European Respiratory Society (ATS/ERS) quality criteria (see Pulmonary Function) [18]. This study was approved by the National Institute of Environmental Health Sciences Institutional Review Board (IRB).

Neighborhood deprivation

We characterized each participant's neighborhood socioeconomic status using an established index of neighborhood deprivation, the "Area Deprivation Index" (ADI) from the year 2013 previously described by Singh et al. [28] and Kind et al [29]. The 2013 ADI provides national percentile rankings of deprivation at the Census Block Group-level that range from 1–100, with lower values representing lower deprivation. The index also provides state-level decile rankings of deprivation that range from 1–10. The ADI uses SES indicators obtained from the American Community Survey (ACS) Five Year Estimates that cover theoretic domains of income, education, employment, and housing quality. We obtained 2013 ADI data from the University of Wisconsin School of Medicine and Public Health "Neighborhood Atlas" [30]. The 2013 ADI is based on five-year averages of data obtained between 2009 and 2013.

National- and state- level ADI percentiles were linked to Gulf Study participants' geo-coded enrollment address using the 12-digit Federal Information Processing Standard (FIPS) code. State ADI is provided in deciles (1–10) and was treated continuously in models due to the limited range of scores and based on the prior work by the area deprivation index authors[29]. For analyses of neighborhood deprivation relative to neighborhoods nationwide, we categorized deprivation into quartiles based on the nationwide index value itself (as opposed to the distribution within our cohort) as (Quartile 1 (Q1): <25^{th} percentile; Quartile 2 (Q2: 25^{th}-<50^{th} percentile; Quartile 3 (Q3): 50^{th}-<75^{th} percentile; Quartile 4 (Q4): >75^{th} percentile).

Individual-level socioeconomic status and financial strain

Information on current individual-level SES measures and financial strain was collected in a structured enrollment telephone interview. Individual-level SES was defined by annual household income (≤$20,000, $20,001–$50,000, >$50,000) and educational attainment (less than high school/equivalent, high school diploma/GED, some college/2-year degree, 4-year college graduate or more). To identify financial strain, we used questionnaire items on stress related to affording food and housing. Specifically, participants were asked: "*how often would you say you were worried or stressed about having enough money to pay your rent or mortgage*?" and "*how often would you say you were worried or stressed about having enough money to buy food*?*"*. Participants answering "always" or "usually" were considered as exposed to financial strain, while participants answering "sometimes", "rarely", or "never" were considered as unexposed.

Pulmonary function

Home visit participants performed spirometry using an ultrasonic spirometer (EasyOne™, ndd Technologies, Andover, MA) administered by trained examiners. 10,019 participants (workers and non-workers) had tests overread by a spirometry expert for quality control and 7,487 met the ATS/ERS within- and between- maneuver acceptability criteria defined as 3 acceptable maneuvers with the difference between the largest and next largest maneuver ≤150 mL or representative quality as deemed by a spirometry expert [18]. After excluding N=299 without an area deprivation index (or FIPS code from home visit), and those without complete covariate information (N=1,020; 418 of which were missing income) primary analyses included 6,168 participants. All home visit participants provided written informed consent. Primary outcomes analyzed included the forced expiratory volume in one second (FEV_1, mL), forced vital capacity (FVC, mL) and the ratio (FEV_1/FVC%).

Covariates

Information on demographic, socioeconomic, lifestyle, and health measures were collected at enrollment using a structured telephone interview. Anthropometric measures were obtained by examiners at the home visit including height and weight. Potential confounders were selected using a directed acyclic graph (DAG) and included age at home visit (years), gender (male, female), race (White, Black, Other), ethnicity (Hispanic, non-Hispanic), and prevalent respiratory diseases (asthma, emphysema, and bronchitis)(Supplemental Figure 1). Height at home visit (cm) and height squared (cm^2) were included in models based their strong reported predictive and quadratic relationship to lung function [31]. Smoking is an important predictor of lung function. Both smoking (current heavy (≥20 cigarettes/day), current light (<20 cigarettes/day), former, never), and secondhand smoking (exposed, unexposed) were found to be associated with lung function measures in our study so we included smoking exposure in our analytic models.

Oil spill exposures

Oil spill response and cleanup (OSRC) work exposures related to the *DWH* disaster cleanup effort were analyzed as potential effect measure modifiers. Exposures were characterized using questionnaire data on specific jobs and activities provided by participants and exposure monitoring data from the time of the spill analyzed by GuLF Study industrial hygienists [32] and linked to participants via job exposure matrices. Exposures of interest included: 1) ever worked on response or cleanup efforts related to the *DWH* disaster (yes, no); 2) estimated ordinal levels of total hydrocarbon exposure (THC) (Non-worker, Level 1: ≤0.29ppm; Level 2: 0.30–0.90ppm; Level 3: 1.0–2.99ppm; Level 4: ≥3.00ppm); and 3) industrial hygienist assessment of potential exposure to burning oil/gas (non-worker, none, low/medium, high).

Statistical analysis

We compared selected population characteristics between those enrolled (N=32,608) compared to those in the analytic sample to determine representativeness of the study sample to the target population. We then generated descriptive statistics to assess characteristic differences between those in the highest versus lowest national ADI quartile. To estimate associations between area deprivation and lung function measures, we used multilevel modelling, which accounts for hierarchies in the data. Specifically, we used mixed models with a random intercept for each neighborhood (defined by the FIPS code). Mixed models were fitted using PROC MIXED in SAS v 9.4 (SAS, Cary NC). Lung function measures FEV_1 (mL), FVC (mL), and FEV_1/FVC (%) were modeled as dependent variables and treated continuously.

We modeled associations between lung function measures and both the state area deprivation index and national area deprivation index. For state-level ADI, regression coefficients represent a difference in lung function measures associated with a per-quartile increase and assume a linear relationship. For the national-level ADI associations regression coefficients represent a difference in lung function measures associated with specific quartile levels compared to the referent. For each index, we estimated crude associations (Crude model) and associations adjusted for a minimal adjustment set determined by a directed acyclic graph (DAG)[33] including age, gender, race, ethnicity, prevalent respiratory disease, height (cm), $height^2$ (cm^2), income, and education (Model 1). We also further adjusted for smoking and secondhand smoke exposure (Model 2) since smoking is such a strong predictor of lung function. Finally, we assessed models that also included primary inhalation hazards related to oil spill response and cleanup work (i.e. total hydrocarbons and potential exposure to burning oil/gas related) (Model 3) due to the unique exposures experienced by GuLF Study participants who worked on oil spill cleanup. In sensitivity analyses, we restricted to participants with no exposure to high levels of burning oil/gas, which was previously identified to be independently associated with lower lung function measures [34].

In addition to assessing lung function and area deprivation, we also evaluated relationships between lung function and individual-level SES measures of income, highest educational attainment and of self-reported financial strain (worry about paying rent and food). For these associations we used multivariable linear regression to mean differences (Beta) and 95% confidence intervals (95% CI) between individual-level SES and/or strain measure in relation to lung function measures. All statistical analyses were conducted using Statistical Analysis Software (SAS 9.4, Cary, NC).

RESULTS

There were some population characteristic differences between those enrolled and those in the study sample. Those in the analytic sample vs enrollment were more likely to be Black (32% vs 23%); lower income of $<20,000 per year (37% vs 26%); more worried about paying rent (48% vs 36%); and less likely to be a 4-year college graduate or more (16% vs 24%). On average study participants resided in neighborhoods with higher deprivation scores relative to the US, with mean and median percentiles of ADI in the study sample of 63 and 66, respectively (higher score=higher deprivation) (Table 1). Participants whose neighborhood was classified in the highest (most deprived) versus lowest US ADI quartile were younger on average (42 years vs 46 years), more likely to be Black (54% vs 6%), to be current smokers (39% vs. 19%), as well as be exposed to secondhand smoke (32% vs. 17%) (Table 2). Individuals in the highest versus lowest ADI quartile were also more likely to earn report household income ≤$20,000 (50% vs, 14%), and have lower educational attainment defined as <high school (24% vs. 5%). Those in the highest versus lowest ADI quartile were also slightly more likely to have participated in cleanup efforts following the *DWH* disaster (81% vs. 77%) but as likely to have had high potential exposure to burning oil/flaring natural gas (1 % vs. 0.6%).

Decile-unit increases in state-level ADI were modestly inversely associated with FEV_1 and FVC, but not the FEV_1/FVC ratio (Table 3). For example, in fully adjusted models FEV_1 was observed to have a modest decrease per decile increase in state ADI (β: −10 mL (95% CI: −15, −4) (Model 3, Table 3). Similar results were seen for FVC but no association was observed for the FEV_1/FVC ratio. Using national level cut-points of ADI higher ADI was associated with lower FEV_1 values in fully adjusted models: β_{Q3vsQ1}: −70 mL (95% CI: −135, −4) and (β_{Q4vsQ1}: −104 mL (95% CI: −171, −36) with a p-test for trend <0.001 (Model 3, Table 4). Results were similar for FVC: β_{Q3vsQ1}: −72 mL (95% CI: −150, 6) and β_{Q4vsQ1}: −111 mL (95% CI: −191, −30) with a p-test for trend <0.001). However, using national cut-points ADI was not associated with the FEV_1/FVC ratio (Model 3, Table 4). These results were not substantively different from models not adjusted for smoking and secondhand smoke (Model 1, Table 4) and models adjusting for smoking information but not oil spill cleanup (Model 2, Table 4).

Both lower income and education were independently associated with lung function even after adjustment for ADI rankings (Table 5). For the FEV_1, compared to an annual household income of >$50,000 per year, those with an annual household income ≤$20,000 had an average lower FEV_1 of −79 mL (95% CI: −119, −39) while those with income $20,001–$50,000 had an average lower FEV_1 of −80 mL (95% CI: −117, −43). For the FVC, compared to an annual household income of >$50,000 per year, those with an annual household income ≤$20,000 had an average lower FVC of −45 mL, (95% CI: −92, −2) while those with income $20,001–$50,000 had an average lower FVC of −47 mL (95% CI: −90, −3). The FEV_1/FVC ratio was lower for both those making ≤$20,000 (β: −1.25, 95% CI: −1.72, −0.77) and those making $20,001–$50,000 (β: −1.12, 95% CI: −1.55, −0.68).

All levels of education less than college compared to those with 4-year college degree were associated with reduced FEV_1 and FVC, but not the ratio. Individual-level financial strain evaluated as self-report of either having trouble paying rent or buying food was not associated with reduced lung function (Table 5). In secondary analyses restricted to participants with no exposure to high levels of burning oil/gas results were unchanged *(data not shown)*.

DISCUSSION

This study examined neighborhood and individual level SES characteristics in relation to lung function among a large population of adults living in US Gulf states. We found that participants living in a more deprived neighborhood, measured by the ADI, had lower FEV_1 and FVC but not lower FEV_1/FVC measures. FEV_1 and FVC were observed to be associated with neighborhood deprivation in a dose-dependent manner. Lung function measures presented are those that were directly measured, not calculated as percent predicted values. They do not represent a comparison to a clinically meaningful difference necessarily. However, it is well-established that a clinical presentation of a low FEV_1, low FVC, but normal or supranormal FEV_1/FVC ratio suggests a restrictive pulmonary pattern pathology[35]. However, as suggested in a recent review of lung function loss in healthy aging, the annual average FEV_1 loss attributable to normal aging was 30.5 mL/year for women, and 43.3 mL/year for men [36]. Observed FEV_1 loss in our study exceeds these estimates, suggesting that observed differences are clinically relevant.

Relationships appeared to be stable, regardless of included covariates (i.e. including smoking variables and oil spill cleanup exposures). Also, this association was present regardless of whether deprivation was classified relative to neighborhoods across the US or at the state level, though state-level analyses were limited by the range of scores (1–10). The dose-dependent relationship observed for neighborhood deprivation and reduced lung function is supported by prior work showing longitudinal associations between neighborhood deprivation and reduced FEV_1 [13] among adults and among young adults[13]. Dose-dependent associations have also been identified between area deprivation scores and COPD [14]. Other aspects of neighborhoods, including community violence has been shown to increase in emergency department visits related to asthma among adults [37] showing one of multiple potential pathways that may play a role in this link.

Mechanisms explaining how neighborhoods may negatively impact respiratory health are likely multifaceted [38]. Research suggests psychosocial stress may play a primary role [1, 39]. Psychological stress leads to hyperresponsiveness of the hypothalamic pituitary axis, increasing secretion of inflammatory cytokines and the release of cortisol that may trigger hormones (e.g. increased levels of corticotrophin). This can potentiate the immune system, or autonomic control resulting in bronchoconstriction [40]. Chronic stress can modulate the hypothalamic-pituitary-adrenal axis, modify immune responses, and lead to bronchoconstriction that can reduce airway flow and lung function [41]. Increased exposure to chemical hazards may also explain the link. Living in a disadvantaged neighborhood is well-associated with poor indoor[42] and outdoor air quality[43] from increased traffic and poor housing quality [1, 38]. For example, lung irritants stemming from poor housing quality are risk factors for childhood asthma[44]. Regardless of the exact mechanisms, findings suggest neighborhood deprivation independently captures individual susceptibilities to reduced lung function and more studies are needed to assess exact reasons why.

Similar to other studies, we found associations between individual-level SES measures of income and education inversely associated with FEV_1. We did not however observe independent associations between lung function and financial strain (i.e. worry about paying rent and affording food) in our study population despite observing associations between lung function and traditional measures of SES at the individual-level (i.e. education and income). Little information exists on health impacts of financial strain with which to compare our results. Financial strain occurs when an individual's expenses exceed their income, which can threaten their identity and lead to chronic stress and can occur across income strata. Financial and social hardship have been shown to play a role in asthma racial disparities[45]. While it is possible that there no association between financial strain and lung function, it is also possible that our findings are subject to bias from self-reported financial strain, as compared to a more objective measure such the ratio of debts-to-assets. It is also unclear whether our measure of financial strain represents a chronic or transient exposure given that information was collected following the *DWH* disaster which led to employment loss for individuals who were dependent on fishing or other jobs (e.g. restaurants) affected by the spill. Individuals experiencing chronic versus transient strain may have more opportunity to experience adverse physical health effects related to this exposure.

It is possible that exposures related to oil spill response and cleanup work could have directly or indirectly confounded the relationship between neighborhood deprivation and lung function. For example, Gulf coast residents exposed to the oil spill disaster suffered negative impacts on their economic welfare including income loss[46]. Furthermore, the oil spill may have led to a change in residential address in some cases which could have led to ADI exposure misclassification. On the other hand, models adjusting for exposures to oil spill chemicals did not show evidence of meaningful confounding of the association between neighborhood deprivation and lung function. Similarly, results were unchanged in analyses restricted to workers unexposed to burning oil/gas, suggesting that the observed association between neighborhood SES status and lung function is likely not attributable to factors related to the oil spill.

Our study has several notable limitations. Lung function measures were obtained at a single time point, limiting a causal interpretation of findings. There is also the possibility of measurement error in neighborhood deprivation because of variability within block-groups, although the use of the area deprivation index was more spatially resolved than other measures defined at the census-tract level. We also lacked information on time spent living at the reported residence, limiting our ability to assess exposure duration. Missing information on previous residence and address changes also raises a concern about potential misclassification of neighborhood disadvantage over the relevant time period. The ADI is based on a long-term index that represents five-year averages of data obtained between 2009–2013. Thus, ADI values assigned to participants who moved within that timespan will have greater uncertainty. Participants who change address may be more susceptible to reduced lung function, but it is also possible that they move between neighborhoods with similar characteristics. Unfortunately, we have no way of testing to what degree and how these factors might have impacted observed results. Finally, comparisons of selected population characteristics between those enrolled and those in our analytic sample showed some differences in demographic and lifestyle characteristics.

Area deprivation can be considered as an indicator of both the social and physical environment, but our analysis does not identify the specific exposure pathways underlying the relationship between neighborhood deprivation and reduced lung function. Specifically, our study does not provide any information on the degree to which specific factors correlated with deprivation (e.g. air pollution, build environmental factors, lack of access to health care, increased exposure to violence etc.) may play a role in reduced lung function. Future studies are needed to further interrogate causal factors involved in this relationship. Classification of neighborhood deprivation in 2013 may slightly differ from the time of enrollment (which spanned 2011–2013) though the correlation in our sample between scores using the 2013 measure and the 2000 and 2015 measures were high (>80%). Finally, GuLF Study participants are more socioeconomically disadvantaged than the general population limiting the generalizability of results. In addition, despite the cohort's diversity, the GuLF Study was designed to assess health effects of oil spill response and cleanup workers further limiting generalizability. Our results are also not generalizable to international populations. However, neighborhood deprivation has been linked to adverse health (and related outcomes) in several other countries[47, 48] suggesting that studies utilizing high spatially resolved deprivation measures may be informative in communities worldwide.

Study strengths include the assessment of the independent associations of neighborhood- and individual-level SES with lung function among a vulnerable population living in the US Gulf States. We used an established index that is widely accessible to researchers[49] to measure neighborhood SES[23]. Use of an established index based on U.S. percentiles allows for potential comparability of findings across studies interested exploring similar hypotheses. Finally, we used spirometry testing to assess respiratory health. Use of this objective measure reduces measurement error and provides insight that is clinically relevant.

Study findings add to the growing body of evidence linking neighborhood deprivation to adverse health impacts on lung health. Notably, we found neighborhood deprivation to be adversely associated with lung function measures in a dose-dependent manner suggesting the importance of neighborhood context and clinical lung health endpoints. Our results suggest that neighborhood factors may be an important consideration for clinicians when evaluating risk for poor lung health among patients. Further, health policies may need to address neighborhood SES factors when planning intervention strategies for populations suffering from poorer respiratory health. Neighborhood deprivation should be considered as an independent risk factor in studies assessing the relationship between SES and respiratory health, especially among socioeconomically disadvantaged populations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

We thank Dr. Symielle Gaston and Dr. Thanh Hoang for reviewing an earlier draft of this manuscript.

Sources of Financial Support:

This research was funded by the Intramural Research Program of the NIH, the National Institute of Environmental Health Sciences (Z01 ES 102945)

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Table 1.

Distribution of National 2013 Area Deprivation Index percentiles across the US and in the GuLF Study analytic sample (N=6,168)

	Mean	Median	Min	Max	P5	P25	P50	P75	P95
National ADI percentiles	50	50	1	100	5	25	50	75	95
GuLF Study percentiles	63	66	2	100	25	47	66	82	95

ADI=Area deprivation index; GuLF Study=Gulf Long-Term Follow-up Study

Table 2.

Population characteristics in lowest versus highest quartiles of area deprivation index (N=6,168) (GuLF Study Participants, 2011–2013)

	High Deprivation (4th quartile)[a] (N=2,118)	Low Deprivation (1st Quartile)[a] (N=327)
	Mean(SD)	**Mean(SD)**
Age, years	42(12)	46(14)
Height, cm	69(3)	68(4)
FEV_1, L	3.06(0.75)	3.36(0.77)
FVC, mL	3.90(0.92)	4.28(0.95)
FEV_1/FVC%	78.62(6.76)	78.69(6.16)
	N(%)	**N(%)**
Gender		
Male	1639(77)	252(77)
Female	479(23)	75(23)
Race		
White	755(36)	283(87)
Black	1157 (54)	19(6)
Other	206(10)	25(8)
Hispanic Ethnicity		
No	1979(93)	308(94)
Yes	139(7)	19(6)
Smoking		
Current Heavy	237(11)	22(7)
Current Light	595 (28)	40(12)
Former	376(18)	105 (32)
Never	910(43)	160(49)
Secondhand smoke		
No	1443(68)	272(83)
Yes	675(32)	55(17)
Income		
<$20,000	1066(50)	45(14)
$20,001–$50,000	698(33)	81(25)
>$50,000	354(17)	201(61)
Educational Attainment		
Less than high school/equivalent	504(24)	16(5)
High school diploma/GED	799(38)	57(17)
Some college/2-year degree	649(31)	107(33)
4-year college graduate or more	166(8)	147(45)
Worked on Deepwater Horizon disaster cleanup		
No	399(19)	75(23)
Yes	1719(81)	252(77)
Maximum total hydrocarbon exposure level		

	High Deprivation (4th quartile)[a] (N=2,118)	Low Deprivation (1st Quartile)[a] (N=327)
Non-workers	399(19)	75(23)
Level 1: ≤0.29ppm	235(11)	65(20)
Level 2: 0.3–9.9ppm	665 (31)	74(23)
Level 3: 1.0–2.99ppm	531(25)	79(24)
Level 4: ≥3.0ppm	288(14)	34(10)
Potential exposure to burning oil/natural gas		
Non-workers	399(19)	75(23)
Unexposed	1534 (72)	228(70)
Low/Medium	157(7)	22(7)
High	28(1)	2(0.60)

[a]Quartiles derived from the US percentiles: Q_1(N=327); Q_2(N=1,513); Q_3(N=2,210); Q_4(N=2,118)

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Table 3.

State area deprivation index and lung function (n=6,168) (GuLF Study participants, 2011–2013)

	Crude	Model 1	Model 2	Model 3
	β(95% CI)	**β(95% CI)**	**β(95% CI)**	**β(95% CI)**
FEV_1, mL	−30(−37,−23)	−11(−16,−5)	−10(−15,−4)	−10(−15,−4)
FVC, mL	−42(−51,−33)	−13(−19,−7)	−13(−19,−6)	−13(−19,−6)
FEV_1/FVC%	0.09(0.02,0.15)	−0.00(−0.07,0.07)	0.01(−0.06,0.08)	0.01(−0.06,0.07)

Higher area deprivation index score denotes greater deprivation

Beta coefficients represent difference per decile increase in state-level area deprivation index score

Model 1: Age, gender, race, ethnicity, height, height^2, income, education

Model 2: Model 1+ smoking and secondhand smoking

Model 3: Model 1+ oil spill exposures (total hydrocarbons and potential exposure to burning oil/gas)

Table 4.

National area deprivation index and lung function (n=6,168) (GuLF Study participants, 2011–2013)

	Crude β(95% CI)	Model 1 β(95% CI)	Model 2 β(95% CI)	Model 3 β(95% CI)
FEV_1, mL				
Quartile 2 vs 1	−128(−233,−32)	−34(−100,33)	−27(−93, 39)	−30(−97,36)
Quartile 3 vs 1	−196(−289,−103)	−77(−143,−11)	−66(−132,−1)	−70(−135,−4)
Quartile 4 vs 1	−290(−384,−197)	−110(−178,−42)	−102(−170,−34)	−104(−171,−36)
P-test for trend	<.0001	<.0001	<.0001	<.0001
FVC, mL				
Quartile 2 vs 1	−128(−244,−12)	−19(−97,60)	−17(−96,61)	−21(−100,58)
Quartile 3 vs 1	−220 (−333,−107)	−72(−150, 6)	−68(−146,10)	−72(−150,6)
Quartile 4 vs 1	−358(−472,−244)	−110(−191,−30)	−108(−188,-28)	−111(−191,−30)
P-test for trend	<.0001	<.0001	<.0001	<.0001
FEV_1/FVC%				
Quartile 2 vs 1	−0.71(−1.55,0.13)	−0.52(−1.32,0.28)	−0.38(−1.17,0.41)	−0.41(−1.20,0.38)
Quartile 3 vs 1	−0.62(−1.45,0.20)	−0.55(−1.34,0.24)	−0.37(−1.15,0.41)	−0.39(−1.17,0.39)
Quartile 4 vs 1	−0.10(−0.92,0.73)	−0.59(−1.40,0.23)	−0.43(−1.23,0.37)	−0.44(−1.24,0.37)
P-test for trend	0.10	0.35	0.49	0.51

Higher area deprivation index score denotes greater deprivation

Model 1: Age, gender, race, ethnicity, prevalent respiratory disease, height, $height^2$, income, education

Model 2: Model 1+ smoking and secondhand smoking

Model 3: Model 2+ oil spill exposures (total hydrocarbons and potential exposure to burning oil/gas)

Table 5.

Individual-level socioeconomic status, financial strain, and lung function (n=6,168) (GuLF Study participants 2011–2013)[a]

	N(%)	FEV_1, mL Mean Differences (95% CI)	FVC, mL Mean Differences (95% CI)	FEV_1/FVC% Mean Differences (95% CI)
Income				
≤$20,000	2312(37)	−79(−119,−39)	−45(−92,−2)	−1.25(−1.72,−0.77)
$20,001–$50,000	2070(34)	−80(−117,−43)	−47(−90,−3)	−1.12(−1.55,−0.68)
>$50,000	1786(29)	Ref	Ref	Ref
P-test for trend		0.0002	0.08	<.0001
Education				
Less than HS/Equivalent	1145(19)	−78(−131,−27)	−105(−170,−44)	0.04(−0.58,0.66)
High School Diploma/GED	2081(34)	−85(−130,−39)	−106(−160,−52)	−0.05(−0.59,0.49)
Some College/2 Year Degree	1943(32)	−56(−100,−12)	−68(−120,−16)	−0.01(−0.54,0.51)
4 Year College Graduate or More	999(16)	Ref	Ref	Ref
P-test for trend		0.0021	0.0004	0.93
Worried about paying rent				
Yes	2951(48)	−3(−32,26)	4(-30,39)	−0.13 (−0.47,0.22)
No	3217(52)	Ref	Ref	Ref
Worried about buying food				
Yes	1777(29)	−10(−41,22)	−12(−49, 25)	−0.02(−0.39,0.36)
No	4391(71)	Ref	Ref	Ref

Models adjusted for: age, sex, race, ethnicity, prevalent respiratory disease, height, $height^2$, smoking, secondhand smoke, area deprivation index; each model is additionally mutually adjusted for other individual SES and financial strain variables assessed

HS= High school; GED= General education development degree