Association between *Deepwater Horizon* oil spill response and cleanup work experiences and lung function

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Abstract

Introduction: Oil spill response and cleanup (OSRC) workers had potentially stressful experiences during mitigation efforts following the 2010 *Deepwater Horizon* disaster. Smelling chemicals; skin or clothing contact with oil; heat stress; handling oily plants/wildlife or dead animal recovery; and/or being out of regular work may have posed a risk to worker respiratory health through psychological stress mechanisms.

Objective: To evaluate the association between six potentially stressful oil spill experiences and lung function among OSRC workers 1-3 years following the *Deepwater Horizon* disaster, while controlling for primary oil spill inhalation hazards and other potential confounders.

Methods: Of 6,811 GuLF STUDY participants who performed OSRC work and completed a quality spirometry test, 4,806 provided information on all exposures and confounders. We carried out complete case analysis and used multiple imputation to assess risk among the larger sample. Potentially stressful work experiences were identified from an earlier study of these workers. The

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lung function parameters of interest include the forced expiratory volume in 1 second (FEV_1, mL), the forced vital capacity (FVC, mL) and the ratio (FEV_1/FVC, %).

Results: On average, participants in the analytic sample completed spirometry tests 1.7 years after the spill. Among workers with at least 2 acceptable FEV_1 and FVC curves, workers with jobs that involved oily plants/wildlife or dead animal recovery had lower values of FEV_1 (Mean difference: −53 mL, 95% CI: −84, −22), FVC (Mean difference: −45 mL, 95% CI: −81, −9) and FEV_1/FVC (Mean difference: −0.44%, 95% CI: −0.80, −0.07) compared to unexposed workers in analyses using multiple imputation.

Conclusions: Workers involved in handling oily plants/wildlife or dead animal recovery had lower lung function than unexposed workers after accounting for other OSRC inhalation hazards.

Keywords

Lung function; spirometry; nonchemical stressors; oil spill; *Deepwater Horizon*

Introduction

Tens of thousands of oil spill response and cleanup (OSRC) workers performed activities offshore and on land in the US Gulf of Mexico and adjacent states to help mitigate the environmental impacts of the 2010 *Deepwater Horizon (DWH)* disaster [1]. During the oil spill mitigation effort, OSRC workers were exposed to mental health stressors [2, 3] and chemical and physical hazards [2, 4]. OSRC workers smelled oil chemicals, had skin or clothing contact with oil/tar/oily water, handled oily plants/wildlife or dead animal recovery, worked under physically demanding conditions such as high heat [2], and faced disruption of regular work due to the closure of coastal fisheries during and after the disaster [3, 5]. Specific OSRC work experiences may have induced psychological stress or related adverse mental health sequelae [3] posing a risk to workers' respiratory health.

Psychological stress can induce neuroendocrine-induced immunological changes that can lead to inflammation and bronchoconstriction [6-8] and has been linked to adverse respiratory outcomes including reduced lung function. In a general population setting, exposure to trauma and post-traumatic stress disorder has been associated with reduced lung function, asthma, and COPD [9]. In disaster settings, post-traumatic stress disorder was associated with asthma symptoms among first responders of the World Trade Center terrorist attack and incident asthma among older adults exposed to war-related stressors [10-12].

Adverse mental health outcomes have been observed in communities affected by prior oil spills including *Exxon Valdez* [13, 14], *Sea Empress* [15, 16], *Hebei Spirit* [17], and *Prestige* [18]. Adverse mental health outcomes have also been observed among affected communities following the *DWH* disaster, and is associated with being a coastal fisher [19] as well as with disruption of participants' lives, work, family and social engagements [20]. Additionally, increased prevalence of depression and post-traumatic stress symptoms were associated with specific experiences among *DWH* OSRC workers. These experiences included smelling chemicals; stopping work due to heat; and working as a commercial fisher before the spill [3].

Prior studies also have identified adverse respiratory health in relation to oil spill work exposures. Transient lung function decrements were also identified in oil spill cleanup workers following the *Tasman Spirit* but were not identified at 1-year follow up [21]. After the *Prestige* oil spill, although lung function was not found to be associated with cleanup work, markers of lung inflammation were elevated in exposed versus unexposed among non-smokers 2 years after the spill [22]. We previously examined associations between primary inhalation hazards and lung function 1-3 years following the *DWH* disaster [23, 24]. Among workers, lung function was inversely associated with high potential exposure to burning oil/gas and decontamination work [23], but was not associated with ordinal estimates of total hydrocarbons (THC) levels, used as a general marker of oil spill chemical exposures [24]. Although prior studies suggest acute adverse respiratory health outcomes, none have explored risks unique to *DWH* OSRC work experiences that may have been stressful. The objective of this study is to evaluate the relationship between six previously identified unique oil spill experiences [3] and lung function among OSRC workers 1-3 years following the 2010 *DWH* disaster, while accounting for other indicators of chemical exposures from the spill.

Methods

Study design and population

The Gulf Long-Term Follow-up Study (GuLF STUDY), is a large prospective cohort study of the health effects of the *DWH* disaster. The study includes 32,608 adults who participated in the oil spill response and cleanup (workers) or received safety training but did not work (non-workers) [25, 26]. All participants were first administered an enrollment questionnaire by telephone (March 2011-May 2013). During enrollment, participants who worked at least 1 day on any OSRC activity (workers) provided work histories detailing OSRC jobs and tasks. A subgroup of participants who lived in a US Gulf state (Alabama, Louisiana, Mississippi, Florida, or Texas) and spoke English or Spanish were eligible for a home visit (N=25,304). During the home visit (May 2011-May 2013) examiners coached participants (N=11,193) to perform spirometry and collected anthropometric measurements including height and weight. Participants also completed an additional questionnaire that collected more detail on OSRC and other work history information, demographics, lifestyle, and health. Of the 10,040 home visit participants who completed a spirometry test, 10,019 received expert over-reading scores. Our primary analysis included those who met spirometry quality criteria (see Lung function) and had complete information on exposures and covariates (N=4,806) (Figure 1).

Ethical approval

The Institutional Review Board of the National Institute of Environmental Health Sciences approved the study procedures. Home visit participants provided written informed consent.

Lung function

Our analysis focused on OSRC workers as the exposures of interest were only relevant to those who worked at least one day in response and cleanup efforts following the disaster. Ultrasonic spirometers were used to collect the lung function measurements (Easy on-PC;

ndd Medical Technologies, Andover, MA). Participants were seated with a nose-clip and performed spirometry until they achieved either three acceptable or a maximum of eight maneuvers. To increase data quality control, an expert reviewed machine-read spirometry quality scores. The expert was able to recover valid spirometry tests that were excluded by a stricter computer interpretation of quality criteria. We defined meeting quality spirometry two ways: Those with spirometry quality ≥ D defined as two FEV_1 and two FVC curves that met within-maneuver acceptability criteria and those with spirometry quality ≥ C defined as three acceptable curves with ≤ 150 mL difference between the largest and second largest curve for FEV_1 or FVC or those deemed to have met comparable spirometry quality based on over-reading expert review [27]. We used the former definition to maximize sample size and to address potential selection bias and the latter stricter definition to determine whether using the less-strict definition of quality affected point estimates and 95% confidence intervals. Measures of lung function included the forced expiratory volume in 1 second (FEV_1; mL), the forced vital capacity (FVC; mL), and the ratio (FEV_1/FVC%). For each participant, we analyzed the best FEV_1 curve and best FVC curve among available acceptable curves. Following American Thoracic Society/European Respiratory Society standards, we calculated the FEV_1/FVC ratio from these parameters.

Oil spill response and cleanup experiences

We assessed six oil spill experiences that were previously identified as potentially stressful and examined in relation to mental health outcomes (Supplemental Figure 1) [3]. Oil spill experiences were derived from the enrollment and home visit questionnaires. Participants were defined as exposed if they responded positively to the related question on ever participated in the particular *DWH* spill-related experience, and unexposed if they responded negatively to the same question. These experiences included jobs that involved smelling chemicals; skin or clothing contact with oil/tar/oily water; body or clothing ever became wet with chemicals; ever had to stop working because of heat; and worked any job involving oily plants/wildlife or dead animal recovery; and potentially being out of regular work. Participants were classified separately for each oil spill experience, such that participants could be classified as exposed for one experience and unexposed for another.

Covariates

Potential confounders were selected based on a minimally sufficient adjustment set from a directed acyclic graph that was previously described [23]. Considerations of inclusion of basic adjustments for lung function (gender, race, ethnicity, age, height, and height squared) were based on prior literature describing spirometric reference values for US adults [28]. Body mass index was required to meet the adjustment set, so we included weight because height squared was already included in the model. All study participants were asked questions about demographics, lifestyle, and health during the telephone enrollment interview and home visit. Identified confounders included: age at home visit (years), height (inches), height^2, weight (pounds), gender (male, female), Hispanic ethnicity (yes, no), race (white, black, other), annual household income (less than or equal to $20,000, $20,001 to $50,000, more than $50,000), highest level of educational attainment (<high school/ equivalent, high school diploma/General Education Diploma, some college/2 year degree, 4 year college graduate or more), employment status at the time of enrollment (employed,

unemployed, other), pre-spill lung disease (bronchitis, asthma, or emphysema) (yes, no), pre-spill diabetes (yes, no), previous oil industry experience (yes, no), previous oil spill cleanup work (yes, no), residential proximity to the US Gulf Coast (living on a coastal county, living adjacent to a coastal county, other Gulf state residence), smoking status at enrollment (never, former, light current (<20 cigarettes/day), heavy current (20 cigarettes/day)), and exposure to passive smoke at the time of the home visit defined as having a regular smoker in the home (yes, no).

Statistical Analysis

We calculated frequencies and percentages for dichotomous and categorical variables and means and standard deviations for continuous variables. We used multivariable linear regression models to estimate adjusted mean differences and 95% confidence intervals in FEV_1 (mL), FVC (mL), and FEV_1/FVC (%) between exposed and unexposed groups, for each oil spill experience. We adjusted for identified confounders as well as other OSRC chemical exposures. To adjust for THC exposures, we categorized the maximum ordinal estimated THC exposure level across all jobs held as: 0.29 ppm; 0.30-0.99 ppm; 1.00-2.99 ppm; 3.00 ppm [29]. To adjust for burning oil/gas (none, low/medium, high) and dispersant exposures (no, yes), we used self-reported data from work histories that were classified by industrial hygienists [29]. We calculated Spearman's correlation coefficients to examine correlations among the six potentially stressful oil spill experiences and among the OSRC work inhalation exposures.

We conducted a complete case analysis among workers with complete information on exposure and confounders. In our primary analytic sample, 30% of participants were excluded due to missing information on either exposures or the model covariates. To address potential bias that could arise from excluding these participants, we analyzed associations among OSRC workers with data imputed for missing exposure and covariates [30, 31]. Multiple imputation was conducted 10 times using the fully conditioned specification (FCS) [32]. Models used to impute missing covariates included all exposure, outcome, and covariates terms in the multivariable models. Statistical analyses were conducted in SAS 9.4 (Cary, NC).

Sensitivity analyses

We performed several sensitivity analyses to address potential bias and assess effect modification in our sample. To assess the impact of using the above less-strict spirometry quality definition, we repeated complete case and imputed analyses among those who met stricter quality spirometry of C (N=4,263; N=6,048, respectively). We repeated analyses among those without pre-spill lung disease (N=4,151) to determine the impact of having included participants with prior lung disease. Separately, we examined associations among OSRC workers with no previous oil industry or oil spill cleanup experience (N=3,716) because these workers might experience greater stress in response to seeing and smelling oil. We also repeated analyses restricted to never-smokers (N=2,010) to assess potential bias from residual confounding by smoking status. We explored effect measure modification by gender to test potential differences in physiologic responses to environmental stressors suggested in prior research [33, 34]. We also stratified by time elapsed between participants'

last day of OSRC work and spirometry test to assess whether any lung function differences were stronger closer in time to spill exposures. Finally, we evaluated individual interview items that comprised the experience of handling oily plants/wildlife or dead animal recovery by separately estimating the effect of performing tasks related to handling plants ("Did you cut, collect, or put oily plants, sargassum weed or grass, or garbage into bags or containers for disposal?") and handling wildlife ("Did you handle any wildlife, whether alive or dead, during the cleanup?") to further explore the impact of witnessing environmental degradation.

Results

Selected population characteristics among OSRC workers with a spirometry quality score of ≥ D are presented in Table 1. The analytic sample was predominately men (80%), Non-Hispanic (94%), and white (54%). Thirty-nine percent of participants had an annual household income less than or equal to $20,000 per year. Correlation coefficients among the oil experiences or among exposures were generally low (−0.01-0.36) (Supplemental Table 1 and 2).

Among workers with a less strict spirometry test quality scores ≥ D who had complete exposure and covariate information (N=4,806), those who smelled chemicals had higher FEV_1 (Mean difference: 31 mL; 95% CI: −3, 64), and FVC (Mean difference: 30 mL, 95% CI: −9, 69) values than unexposed workers (Table 2). However, these associations were weaker after including workers with imputed data (N=6,811). Additionally, workers who had jobs that involved oily plants/wildlife or dead animal recovery had a significantly lower FEV_1 (Mean difference: −70 mL, 95% CI: −105, −34), FVC (Mean difference: −56 mL, 95% CI: −97, −15) and FEV_1/FVC (Mean difference: −0.60%, 95% CI: −1.02, −0.19) compared to unexposed. These associations were similar but attenuated for workers with imputed data for FEV_1 (Mean difference: −53 mL, 95% CI: −84, −22), FVC (Mean difference: −45 mL, 95% CI: −81, −9), and FEV_1/FVC ratio (Mean difference: −0.44%, 95% CI: −0.80, −0.07). Lung function parameters were not associated with any other oil spill experiences that we evaluated. Analyses restricted to workers who achieved stricter spirometry test quality scores ≥ C with complete exposure and covariate information (N=4,263) did not change the main finding, however the association between oily plants/wildlife or dead animal recovery was slightly attenuated (Table 3).

In sensitivity analyses, associations between jobs involving oily plants/wildlife, or dead animal recovery and lung function remained among both those spirometry test quality scores ≥ D without pre-spill lung disease (Supplemental Table 3) and among those with no previous oil industry or oil spill cleanup experience (Supplemental Table 4). Among never-smokers, associations between jobs that involved oily wildlife, plants, or dead animal recovery and FEV_1 and FVC measures were slightly stronger than comparable associations found in primary analyses: FEV_1 (Mean difference: −90 mL, 95% CI; −142, −37), FVC (Mean difference: −86 mL, 95% CI: −147, −24) (Supplemental Table 5).

More women (48%) than men (39%) worked a job involving oily plants/wildlife or dead animal recovery. In gender stratified analyses, the associations between jobs involving oily plants/wildlife or dead animal recovery and FEV_1 and FVC were slightly stronger in men

than women. The association between this experience and the FEV_1/FVC ratio in men was similar to, but slightly weaker than the association in women (Supplemental Table 6).

In analyses stratified by time elapsed between participants' last day of OSRC work and spirometry test, associations between working any job involving oily plants/wildlife, or dead animal recovery and lung function measures were similar across time (≤ 1 year, >1 year and ≤ 2 years, and >2 years since last day of work) (Supplemental Table 7).

In analyses among workers with spirometry test quality scores ≥ D that assessed the individual components of the composite job of oily plants/wildlife or dead animal recovery, workers who handled wildlife or dead animals had no significant differences for FEV_1 (Mean difference: 11 mL; 95% CI: −90, 113), FVC (Mean difference: 46 mL; 95% CI: −72, 164), or FEV_1/FVC (Mean difference: −0.50%, 95% CI: −1.69, 0.68). Workers who cut, collected, or put oily plants, sargassum weed or grass, or garbage into bags or containers for disposal had a lower FEV_1 (Mean difference: −73 mL, 95% CI: −111, −34), FVC (Mean difference: −70 mL, 95% CI: −115, −26), and FEV_1/FVC ratio (Mean difference: −0.45%, 95% CI: −0.90, 0.01) compared to unexposed workers.

Discussion

We observed lower lung function associated with jobs that involved oily plants/wildlife or dead animal recovery and suggestively better lung function associated with smelling oil spill chemicals. We did not observe associations between any other oil spill experience evaluated and lung function in our primary sample. The inverse association between jobs involving oily plants/wildlife or dead animal recovery and lung function was robust to inclusion of participants with imputed data on exposure and covariate information and to multiple sensitivity analyses, i.e. using a stricter definition of quality spirometry, although the association was slightly attenuated for both types of analyses. Findings for this oil spill experience were also robust to sensitivity analyses that restricted to those participants with no previous respiratory disease, with no previous oil industry/spill experience and among never smokers, although differences observed varied slightly depending on the analytic subpopulation. We also evaluated individual components of the composite experience of jobs involving handling of oily plants/wildlife or dead animal recovery by assessing just those who handled oily plants and separately, those who handed wildlife. Results suggest that handling oily plants might be driving the observed association.

The magnitude of the association observed between oily wildlife/plants or dead animal recovery and FEV_1 ranged from −70 mL to −49 mL among primary analytic subgroups. This is larger than the expected age-related decline in FEV_1 for adults (age 35-40 years) which is estimated as 25-30 mL/year [35]. In addition to normal age-related FEV_1 loss, the functional relevance of the magnitude of associations observed in our study can be better understood in the context of lung function impacts of other known respiratory irritants. For example, short-term ambient air pollution ($PM_{2.5}$) exposure has been associated with ~20 mL lower FEV_1 and FVC among nonsmoking adults [36], whereas long-term air pollution ($PM_{2.5}$) has also been associated with an additional ~11 mL in FEV_1 annual decline above expected age-related decline [37]. Further, current cigarette smoking habit has been

associated with declines of 12.6 mL/year per pack/day in FEV_1 for men, and 7.2 mL/ year per pack/day in FEV_1 for women [38].

We initially hypothesized that certain oil spill experiences induced psychological stress or related sequalae, which may have reduced OSRC workers' lung function. Prior work showed that adverse mental health outcomes associated with cleanup work may have persisted 1-3 years following the cleanup efforts of the *DWH* spill [3]. Psychological stress, anger, and negative emotions have been associated with reduced lung function and other adverse respiratory outcomes [11, 12, 39-41], including asthma [11] and reduced lung function [42]. Stress can induce changes in neuroendocrine pathways and in the immune response that can lead to airway inflammation [6]. In GuLF STUDY OSRC workers, Kwok et al. did not observe an association between jobs that involved oily plants/wildlife or dead animal recovery and either post-traumatic stress (prevalence ratio (PR): 1.17, 95% CI: 0.95, 1.44) or depression (PR: 0.96, 95% CI: 0.87, 1.07). But, it is possible that exposed OSRC workers with jobs that involved oily plants/wildlife or dead animal recovery experienced stress that was not detected by these mental health indicators but that still may have led to reduced lung function. Workers with jobs that involved oily plants/wildlife or dead animal recovery may have had lower lung function due to the stress of witnessing or seeing environmental pollution and degradation firsthand. Alternatively, the inverse association may be due to other chemical exposures (e.g., due to accidental ingestion) resulting from close contact with oiled plants or wildlife or findings may have been due to chance.

Smelling chemicals was suggestively associated with better lung function in the complete case analyses and in analyses with imputed data. Higher lung function in this group may suggest that a healthy worker effect for those sensitized to smelling spill chemicals may be present in analyses. It is important to note that we hypothesized that smelling odors would be associated with perceived stress, which in turn may have induced adverse effects on lung function. The experience of smelling chemicals itself is not indicative of chemical exposure and is, in fact, a poor surrogate of exposure and can be misleading. Odor thresholds for the major components of oil, benzene, toluene, ethylbenzene, xylene, and n-hexane (BTEX-H) [43-47] are 10-100 times higher than the exposure levels encountered by the GuLF STUDY workers. Similarly, odor thresholds for the components of oil spill dispersants are at least 10 times higher than the exposure encountered in our study [4]. Any odor associated with the oil is likely due to minor non-BTEX-H components. The cleaning agents had some components that had an odor at the exposure levels encountered by workers.

Overall, we did not observe reduced lung function associated with the oil spill experiences that were found to be associated with adverse mental health indicators by Kwok et al. [3]. For example, while Kwok et al. observed that workers who smelled oil, dispersants, or cleaning chemicals, had to stop work because of heat, or who worked as a commercial fisherman prior to the spill had higher prevalence of depression and post-traumatic stress, we found no effect of these experiences on lung function.

Several study limitations need to be considered. One primary limitation is that the oil spill experiences evaluated do not measure stress directly and represent a heterogenous mixture of exposures including stress, and/or chemical exposures. Our analysis does not shed light

on the possible reasons why lung function is lower in oily plants group, or if differences are attributable to stress or toxic contaminants or both. However, it is not clear what contaminants could be causing this effect. Estimated exposure to THC is a crude indicator of the oil spill experience and does not reflect actual exposures to its components of BTEX-H and other compounds. However, the categorical exposure levels to THC components (very low, low, medium, or high) and dispersants (yes, no) may also result in misclassification. Such misclassification may lead to potential residual confounding in associations observed. We also know of no other chemical exposures to this group of workers. In addition, if exposures like THC and burning are highly correlated with stress it may be difficult to adjust for these factors. Further, exposures were defined as "ever"/ "never", which did not account for how much time a worker was exposed to each experience. There may have been other oil spill experiences that the oily plant workers and the OSRC workers as a whole had that were not assessed by Kwok et al., that may have also been stressful. Finally, use of a one-time measurement of lung function 1-3 years after the spill limits our ability to make causal inferences, because we lack the ability to compare this measure to a baseline measure preceding the oil spill.

This study is the first to assess the potential impact on lung function of oil spill experiences independent of indicators of chemical exposure. This type of analysis was not possible in studies of prior oil spills due to the lack of detailed information on experiences and on chemical exposures. We took advantage of the GuLF STUDY's unique dataset, which allowed for exploration of OSRC work experiences impact on lung function, separate from the primary chemical exposures of interest. Previous studies of oil spills assessing lung function among oil spill cleanup workers were not able to study these experiences independent of inhalation exposure estimates. Additionally, the sample of OSRC workers with measured lung function is also large compared to existing studies on prior spills. Finally, our study controlled for multiple potential confounders, was robust to multiple sensitivity analyses, and used objective measures of lung function that are clinically meaningful.

Conclusions

In the present study, we examined the associations between six unique oil spill experiences related to OSRC activities identified as potentially stressful for a previous study [3], and lung function 1-3 years following the *DWH* disaster. OSRC workers with jobs that involved oily plants/wildlife or dead animal recovery had lower lung function than unexposed OSRC workers, independent of estimated THC exposure levels and surrogates of potential exposure to dispersant, and burning oil/gas. It is unclear whether this association reflects stress related to this cleanup job or other exposures. The evaluation of stress measures such as psychosocial instruments, is needed to further elucidate the relationship between stress related to oil spill cleanup work-related activities and lung function. Additionally, the prospective assessment of stress and follow-up lung function measurements will provide an understanding of whether these effects are transient or persistent in this population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Highlights

- Oil spill response and cleanup (OSRC) workers involved with the *Deepwater Horizon* disaster had potentially stressful work experiences that may have posed a risk to respiratory health.

- In this study, we examined potentially stressful OSRC experiences in relation to lung function parameters forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio.

- Jobs that involved handling oily plants/wildlife or dead animal recovery were associated with lower FEV_1, FVC, and FEV_1/FVC after accounting for OSRC work inhalation exposures.

- This large study is the first to examine lung function in relation to potentially stressful work experiences during the *DWH* disaster response and clean-up effort.
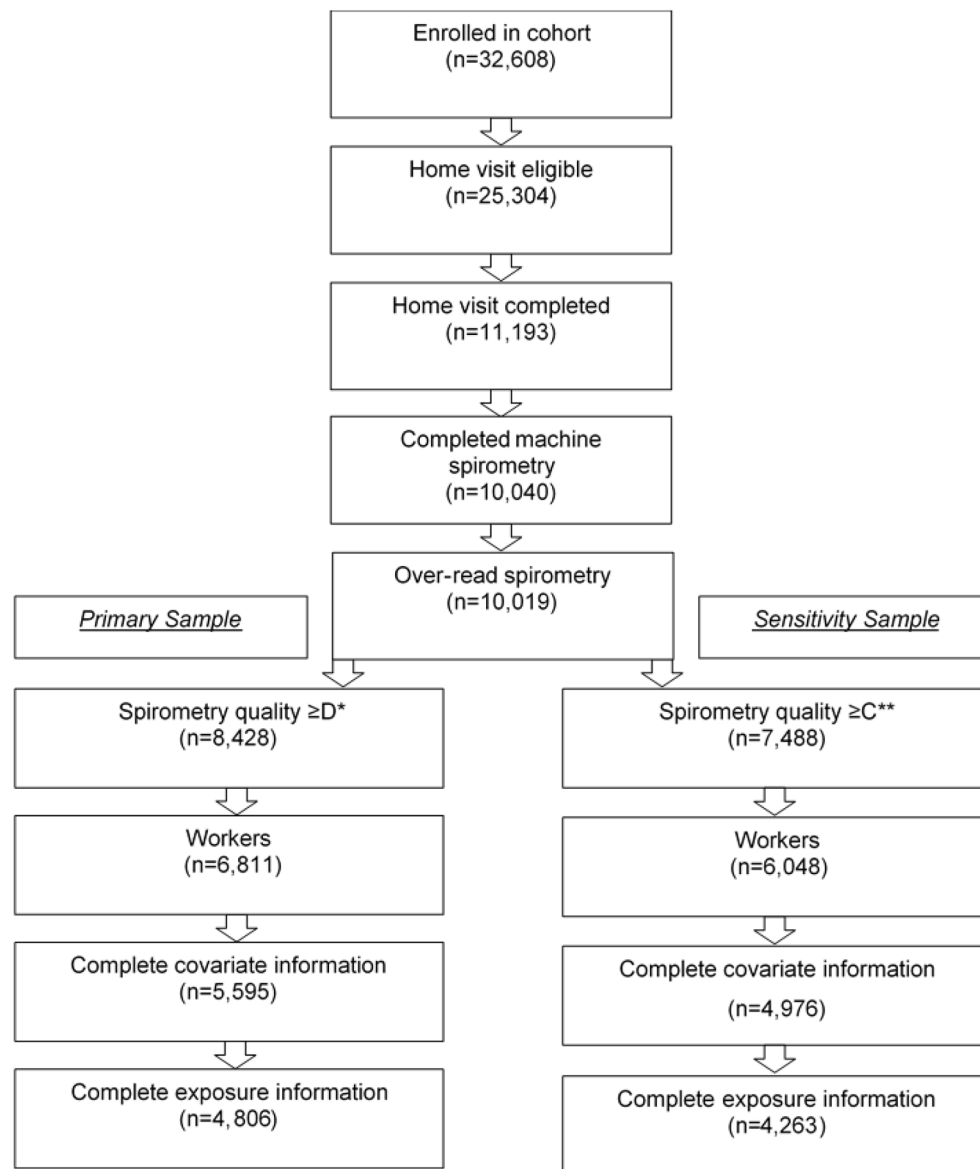
Figure 1.
Participant eligibility.

*Spirometry quality D: 2 acceptable curves with no reproducibility requirement.

**Spirometry quality C: 3 acceptable curves with 150 mL between the highest and second highest curves or equivalent as deemed by pulmonary function expert.

*n=1 participant has an FVC of 26 mL so we excluded this curve and assigned the participants next highest curve

Table 1.

Selected population characteristics of oil spill response and cleanup workers with D spirometry quality scores[*] (N=4,806)

Characteristic	Mean (SD)
Age, years	43 (13)
Height, m	1.74 (0.09)
Weight, kg	91 (21)
Time elapsed between last day of OSRC work and spirometry, years	17 (0.5)
FEV_1, mL	3,197 (791)
FVC, mL	4,084 (955)
FEV_1/FVC%	78.31 (7.08)
	N (%)
Gender	
Male	3867 (80)
Female	939 (20)
Hispanic ethnicity	
Non-Hispanic	4496 (94)
Hispanic	310 (6)
Race	
White	2614 (54)
Black	1701 (35)
Asian/Other	491 (10)
Annual household income	
More than $50,000	1264 (26)
$20,001 to $50,000	1666 (35)
Less than or equal to $20,000	1876 (39)
Highest level of educational attainment	
4-Year College Graduate or More	619 (13)
Some College/2-Year Degree	1537 (32)
High School Diploma/GED	1710 (36)
Less than High School/Equivalent	940 (20)
Employment at the time of enrollment	
Employed	2672 (56)
Unemployed/looking for work	1325 (28)
Other	809 (17)
Pre-spill lung disease	
No	4151 (86)
Yes	655 (14)
Pre-spill diabetes	
No	4560 (95)
Yes	246 (5)
Previous oil industry experience	

Characteristic	Mean (SD)
No	3976 (83)
Yes	830 (17)
Previous oil spill cleanup experience	
No	4406 (92)
Yes	400 (8)
Residential proximity to the Gulf Coast [†]	
Direct contact	3503 (73)
Indirect contact	337 (7)
Other Gulf state residence	966 (20)
Smoking status at enrollment	
Never smoker	2010 (42)
Former smoker	949 (20)
Light current smoker	1223 (25)
Heavy current smoker	624 (13)
Secondhand smoke at home visit	
No	3356 (70)
Yes	1450 (30)
Maximum ordinal total hydrocarbons (THC) level	
0.29 ppm	502 (10)
0.30-0.99 ppm	1910 (40)
1.00-2.99 ppm	1655 (34)
3.00 ppm	739 (15)
Potential exposure to dispersants	
No	4135 (86)
Yes	671 (14)
Potential exposure to burning oil/gas	
Unexposed	4347 (90)
Low/Medium	403 (8)
High	56 (1)
Smelled oil, dispersants, or cleaning chemicals	
No	2014 (42)
Yes	2972 (58)
Skin or clothing in contact with oil/tar/oily water	
No	1695 (35)
Yes	3111 (65)
Body or clothing ever became wet with chemicals	
No	3163 (66)
Yes	1643 (34)
Ever had to stop working because you were hot	
No	2777 (58)
Yes	2029 (42)
Worked any job involving oily plants/wildlife or dead animal recovery	

Characteristic	Mean (SD)
No	2832 (59)
Yes	1974 (41)
Ever worked as a commercial fisherman	
No	3996 (83)
Yes	810 (17)

SD, standard deviation; FEV$_1$, forced expiratory volume in 1 second; FVC, forced vital capacity,

*
Quality   D defined having at least two curves that meet the 2005 American Thoracic Society/European Respiratory society inter-maneuver criteria for both FEV$_1$ and FVC or expert deemed equivalent score,

†
Residential proximity to the coast is defined as: living in a county directly adjacent to the Gulf of Mexico (direct), living in a county adjacent to coastal counties (indirect), or living in another Gulf state county.

Table 2.

Oil spill experiences and lung function among oil spill response and cleanup workers with quality spirometry D[*]

	N(%)	Complete case (N=4,806) Mean Difference (95% CI)[†]	Imputed (N=6,811) Mean Difference (95% CI)[†]
Smelled oil, dispersants, or cleaning chemicals			
FEV_1(mL)	2792 (58)	31 (−3, 64)	17 (−13, 46)
FVC(mL)		30 (−9, 69)	25 (−8, 59)
FEV_1/FVC%		0.22 (−0.17, 0.62)	−0.009 (−0.36, 0.34)
Skin or clothing in contact with oil/tar/oily water			
FEV_1(mL)	3111 (65)	−23 (−58, 12)	−17 (−48, 13)
FVC(mL)		−18 (−59, 23)	−4 (−40, 31)
FEV_1/FVC%		−0.13 (−0.55, 0.28)	−0.22 (−0.59, 0.14)
Body or clothing ever became wet with chemicals			
FEV_1(mL)	1643 (34)	17 (−18, 52)	26 (−5, 56)
FVC(mL)		4 (−37, 44)	21 (−15, 56)
FEV_1/FVC%		0.39 (−0.02, 0.79)	0.27 (−0.09, 0.63)
Ever had to stop working because you were hot			
FEV_1(mL)	2029 (42)	−16 (−49, 18)	−14 (−43, 15)
FVC(mL)		−23 (−62, 16)	−17 (−51, 17)
FEV_1/FVC%		0.14 (−0.25, 0.54)	0.08 (−0.27, 0.42)
Jobs that involved oily plants/wildlife or dead animal recovery			
FEV_1(mL)	1974 (41)	−70 (−105, −34)	−53 (−84, −22)
FVC(mL)		−56 (−97, −15)	−45 (−81, −9)
FEV_1/FVC%		−0.60 (−1.02, −0.19)	−0.44 (−0.80, −0.07)
Worked as a commercial fisherman full-time, part-time or seasonally			
FEV_1(mL)	810 (17)	28 (−19, 75)	20 (−20, 60)
FVC(mL)		34 (−21, 89)	25 (−22, 72)
FEV_1/FVC%		0.15 (−0.40, 0.71)	0.02 (−0.46, 0.49)

Abbreviations: CI, confidence interval; N(%), number of participants exposed in the complete case sample; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity, mL, milliliters.

[*]Quality D is defined having at least two acceptable curves that meet the 2005 American Thoracic Society/European Respiratory society intermaneuver criteria,

[†]Adjusted for: Maximum ordinal total hydrocarbon exposure levels, potential exposure to burning oil/gas, potential dispersant exposure, age, height, $height^2$, weight, gender, ethnicity, race, pre-spill diabetes, pre-spill lung disease, income, education, employment at time of enrollment, previous oil industry experience, previous oil spill cleanup work, residential proximity to coast, smoking, secondhand smoke.

Table 3.

Oil spill experiences and lung function among oil spill response and cleanup workers with spirometry quality grade C*

	N(%)	Complete case (N=4,263) Mean Difference (95% CI)†	Imputation (N=6,048) Mean Difference (95% CI)†
Smelled oil, dispersants, or cleaning chemicals			
FEV_1(mL)	2479 (58)	35 (−0.34, 70)	19 (−12, 49)
FVC(mL)		32 (−9, 73)	25 (−10, 61)
FEV_1/FVC%		0.31 (−0.10, 0.71)	0.06 (−0.29, 0.42)
Skin or clothing in contact with oil/tar/oily water			
FEV_1(mL)	2741 (64)	−18 (−55, 19)	−16 (−47, 16)
FVC(mL)		−13 (−56, 30)	−2 (−39, 35)
FEV_1/FVC%		−0.13 (−0.55, 0.30)	−0.24 (−0.61, 0.13)
Body or clothing ever became wet with chemicals			
FEV_1(mL)	1453 (34)	14 (−22, 50)	22 (−10, 54)
FVC(mL)		3 (−40, 46)	22 (−16, 59)
FEV_1/FVC%		0.31 (−0.11, 0.73)	0.17 (−0.20, 0.54)
Ever had to stop working because you were hot			
FEV_1(mL)	1788 (42)	−8 (−43, 27)	−9 (−39, 22)
FVC(mL)		−17 (−58, 24)	−15 (−, 21)
FEV_1/FVC%		0.21 (−0.19, 0.62)	0.13 (−0.22, 0.49)
Job involving oily plants/wildlife or dead animal recovery			
FEV_1(mL)	1739 (41)	−60 (−97, −23)	−49 (−81, −16)
FVC(mL)		−44 (−88, −1)	−37 (−74, 1)
FEV_1/FVC%		−0.58 (−1.01, −0.15)	−0.46 (−0.84, −0.08)
Worked as a commercial fisherman full-time, part-time or seasonally			
FEV_1(mL)	716 (17)	25 (−24, 75)	12 (−30, 54)
FVC(mL)		25 (−33, 84)	9 (−40, 59)
FEV_1/FVC%		0.25 (−0.32. 0.82)	0.10 (−0.39. 0.59)

Abbreviations: CI, confidence interval; N(%), number of participants exposed in the complete case sample; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity, mL, milliliters.

*Quality C is defined as having three acceptable curves that meet the American Thoracic Society/ European Respiratory Society inter-maneuver criteria and between-maneuver criteria with reproducibility of 150mL or equivalent deemed by a spirometry expert.

†Adjusted for: Maximum ordinal total hydrocarbon exposure levels, potential exposure to burning oil/gas, potential dispersant exposure, age, height, $height^2$, weight, gender, ethnicity, race, pre-spill diabetes, pre-spill lung disease, income, education, employment at time of enrollment, previous oil industry experience, previous oil spill cleanup work, residential proximity to coast, smoking, secondhand smoke.