Incidence of Chronic Respiratory Conditions Among Oil Spill Responders: Five Years of Follow-up in The Deepwater Horizon Oil Spill Coast Guard Cohort Study

Jennifer A. Rusiecki [a,*], Hristina Denic-Roberts [a,b], Dana L. Thomas [c], Jacob Collen [d], John Barrett [a], Kate Christenbury [e], Lawrence S. Engel [f]

[a] Department of Preventive Medicine and Biostatistics, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

[b] Oak Ridge Institute for Science and Education, MD, USA

[c] United States Coast Guard Headquarters, Directorate of Health, Safety, and Work Life, Washington, D.C., USA

[d] Department of Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

[e] Social & Scientific Systems, a DLH Corporation Holding Company, Durham, NC, USA

[f] Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina, Chapel Hill, NC, USA

[*] Corresponding author (E-mail: jennifer.rusiecki@usuhs.edu)

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The authors report no competing interests.

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Abstract

Background: Over ten years after the Deepwater Horizon (DWH) oil spill, our understanding of long term respiratory health risks associated with oil spill response exposures is limited. We conducted a prospective analysis in a cohort of U.S. Coast Guard personnel with universal military healthcare. Methods: For all active-duty cohort members (N=45,193) in the DWH Oil Spill Coast Guard Cohort Study we obtained medical encounter data from 01 October 2007 to 30 September 2015 (i.e., ~2.5 years pre-spill; ~5.5 years post-spill). We used Cox Proportional Hazards regressions to calculate adjusted hazard ratios (aHR), comparing risks for incident respiratory conditions/symptoms (2010-2015) for: responders vs. non-responders; responders reporting crude oil exposure, any inhalation of crude oil vapors, and being in the vicinity of burning crude oil versus responders without those exposures. We also evaluated self-reported crude oil and oil dispersant exposures, combined. Within-responder comparisons were adjusted for age, sex, and smoking. Results: While elevated aHRs for responder/non-responder comparisons were generally weak, within-responder comparisons showed stronger risks with exposure to crude oil. Notably, for responders reporting exposure to crude oil via inhalation, there were elevated risks for all *sinusitis* (aHR=1.48; 95%CI, 1.06-2.06), *unspecified chronic sinusitis* (aHR=1.55; 95%CI, 1.08-2.22), *chronic obstructive pulmonary disease (COPD) and other allied conditions* (aHR=1.43; 95%CI, 1.00-2.06), and *dyspnea and respiratory abnormalities* (aHR=1.29; 95%CI, 1.00-1.67); there was a suggestion of elevated risk for diseases classified as *asthma and reactive airway diseases* (aHR=1.18; 95%CI, 0.98-1.41), including the specific condition, *asthma* (aHR=1.35; 95%CI, 0.80-2.27), the symptom, *shortness of breath* (aHR=1.50; 95%CI, 0.89-2.54), and the overall classification of *chronic respiratory conditions* (aHR=1.18; 95%CI, .98-1.43). Exposure to both crude oil and dispersant was positively associated with elevated risk for *shortness of breath* (HR=2.24; 95%CI, 1.09-4.64). Conclusions: Among active-duty Coast Guard personnel, oil spill clean-up exposures were associated with moderately increased risk for longer-term respiratory conditions.

Introduction

The largest marine oil spill in United States history, the *Deepwater Horizon* (DWH) disaster, discharged around 200 million gallons of crude oil into the Gulf of Mexico between 20 April 2010 and 15 July 2010, when the well was capped[1 2]. As part of the clean-up response, approximately two million gallons of the oil dispersants Corexit™ 9500 and 9527A were also released, both on the water surface and subsea. The interagency clean-up response efforts were led by the United States Coast Guard (USCG) and involved nearly 9,000 Coast Guard responders. The U.S. National Institute for Occupational Safety and Health (NIOSH) identified adverse respiratory effects as one of the main human health concerns following the DWH disaster [3].

Human health risks from oil spill exposures have been studied among various populations worldwide responding to or living in the vicinity of large oil spills [4 5]. Studies investigating adverse effects on the respiratory system have largely focused on acute respiratory symptoms assessed via self-reported questionnaires, while only a few have relied on spirometry-measured lung function, or biomarkers of lung injury associated with oil spill exposures [6-18]. In general, these acute health studies have found associations between oil-spill-related exposures and increased prevalence of respiratory symptoms and decreased lung function. Only a few studies to date have evaluated longer term or persistent respiratory conditions associated with oil spill-related exposures, and results have been mixed [19-27]. While respiratory conditions or decreased lung function persisted for up to five years post-spill in some studies [20 21 23-25], other investigations have not observed long-term adverse effects [19 22 26 27].

The Deepwater Horizon Oil Spill Coast Guard Cohort (DWH-CG) study enables the investigation of longer term health effects of oil spill response work and exposures. Previously, we reported associations between crude oil exposure and incident respiratory conditions ascertained from objectively measured health encounter data based on medical records [17]. In that analysis, we only reported associations between oil spill exposures and two broad categories of respiratory illnesses (an overall *chronic respiratory conditions* category and a *chronic obstructive pulmonary disease (COPD) and other allied conditions* category) and asthma during the first two years (2010-2012) after the DWH oil spill [17]. In analyses adjusted for age and smoking, we observed that USCG responders who reported ever being exposed to crude oil during the DWH oil spill had significantly increased risk of chronic respiratory conditions (RR=1.32, 95% CI: 1.09-1.58) and asthma (RR=1.83, 95% CI: 1.05-3.19), compared to responders who reported never being exposed to crude oil during the response[17]. The DWH-CG study is well poised to evaluate *longer* term incident health outcomes potentially associated with oil spill clean-up exposures. In the present cohort study of 45,193 USCG active duty members, we evaluated incident respiratory conditions associated with the DWH oil spill response, crude oil exposure, crude oil exposure via inhalation, being in the vicinity of burning crude oil, and combined crude oil and dispersant exposure up through five and a half years following the spill, using the health encounter data based on medical records.

Methods

Study Population

The Deepwater Horizon Oil Spill Coast Guard Cohort has been described previously [17]. Briefly, all 53,519 people included in the cohort study were USCG members, either on active duty or in the Selected Reserve, between the start of the oil spill, 20 April 2010, and the end of the *transitional* phase of the oil spill response[1] on 17 December 2010. The cohort includes 8,696 USCG personnel who responded to the DWH oil spill ("responders") and 44,823 USCG personnel who did not ("non-responders"). Of these, 68.6% of the responders (N=5,964) and 87.6% of the non-responders (N=39,260) were active duty, and therefore have full coverage medical encounter data available (Select Reservists do not). USCG personnel are part of the Armed Forces, and as such, are eligible for military healthcare benefits under a system designed for equal access, the Military Health System. Active duty personnel in the USCG, like members of the other Armed Forces (Army, Navy, Air Force, and Marines) have full-coverage healthcare, via either "direct care" (seen at a military treatment facility, MTF, or clinic) or "purchased care" (seen by a civilian healthcare provider), both described in more detail below. The military maintains all medical encounter data from four types of care – direct outpatient, direct inpatient, purchased outpatient, and purchased inpatient – in a large data repository, the Military Health System Data Repository (MDR). In the current study we utilized the MDR data to carry out a prospective evaluation of the risk of longer term chronic respiratory conditions associated with DWH oil spill response exposures.

This study was approved by the Institutional Review Boards (IRB) of the Uniformed Services University, The U.S. Coast Guard, and the University of North Carolina, Chapel Hill.

Prospective Health Encounter Medical Data

The military healthcare system is comprised of two overarching programs, 1) the Direct Care System and 2) the Purchased Care System. In broad terms, the Direct Care System can be thought of as care and services provided at MTFs; whereas, the Purchased Care System includes care and services provided at civilian facilities in the community. The Direct Care System includes roughly 60 inpatient acute care hospitals, 385 stand-alone medical clinics and 350 stand-alone dental clinics. These facilities serve over 9.5 million beneficiaries. Beneficiaries include active duty, activated guard and Reserve, retirees, survivors, some inactive guard and reserve, and their family members. Service members must generally serve 20 years to obtain retiree medical benefits. Services in the Direct Care System are free to qualified beneficiaries. Encounter data that are captured include the type of care received and the date and duration of the care provided. The Purchased Care System allows many beneficiaries to also receive care using civilian providers. This provides a mechanism for care when a military hospital or clinic is unavailable [28].

For all active-duty cohort members, we obtained medical encounter data from the MDR for a period between 01 October 2007 and 30 September 2015 (i.e., ~2.5 years before and ~5.5 years after the DWH spill). We utilized the four major data sources from the MDR: 1) outpatient direct/military care, i.e., Comprehensive Ambulatory/Professional Encounter Record (CAPER), 2) inpatient direct/military care, i.e., Standard Inpatient Data Record (SIDR), 3) outpatient purchased/civilian care, i.e., TRICARE Encounter Data - Non-Institutional (TED-NI), and 4) inpatient purchased/civilian care. i.e., TRICARE Encounter Data - Institutional (TED-I). A helpful, succinct description of these data files is provided in Rhon et al., 2018 [29]. We merged the four data sources to create a comprehensive healthcare encounter database for each active duty person in our cohort.

Outcomes Assessment

Health encounter MDR data for the dates we queried were coded using the International Classification of Diseases, 9th Revision (ICD-9). The ICD-9 codes for Diseases of the Respiratory System are 460-519, and ICD-9 codes pertaining to Symptoms Involving the Respiratory System are under the code, 786. In this study, we focused on chronic respiratory conditions and respiratory symptoms classified by ICD-9 three, four, or five digit codes. A full listing of each condition/symptom or grouping of conditions/symptoms we considered, along with their corresponding code(s) and reasons for not including some of them, is provided in Supplemental Table 1. Because some of these conditions/symptoms had small counts in our study population, we were not able to evaluate all of them. We investigated the following respiratory conditions and symptoms: a general category of *Chronic Respiratory Conditions*

(ICD-9 472.0, 473, 477.9, 490-496); *Chronic Rhinitis* (ICD-9 472.0), *Chronic Sinusitis* (ICD-9 473), *Unspecified Chronic Sinusitis* (ICD-9 473.9), *Allergic Rhinitis*, *cause unspecified* (ICD-9 477.9), *Chronic Obstructive Pulmonary Disease (COPD) and Other Allied Conditions* (ICD-9 490-496), *All Bronchitis* (ICD-9 490-491), *Bronchitis, not specified as acute or chronic* (490), *Asthma* (ICD-9 493); a general category of *Symptoms involving respiratory system and other chest symptoms* (ICD-9 786); and individual symptoms, *Dyspnea and respiratory abnormalities* (ICD-9 786.0), *Shortness of Breath* (ICD-9 786.05), *Wheezing* (ICD-9 786.07), and *Cough* (ICD-9 786.2). We also constructed a category of *Asthma and reactive airway diseases*, which combined the following ICD-9 codes: 472.0, 477.9, 493, 786.05, 786.07, and 786.2. To be considered a case for a given condition/symptom, a cohort member had to have either two outpatient encounters or one inpatient encounter for a given condition/symptom or group of conditions/symptoms within the approximately five year post-spill period.

Exposure Assessment

For this study, we relied on several exposure metrics. First, we considered exposure as oil spill response work using responder vs. non-responder comparisons. We then considered exposures within responders: exposure to crude oil via any route (inhalation, dermal contact, submersion, and ingestion), exposure to crude oil via inhalation, ever being in the vicinity of burning oil, and exposure to both crude oil and oil dispersant. For the within-responder exposures, we used self-reported exposure data from two post-deployment surveys completed by the USCG responders (N=3,491 active duty). These surveys have been described in greater detail previously [17]. Briefly, the first survey (Survey 1) was launched in June of 2010 and the second survey (Survey 2) was launched in November of 2010. Many of the factors assessed were similar between the two surveys, however, while Survey 1 assessed exposures to crude oil via self-report of crude oil/oily water (hereafter referred to as simply “crude oil”) inhalation, ingestion, skin contact and submersion on an ever/never scale, Survey 2 ascertained these exposures on a 5-point Likert scale ("never," "rarely," "sometimes," "most of the time," "all of the time"). Survey 2 also included questions about being in the vicinity of burning oil and contact with oil dispersant. For some of these analyses (i.e., crude oil via inhalation and combined crude oil/dispersant exposure) we combined those who reported "rarely" and "never" into the never exposed category.

Statistical Analyses

We limited all analyses to active duty, medically deployable responders and non-responders, hereafter referred to as "responders" and "non-responders." We performed multivariable Cox proportional hazards regression to evaluate risks between the exposure metrics described above and the incidence of respiratory conditions/symptoms. Our main analyses included ICD-9 codes in any diagnostic position. The follow-up period lasted approximately five and a half years post-DWH spill (20 April 2010 – 30 September, 2015), during which we examined the hazards of DWH oil spill exposures. Prevalent cases, the cohort members who had a documented pre-existing respiratory condition/symptom during the period prior to the start date of the DWH oil spill (20 April 2010) to the earliest pre-DWH date of our MDR data (01 October 2007), ascertained via the same criteria as a post-DWH case, were excluded from the Cox proportional hazards regression analyses for that condition/symptom. We excluded 31 USCG members (1 responder; 30 non-responders) with evidence from a centralized USCG database of personnel not meeting deployment readiness requirements in the time period just prior to the DWH oil spill.

The start of follow-up time for all people in the study was the later of April 20th, 2010 or date of entry into the Coast Guard. Responders contributed events and person-time as non-responders (and in the case of within-responder analyses, as "non-exposed") until the first day of their response deployment. Since responders may have sought healthcare outside of the Military Health System during the DWH response and thus their health encounters would have not been captured in a systematic way, responders' events and person-time during the response were excluded from the observation period. Following their deployment, responders contributed events and person-time to the responder group or for the within-responder analyses to the appropriate exposure group. Follow-up time for everyone in the study ended at the earliest of 1) the date they became a case of a given condition/symptom, 2) the end of follow-up period (30 September 2015), or 3) the date they left the Coast Guard.

Our analyses for the within-responder exposure comparisons (ever/never crude oil via any route, ever/never crude oil via inhalation, ever/never in the vicinity of burning oil, and crude oil/dispersant comparisons) were adjusted for age (continuous), sex (male, female), and smoking status (never, former, current, unknown). The responder vs. non-responder models were adjusted only for age and sex because smoking information was not available for non-responders or for responders who did not complete one of the surveys (N=2,472).

We used the PROC PHREG procedure in SAS Version 9.4 (SAS Institute, Cary, NC, USA) to calculate adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for all analyses. We tested the proportionality of hazards assumption across the entire follow-up period using Schoenfeld residuals. A Pearson correlation coefficient between Schoenfeld residuals and follow-up time with a p-value of less than 0.05 suggested non-proportionality of hazards. In cases where we found evidence of non-proportionality, we split the follow-up period into two approximately equal time periods - an earlier (April 20, 2010-December 31, 2012) and a later (January 1, 2013-September 30, 2015) time period – and repeated analyses in each period. The tables presented here include results for respiratory conditions for which we observed at least 10 cases in each exposure group.

Sensitivity analyses

We performed several sensitivity analyses. For the responder/non-responder analyses only, we restricted cases to those with the relevant ICD-9 codes in either the first or second diagnostic position (instead of in any position) to address the possibility of physicians assigning a "primary" diagnosis. Because this restriction greatly reduced the number of cases, these analyses were limited to comparisons of responders to non-responders.

Additionally, for the responder/non-responder comparisons and for the within-responder analyses based on crude oil exposure, we restricted the study population to those who were not enrolled in the Coast Guard's Occupational Medical Surveillance and Evaluation Program (OMSEP) at the time of the DWH spill or during the follow-up period. This program enrolls Coast Guard personnel who, by way of their usual occupational activities and work environment, may be exposed to various health hazards, such as chemical, particulate, physical, and biological agents [30]. We did not have detailed information on type of usual occupational exposure, only that they were enrolled in this surveillance program, which is designed to meet OSHA requirements for specific health hazards.

Finally, because tobacco smoke contains some of the same constituents as crude oil (i.e., benzene, polycyclic aromatic hydrocarbons, heavy metals) and has also been associated with respiratory disease [31], we restricted the within-responder comparisons with sufficient statistical power (i.e., ever/never crude oil via any route and ever/never crude oil via inhalation) to those responders who reported never smoking, thereby eliminating the potential for confounding by smoking.

Results

Population Characteristics

Figure 1 presents a timeline of the DWH-CG Cohort Study. This population has been previously described in detail [17]. In Table 1, we present baseline characteristics for active duty non-responders (N=39,230), active duty responders who completed a post-deployment survey (N=3,491), and active duty responders who did not complete a post-deployment survey (N = 2,472). The mean baseline age among the three groups was approximately 30 years, and all three groups were predominantly male (85-89%) and white (77-78%). Smoking information was available only for responders who completed a survey; slightly more than half reported never smoking (54%), 15% were former smokers, and 23% current smokers; the smoking status of the remaining 9% was unknown.

Responder vs. Non-responder Comparisons

The risks for incident respiratory conditions/symptoms post-DWH, comparing active duty responders to non-responders after adjustment for age and sex are presented in Table 2. There was some evidence of non-proportional hazards, as evidenced by Schoenfeld's p-values, for *dyspnea and respiratory abnormalities* (p=0.02), and because of this we re-ran the analyses in an earlier (2010-12) period and in a later (2013-15) period for this condition. *Dyspnea and respiratory abnormalities* was elevated in responders compared to non-responders in the later time period (aHR=1.23; 95%CI, 1.06-1.43), but not in the earlier period (HR=0.93; 95%CI, 0.80-1.07); see footnotes in Table 2. Risk was elevated for the group of diseases classified as *asthma and reactive airway diseases* (HR=1.11; 95%CI 1.04-1.20) and was suggestively increased for *wheezing* (HR=1.23; 95%CI, 0.78-1.95) and *cough* (HR=1.09; 95%CI, 0.95-1.24). We observed reduced risk for *all bronchitis* (HR=0.81; 95%CI, 0.66-1.01), likely driven by the sub-condition, *bronchitis, not specified as acute or chronic* (HR=0.79; 95%CI, 0.63-0.98). The risks for *chronic respiratory conditions* as a class and for the remaining respiratory conditions were largely null.

In a sensitivity analysis restricting cases to those with the relevant ICD-9 codes in either the first or second diagnostic positions (Supplemental Table 2), results were similar to those in the main analysis. In another sensitivity analysis, restricted to Coast Guard service members who were not enrolled in OMSEP during the follow-up period (Supplemental Table 3), HRs were somewhat attenuated for the elevated risks and were more reduced for the inverse risks, but patterns of risk remained the same.

Within Responder Comparisons

Oil Ever vs. Oil Never

Hazard ratios adjusted for age, sex, and smoking, comparing USCG responders who reported ever being exposed to crude oil to those reporting never exposure, are presented in Table 3. There was an elevated risk for *dyspnea and respiratory abnormalities* (HR=1.35; 95%CI, 1.05-1.74) and suggestive elevations for the symptom under that category, *shortness of breath* (HR=1.45; 95%CI, 0.86-2.46), as well as for all *chronic respiratory conditions* (HR=1.12; 95%CI, 0.93-1.35), *asthma* (HR=1.38; 95%CI, 0.82-2.33), and *asthma and reactive airway diseases* (HR=1.08; 95%CI, 0.91-1.28). There was a suggestion of reduced risks for *all bronchitis* (HR=0.70; 95%CI, 0.43-1.16) and its sub-condition, *bronchitis, not specified as acute or chronic* (HR= 0.72; 95%CI, 0.42-1.21) as well as for *chronic rhinitis* (HR=0.69; 95%CI, 0.41-1.17).

Findings restricted to the population of responders who reported never smoking (54%) are presented in Supplemental Table 4. In this sensitivity analysis, *dyspnea* was significantly elevated (HR=1.65; 95%CI, 1.17-2.32), and HRs for most of the other conditions/symptoms were similar to those found among all responders, with the exception of *asthma* (HR=0.86; 95%CI, 0.43-1.72), for which there was no increased risk among never smokers reporting ever exposure to crude oil via any route. The number of cases of *shortness of breath* and *wheezing* were too small (<10 in at least one exposure group) to yield meaningful results. In another sensitivity analysis, restricted to responders who were not enrolled in OMSEP during the follow-up period (Supplemental Table 3), HRs were somewhat attenuated for the elevated risks and were more reduced for the inverse risks, but patterns of risk remained essentially the same.

Oil Inhalation Ever vs. Oil Inhalation Never

In analyses based on inhalation of crude oil vapors, there were increased risks for developing most of the respiratory conditions and symptoms we evaluated (Table 4). The general category of *chronic respiratory conditions* was elevated among responders reporting inhalation of crude oil vapors (HR=1.18; 95%CI, 0.98-1.43). In contrast to the previous comparisons, here we found elevated risks for *chronic sinusitis* (aHR=1.48; 95%CI, 1.06-2.06) and its sub-category, *unspecified sinusitis (chronic)* (aHR=1.55; 95%CI, 1.08-2.22), as well as a slightly elevated risk for *allergic rhinitis, cause unspecified* (HR=1.20; 95%CI, 0.93-1.54). We also observed a shift to an increased risk for *COPD and other allied conditions* (aHR=1.43; 95%CI, 1.00-2.06); within that set of conditions, there was a suggestion of elevated risk for asthma (HR=1.35; 95%CI, 0.80-2.27) and for the group of diseases classified as *asthma and reactive airway diseases* (HR=1.18; 95%CI, 0.98-1.41). There was an elevated risk for *dyspnea and respiratory abnormalities* (HR=1.29; 95%CI, 1.00-1.67) and within that category suggestive increases for *shortness of breath* (HR=1.50; 95%CI, 0.89-2.54) and *cough* (HR=1.18; 95%CI, 0.84-1.64). The reduced risks found for bronchitis in prior analyses did not hold for the inhalation exposure metric (i.e.,aHRs were null), but there was still a suggestion of reduced risk for *chronic rhinitis* (aHR=0.60; 95%CI, 0.32-1.15). We present survival curves adjusted for age, sex, and smoking (Figures 2A-2D) for select conditions/symptoms (*chronic sinusitis, COPD and other allied conditions, asthma*, and *dyspnea*) by inhalation exposure of crude oil. These curves illustrate the pattern of incidence/diagnosis of the condition by crude oil inhalation exposure over study follow-up time.

In a sensitivity analysis restricted to never smokers, risk estimates for ever inhalation of crude oil vapors were similar to those in the main analysis and can be found in Supplemental Table 5. Hazard ratios were, in fact, more pronounced in this analysis for *dyspnea and respiratory abnormalities* (aHR=1.65; 95%CI, 1.18-2.31) and for the group of diseases classified as *asthma and reactive airway diseases* (aHR=1.33; 95%CI, 1.04-1.69). In another sensitivity analysis, restricted to responders who were not enrolled in OMSEP during the follow-up period (Supplemental Table 3), HRs were somewhat attenuated for the positive risks and were reduced for the previously null risks, but patterns of risk remained essentially the same.

In the Vicinity of Oil Burning Ever vs. Never

The modest number of active duty responders who reported being in the vicinity of burning oil (N=513) limited our ability to examine risks associated with this exposure for some conditions (e.g., *bronchitis, asthma, COPD, wheezing*). For all the conditions/symptoms for which we did have sufficient counts, aHRs were relatively null (Supplemental Table 6).

Combined Effects of Oil and Dispersant

The combined effects of self-reported exposure to crude oil and oil dispersant compared to a reference group of responders reporting not being exposed to either are presented in Table 5. For comparative purposes, we present these results along with exposure to crude oil without dispersant (oil only) versus not exposed to either. Those who reported being exposed to both crude oil and oil dispersant had an elevated risk for *shortness of breath* (aHR=2.24, 95% CI: 1.09-4.64), which was nearly two times higher than the risk among those exposed to crude oil only (aHR=1.23, 95% CI: 0.66-2.27). In contrast, those exposed to both crude oil and oil dispersant had a slightly lower elevated risk for *dyspnea and respiratory abnormalities* (aHR=1.26, 95% CI: 0.85-1.87) than those exposed to oil only (aHR=1.37, 95% CI: 1.03-1.81).

For those exposed to both crude oil and dispersant, there was a suggestive reduced risk for *sinusitis* (aHR=0.63; 95%CI, 0.34-1.15), while the HR was null for the oil-only group.

Discussion

In this prospective study of U.S. Coast Guard active duty service members with continuous military healthcare coverage, we found evidence of a pattern of of increased risks for diagnosis of incident respiratory conditions and symptoms in the five year period post-DWH. As our exposure metrics progressed from less specific (i.e., responder vs. non-responder) to more specific in relevance to the respiratory tract (i.e., inhalation of crude oil vapors), we observed a general increase in number of respiratory conditions with elevated aHRs, as well as higher magnitude aHRs. In some cases (e.g., *sinusitis*) we observed a shift from having a null association to increased risk. Results of the various sensitivity analyses carried out generally reflected these findings or strengthened these findings. This was found even after excluding those cohort members enrolled in the Coast Guard's medical surveillance program (OMSEP) during the oil spill and the follow-up period, which is based on usual hazardous occupational exposures. Of particular interest is our findings for stronger effects from inhalation exposure on *dyspnea and respiratory abnormalities* and *asthma and reactive airway diseases* once we excluded smokers.

These findings are generally consistent with other recently published studies that have focused on longer term respiratory conditions in the aftermath of oil spills. A series of studies carried out after the 2002 Prestige oil spill off the northern coast of Spain found that one to two years after the spill, fishermen involved in the clean-up had a higher prevalence of self-reported lower respiratory tract symptoms, such as wheeze, shortness of breath, and cough [20], and increased bronchial responsiveness and elevated markers of airway injury in exhaled breath condensate[11] compared to those not involved in the clean-up. In contrast to our study, there was no evidence of an increase in asthma, but similar to our study, there was also no evidence of an increase in chronic bronchitis from participation in the clean-up response. A follow-up study in a subset of the original Prestige cohort of fishermen found persistence of these lower respiratory tract symptoms up to five years after the spill clean-up exposure, with the prevalence of symptoms being higher among fishermen with higher levels of exposure[21], however no differences were found for persistence of the functional and biological respiratory health indicators. Bronchial hyper-responsiveness and levels of respiratory biomarkers of oxidative stress and growth factors were worse among the non-exposed fishermen than the never-smoking exposed fishermen six years after the Prestige spill, though this may have resulted from differential loss to follow-up between the two groups [22]. There are obvious differences between the Prestige studies and ours. Most notable is that our respiratory health data are derived from health encounter diagnoses in a five year period post-spill, while the Prestige studies relied on self-reported data and in-person, clinical tests, generally within a two year period post-spill. However, both studies included a focus on both respiratory conditions and symptoms.

Recent findings from the GuLF Study indicate no association between total hydrocarbon exposure estimates and lung function [(forced expiratory volume in 1 s (FEV1; ml), forced vital capacity (FVC; ml), and FEV1/FVC ratio (%)] among clean-up workers one to three years following the DWH disaster[27], although lung function was reduced among decontamination workers and workers with high exposure to burning oil/gas, as well as among workers handling oily plants/wildlife or dead animal recovery[24]. In a recent publication from the GuLF Study, investigators reported that lung function reductions observed one to three years post-spill were no longer apparent four to six years post-spill [26]. While our study did not assess lung function measures, we found moderate elevations in risk for several respiratory conditions/symptoms during the five years post-spill. However, unlike the GuLF Study we did not find clear associations with burning oil based on our analysis of responders reporting being in the vicinity of oil burning. This could be attributed to this metric being relatively non-specific, given that “in the vicinity” may be prone to various interpretations.

Elevated risk for respiratory conditions/symptoms post-oil spill clean-up exposures is mechanistically plausible. In a recent study of female Wistar and Brown Norway rats exposed to inhalation of fuel oil-derived volatile organic compounds (VOCs) produced to mimic the Prestige oil spill, the exposed animals developed airway hyper-responsiveness (without detectable inflammation), similar to pulmonary emphysema [32]. The exposed rats also developed increased alveolar septal cell apoptosis, likely due to DNA damage and microvascular endothelial damage of lung tissue, and depressed expression of vascular endothelial growth factor (VEGF). The study investigators hypothesized that humans may also respond to crude oil VOCs via pathways distinct from those involved in typical cigarette smoke-driven emphysema in COPD, thus indicating a novel disease mechanism for longer term respiratory disease following inhalational exposure from oil spills. Our study investigated a wide range of chronic respiratory conditions, and while we intended to evaluate additional respiratory conditions, such as all those listed in Supplemental Table 1, including *emphysema*, low case counts precluded us from being able to. However, *emphysema* is one of the conditions comprising our grouped respiratory outcome, *COPD and other allied conditions,* and exposure to crude oil inhalation in both the main analysis and in the sensitivity analysis restricted to never-smoking responders was associated with elevated risk for this outcome.

To our knowledge, our study is the first assessment of longer term incident respiratory conditions following an oil spill clean-up to utilize objective health records. By accounting, via objective health data, for pre-existing conditions among participants, our incidence study further strengthens the hypothesis that exposure to crude oil alone, and in combination with oil dispersants, during an oil spill clean-up may increase the risk of developing adverse respiratory conditions for at least the first five years after a spill. Like other recent studies of these longer term respiratory effects, our study examined respiratory symptoms, but we also examined diagnosed respiratory disease, such as *sinusitis* and *COPD and other allied conditions*, particularly *bronchitis* and *asthma*. While we found consistent elevations for many of *the symptoms involving the respiratory system and other chest symptoms*, which are not specific to a single disease, our findings for diagnosed diseases were not as consistent.

Our most consistent findings of increased risk were for the group of diseases classified as *asthma and reactive airway diseases* and for symptoms under the ICD-9 category of *symptoms involving the respiratory system and other chest symptoms*. Asthma is a chronic inflammatory disorder of the airways that can result in bronchial hyper-responsiveness and obstruction of airflow. Some of the typical symptoms of asthma include those presented here, *dyspnea*, *shortness of breath*, *wheeze*, and *cough* [33]. In fact, among our cohort members who developed *asthma*, approximately 33-39% also developed *dyspnea*; 10-15% developed *shortness of breath*, 6-7% developed *wheezing*, and 26-27% developed *cough*. Asthma is not uncommon among active-duty service members[34], despite it being a service-limiting condition for entrance into the military [35], because military medical guidelines allow service members with controlled asthma diagnosed after military accession to remain on active duty [36], provided they are able to meet standards and perform required duties [33]. We found risk of *asthma* and the more inclusive *asthma and reactive airway diseases* to be moderately elevated in most of the comparisons we carried out, including those with adjustment for smoking. The grouping of *asthma and reactive airway diseases* was utilized to ensure we did not miss subjects who received care for respiratory symptoms that were felt to be due to airway hyperreactivity, but who did not necessarily have a formal diagnosis of asthma [37 38]. This category has been applied to Service Members with respiratory symptoms following deployment (burn pit and dust exposures). The vast majority of Service Members with respiratory complaints after deployment have no objective abnormalities (imaging, pulmonary function testing) but a common finding is spirometry with borderline or mild obstructive findings consistent with reactive airways disease [38]. Numerous challenges exist when trying to definitively evaluate rates of respiratory diagnoses among those with respiratory complaints following deployment in this population [39-41]. When we excluded current or former smokers in our study population, we still found an elevated risk for *asthma and reactive airway diseases,* as well as for the symptom, *dyspnea and respiratory abnormalities*, for both the crude oil ever/never and the inhalation of crude oil ever/never comparisons.

In age- and sex-adjusted analyses relying on the more crude exposure metric based on responder status (i.e., responder vs. non-responder), we found no effects on *chronic sinusitis* and reduced risks for *bronchitis*. However, in age-, sex-, and smoking-adjusted analyses based on the more specific crude oil inhalation exposure metric among responders only, the risks for *chronic sinusitis* were elevated among the exposed, and risks for *bronchitis* were null. This paradox may have resulted from a healthy worker effect when comparing responders to non-responders. Even though we attempted to reduce this possibility by excluding non-medically ready service members identified in a USCG medical readiness database, there were likely considerably more than we could identify who were not fit for deployment. At the time of the DWH oil spill the USCG did not have a comprehensive, central database of personnel not fit for deployment (including those injured, not making weight standards, pregnant, or awaiting medical boards for various conditions), and our study utilized the only database available at that time. Estimates have been made by the U.S. military that over 10% of military service members are not fit for deployment (https://www.militarytimes.com/news/pentagon-congress/2019/03/22/deploy-or-get-out-policy-may-not-have-forced-out-any-troops-at-all/); USCG estimates are similar (personal communications with Dana L. Thomas, USCG on 14 March, 2021). We also lacked the necessary data to account for smoking in these analyses, compared to non-responders. To our knowledge, there have not been other published studies that evaluated the risks of developing chronic sinusitis or bronchitis in the wake of an oil spill. A small body of literature, however, has reported elevated rates of chronic bronchitis in adults and children living near petrochemical plants[42-44]. Increased rates of allergic rhinitis have been reported in children living in communities near petrochemical plants in Taiwan[43]. We found slightly elevated risks for *allergic rhinitis, cause unspecified* in the analyses comparing responders with ever exposure to crude oil via inhalation to those never exposed.

Results for the analyses of combined exposure to crude oil and dispersant were somewhat mixed. The elevated risk for *shortness of breath* was higher among those reporting exposure to both crude oil and dispersant than it was for those reporting exposure to crude oil alone (both groups being compared to those not exposed to either). However, the elevated risk for *dyspnea* was lower for the crude oil and dispersant group than for the crude oil-only group. There was a greater than two-fold increased risk for *shortness of breath* among responders who reported exposure to both crude oil and oil dispersant, though the total count of those diagnosed in the combined exposure group was small (n=13), so this must be considered when interpreting these findings. The combined effects of crude oil and oil dispersant have been described in our previous studies of acute symptoms reported by Coast Guard responders during the DWH response. In particular, we previously reported that associations for acute respiratory symptoms in relation to reported exposure to both oil and oil dispersants were substantially larger than those for exposure to oil alone [16]. These findings corroborate the results of a study that investigated expression patterns of genes after treatment with either crude oil, oil dispersants (Corexit 9527A or 9500), or both in human airway epithelial cells [45] and observed a greater number of differentially expressed genes detected in cells that were treated with both Corexit 9527A and oil. Another recent study that investigated the effects of wave energy and slick properties on emissions reported that total particulate concentration from a slick of crude oil-dispersant mixture relevant to the DWH oil spill (e.g., Louisiana Light Sweet crude oil, a surrogate of the oil released during the DWH oil spill, and Corexit 9500A, the dispersant used during the DWH oil spill) was 1-2 orders of magnitude higher than that of the slick of crude oil alone [46]. This striking increase in ultrafine particle concentrations resulting from dispersed oil raises concerns about inhalation exposures of downstream cleanup workers and communities, since the particles may travel further and embed more deeply into the lungs of people in the vicinity of dispersed oil.

The use of diagnostic and billing codes to determine rates of disease has known limitations. ICD codes are susceptible to a number of potential errors (e.g., variations in electronic medical records across facilities, coder errors, inaccuracies in coding nomenclature, etc.), although they are a generally reliable indicator of diagnoses and symptoms when interpreted appropriately and are consequently widely used in epidemiologic research[47]. In addition, ICD-9 codes are used regularly for military surveillance and have been used to report rates of asthma [34]. Such administrative data do not include clinical variables such as radiologic imaging or spirometry, which would provide more granularity on the conditions we studied. In order to increase diagnostic accuracy of ICD-9 codes, we used either two outpatient visits or one inpatient visit to define cases. We also carried out a sensitivity analysis limiting ICD-based diagnoses to the first or second diagnostic position to address the possibility of physicians assigning a primary diagnosis, but results were similar to the main analyses. It is possible, though highly unlikely, that service members sought self-pay healthcare outside the MHS direct and purchased care, in which case, those health encounters would not be captured within the MDR, leading to an incomplete picture of a service member’s healthcare utilization and outcome.

In this analysis, we carried out many comparisons, some of which may have been statistically significant by chance. However, we were primarily interested in patterns of association, consistency of our findings across our main analyses and sensitivity analyses, and the magnification/strengthening of associations with exposure more likely to directly affect the respiratory system (i.e., inhalation of crude oil vapors), rather than in testing specific hypotheses. Our exposure assessment relied on self-report, and we did not have access to individual-level measurement data for petroleum-related exposures such as total hydrocarbons or volatile organic compounds. Additionally, self-reported exposure could have been influenced by recall bias, however the median time between end of deployment to the response and completion of the exit surveys was relatively short (1 day for survey 1; 153 days for survey 2) [17]. While we cannot rule out the possibility that people with respiratory symptoms during deployment reported more exposure, it may also be the case that their symptoms may have been caused or exacerbated by those exposures. In the responder/non-responder comparisons, there was the potential for a healthy responder effect, as described earlier. This may have resulted in underestimating some of the risks, since it would have potentially attenuated or reduced risks. Although some service members left the military before the end of the follow-up period and were, therefore, censored, most cohort members were followed up through 2015 (62-67%, depending on the analysis). Because our cohort was predominantly white and male, our findings may not be generalizable to all oil spill responders.

Strengths of this study include a large study population, objectively ascertained outcomes based on health records from the same universal military healthcare system available to all members of the cohort, and five years of prospective follow-up. The universal healthcare of this population reduced the potential for selection bias or differential loss to follow-up. Since the study population is comprised of generally healthy, young active duty military service members, the likelihood of existing chronic conditions or co-morbidities was low. Additionally, since we had access to health encounter data both before and after the DWH oil spill, we were able to conduct a longitudinal study and account for pre-existing conditions. The large study population also enabled us to carry out various sensitivity analyses, to confirm the robustness of our findings, particularly to eliminate the potential confounding from smoking by restricting the population to never-smokers. We were able to examine a range of potentially important DWH-related exposures, including crude oil, burning oil, and dispersants.

This study provides an indication that oil spill clean-up exposures, in particular, crude oil, and combined exposure to crude oil and oil dispersants, may lead to the development of longer term respiratory conditions and symptoms. Future analyses in this cohort could incorporate procedure codes and pharmacy data to provide further specificity and refinement of the diagnoses studied here. Another important future investigation will be to determine if those with pre-existing conditions had exacerbation of their conditions post-DWH oil spill. Understanding the long term health consequences of oil spill disasters is essential to protecting the health of those who respond to these disasters. This is particularly important, given the recent relaxation of offshore drilling regulations [48] and increasing trends of aggressive expansion of deepwater exploration and drilling. [49]

Conclusions

In this relatively young, healthy population of Coast Guard active duty personnel, with universal military healthcare coverage, we found evidence for an association between oil spill clean-up exposures and moderately increased risks for longer-term respiratory conditions.

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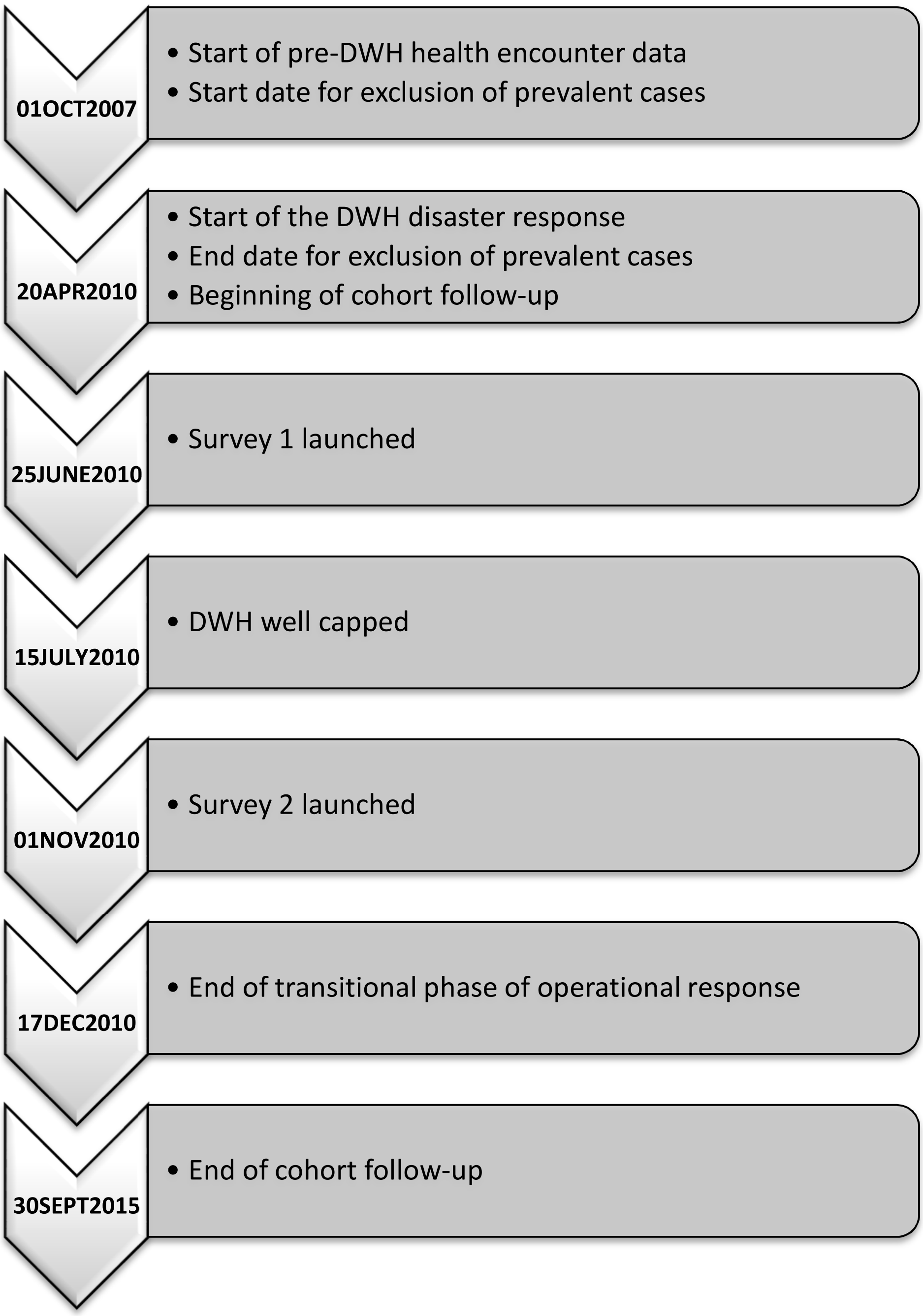


Figure 1. Timeline of the Deepwater Horizon Oil Spill Coast Guard Cohort (DWH-CG) Study

Table 1. Baseline characteristics of the Deepwater Horizon Oil Spill Coast Guard Cohort

Characteristic	Active Duty Non-responders (N=39,230)	Active Duty Responders completing a survey (N =3,491)	Active Duty Responders not completing a survey (N = 2,472)
Age (years)			
Mean (SD)	30.3 (8.2)	30.9 (7.6)	30.5 (7.6)
Median (IQR)	28 (24-36)	30 (25-36)	29 (25-35)
Age category, n (%)			
<25 years old	11,323 (28.9%)	767 (22%)	602 (24.4%)
25-34 years old	17,056 (43.5%)	1,716 (49.1%)	1,210 (48.9%)
35-50 years old	10,295 (26.2%)	968 (27.7%)	631 (25.5%)
>50 years old	556 (1.4%)	40 (1.2%)	29 (1.2%)
Sex, n (%)			
Male	33,512 (85.4%)	3,028 (86.7%)	2,210 (89.4%)
Female	5,718 (14.6%)	463 (13.3%)	262 (10.6%)
Race/Ethnicity, n (%)			
White	30,185 (76.9%)	2,702 (77.4%)	1,927 (78.0%)
Black	2,181 (5.6%)	167 (4.8%)	137 (5.5%)
Asian	361 (0.9%)	38 (1.1%)	23 (0.9%)
AI/AN	937 (2.4%)	101 (2.9%)	55 (2.2%)
NH/PI	242 (0.6%)	14 (0.4%)	9 (0.4%)
Other	2,110 (5.4%)	178 (5.1%)	122 (4.9%)
Unknown	3,214 (8.2%)	291 (8.3%)	199 (8.1%)

Smoking status, n (%)			
Never	--	1,887 (54.0%)	--
Former	--	521 (15.0%)	--
Current	--	786 (22.5%)	--
Unknown	--	297 (8.5%)	--

Abbreviations: AI = American Indian; AN = Alaska Native; NH = Native Hawaiian; PI = Pacific Islander.

Table 2. Risk of respiratory conditions, comparing active duty DWH U.S. Coast Guard responders to non-responders; MDR data 2010-2015, ICD 9 diagnostic codes in any position

	Responder (N=5,963)			Non-responder (N=39,230)				
Condition (ICD 9 code)	**N**	**Person Years**	**IR[1]**	**N**	**Person Years**	**IR[1]**	**HR[2] 95% CI**	**Schoenfeld p-value**
Chronic respiratory conditions (472.0, 473, 477.9, 490-496)	767	21,233	36.12	5,499	143,995	38.19	1.02 (0.94-1.10)	0.67
Chronic rhinitis (472.0)	88	26,219	3.36	567	175,080	3.24	1.04 (0.83-1.31)	0.25
Chronic Sinusitis (473)	236	25,308	9.33	1,619	168,709	9.60	0.99 (0.87-1.14)	0.69
Unspecified chronic sinusitis (473.9)	207	25,434	8.14	1,446	169,671	8.52	0.97 (0.84-1.13)	0.95
Allergic rhinitis, cause unspecified (477.9)	447	23,683	18.87	3,157	159,951	19.74	1.05 (0.95-1.16)	0.83
COPD and Other Allied Conditions (490-496)	190	25,480	7.46	1,359	170,416	7.97	0.96 (0.82-1.12)	0.23
All Bronchitis (490,491)	95	26,002	3.65	795	173,544	4.58	0.81 (0.66-1.01)	0.33
Bronchitis, not specified as acute or chronic (490)	88	26,025	3.38	764	173,700	4.40	0.79 (0.63-0.98)	0.20
Asthma (493)	94	26,146	3.60	564	174,743	3.23	1.15 (0.92-1.43)	**0.06** *
Symptoms involving the respiratory system and								

other chest symptoms (786)	861	21,993	39.15	5,920	149,906	39.49	1.00 (0.93-1.07)	0.25
Dyspnea and respiratory abnormalities (786.0)	409	25,100	16.29	2,536	168,773	15.03	1.06 (0.95-1.18)	**0.02** *
Shortness of breath (786.05)	93	26,260	3.54	593	175,416	3.38	1.05 (0.84-1.31)	0.09
Wheezing (786.07)	22	26,497	0.83	120	177,185	0.68	1.23 (0.78-1.95)	0.18
Cough (786.2)	251	25,309	9.92	1,598	170,274	9.38	1.09 (0.95-1.24)	0.29
Asthma and reactive airway diseases (472.0, 477.9, 493, 786.05, 786.07, 786.2)	853	21,217	40.20	5,637	145,500	38.74	1.11 (1.04-1.20)	0.16

[1] Incidence Rate per 1,000;

[2] All models adjusted for age (years) and sex (male, female);

* Because of an indication of non-proportionality of hazards for *asthma* and *dyspnea and respiratory abnormalities*, we evaluated results by two equal sub-periods (2010-12; 2013-15). Results are as follows: *asthma* (2010-12: HR=0.96; 95%CI, 0.72-1.29; 2013-15: HR=1.48; 95%CI, 1.06-2.07); *dyspnea and respiratory abnormalities* (2010-12: HR=0.93; 95%CI, 0.80-1.07; 2013-15: HR=1.23; 95%CI, 1.06-1.43)

Table 3. Risk of respiratory conditions, comparing active duty DWH U.S. Coast Guard responders ever vs. never exposed to crude oil via any route; MDR data 2010-2015, ICD 9 diagnostic codes in any position

	Oil Ever [1] (N=1,908)			Oil Never [1] (N=1,583)			
Condition (ICD 9 code)	N	Person Years	IR[2]	N	Person Years	IR[2]	HR[3,4] 95% CI
Chronic respiratory conditions (472.0, 473, 477.9, 490-496)	273	6,820	40.03	273	6,375	42.82	1.12 (0.93-1.35)
Chronic rhinitis (472.0)	26	8,529	3.05	39	7,861	4.96	0.69 (0.41-1.17)
Chronic Sinusitis (473)	84	8,201	10.24	75	7,618	9.85	1.09 (0.78-1.51)
Unspecified chronic sinusitis (473.9)	74	8,235	8.99	62	7,675	8.08	1.16 (0.81-1.66)
Allergic rhinitis, cause unspecified (477.9)	146	7,679	19.01	181	7,047	25.68	0.93 (0.73-1.18)
COPD and Other Allied Conditions (490-496)	72	8,274	8.70	65	7,668	8.48	1.13 (0.79-1.62)
All Bronchitis (490,491)	29	8,484	3.42	39	7,806	5.00	0.70 (0.43-1.16)
Bronchitis, not specified as acute or chronic (490)	27	8,491	3.18	36	7,816	4.61	0.72 (0.42-1.21)
Asthma (493)	39	8,475	4.60	28	7,875	3.56	1.38 (0.82-2.33)
Symptoms involving the respiratory system and other chest symptoms (786)	309	7,120	43.40	292	6,605	44.21	1.06 (0.90-1.26)

Dyspnea and respiratory abnormalities (786.0)	163	8,098	20.13	117	7,596	15.40	1.35 (1.05-1.74)
Shortness of breath (786.05)	38	8,534	4.45	26	7,921	3.28	1.45 (0.86-2.46)
Wheezing (786.07)	8	8,619	0.93	8	7,966	1.00	--
Cough (786.2)	80	8,245	9.70	94	7,581	12.40	0.93 (0.67-1.28)
Asthma and reactive airway diseases (472.0, 477.9, 493, 786.05, 786.07, 786.2)	300	6,834	43.90	314	6,349	49.45	1.08 (0.91-1.28)

[1] Ever included those reporting "Ever" on Survey 1 or "Sometimes," "Most of the Time," or "All of the Time" on Survey 2; Never included those reporting "Never" on Survey 1 or "Never" or "Rarely" on Survey 2;

[2] Incidence Rate per 1,000;

[3] All models adjusted for age (years), sex (male, female) and smoking status (never, former, current, unknown);

[4] All Schoenfeld residual p-values >0.05, indicating proportionality of hazards

Table 4. Risk of respiratory conditions, comparing active duty DWH U.S. Coast Guard responders ever vs. never exposed to crude oil inhalation; MDR data 2010-2015, ICD 9 diagnostic codes in any position

	Oil Inhalation Ever[1] (N=1,068)			Oil Inhalation Never[1] (N=2,423)			
Condition (ICD 9 code)	N	Person Years	IR[2]	N	Person Years	IR[2]	HR[3,4] 95% CI
Chronic respiratory conditions (472.0, 473, 477.9, 490-496)	161	3,815	42.20	390	9,484	41.12	1.18 (0.98-1.43)
Chronic rhinitis (472.0)	12	4,833	2.48	53	11,672	4.54	0.60 (0.32-1.15)
Chronic Sinusitis (473)	58	4,623	12.55	102	11,307	9.02	1.48 (1.06-2.06)
Unspecified chronic sinusitis (473.9)	51	4,656	10.95	86	11,366	7.57	1.55 (1.08-2.22)
Allergic rhinitis, cause unspecified (477.9)	95	4,331	21.93	234	10,506	22.27	1.20 (0.93-1.54)
COPD and Other Allied Conditions (490-496)	48	4,659	10.30	90	11,397	7.90	1.43 (1.00-2.06)
All Bronchitis (490,491)	21	4,789	4.39	48	11,616	4.13	1.13 (0.67-1.92)
Bronchitis, not specified as acute or chronic (490)	19	4,796	3.96	45	11,627	3.87	1.10 (0.64-1.91)
Asthma (493)	23	4,786	4.81	44	11,680	3.77	1.35 (0.80-2.27)
Symptoms involving the respiratory system and							

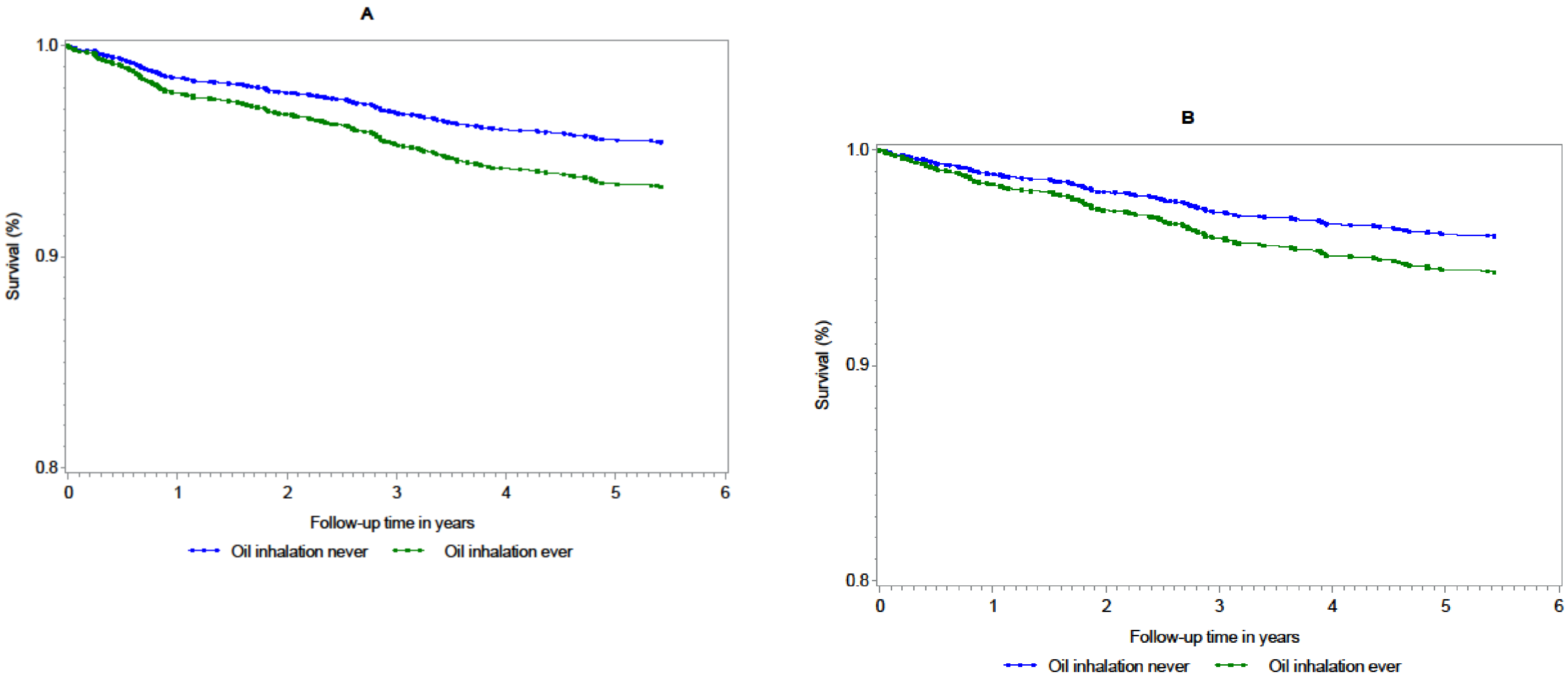
other chest symptoms (786)	174	3,988	43.63	433	9,846	43.98	1.07 (0.89-1.28)
Dyspnea and respiratory abnormalities (786.0)	94	4,551	20.65	186	11,257	16.52	1.29 (1.00-1.67)
Shortness of breath (786.05)	23	4,828	4.76	41	11,743	3.49	1.50 (0.89-2.54)
Wheezing (786.07)	5	4,881	1.02	11	11,820	0.93	--
Cough (786.2)	52	4,654	11.17	124	11,286	10.99	1.18 (0.84-1.64)
Asthma and reactive airway diseases (472.0, 477.9, 493, 786.05, 786.07, 786.2)	180	3,830	47.00	437	9,461	46.19	1.18 (0.98-1.41)

[1] Ever included those reporting "Ever" on Survey 1 or "Sometimes," "Most of the Time," or "All of the Time" on Survey 2; Never included those reporting "Never" on Survey 1 or "Never" or "Rarely" on Survey 2;

[2] Incidence Rate per 1,000;

[3] All models adjusted for age (years), sex (male, female) and smoking status (never, former, current, unknown);

[4] All Schoenfeld residual p-values >0.05, indicating proportionality of hazards


A
B
Survival (%)
1.0
0.9
0.8
0
1
2
3
4
5
6
Follow-up time in years
Oil inhalation never
Oil inhalation ever

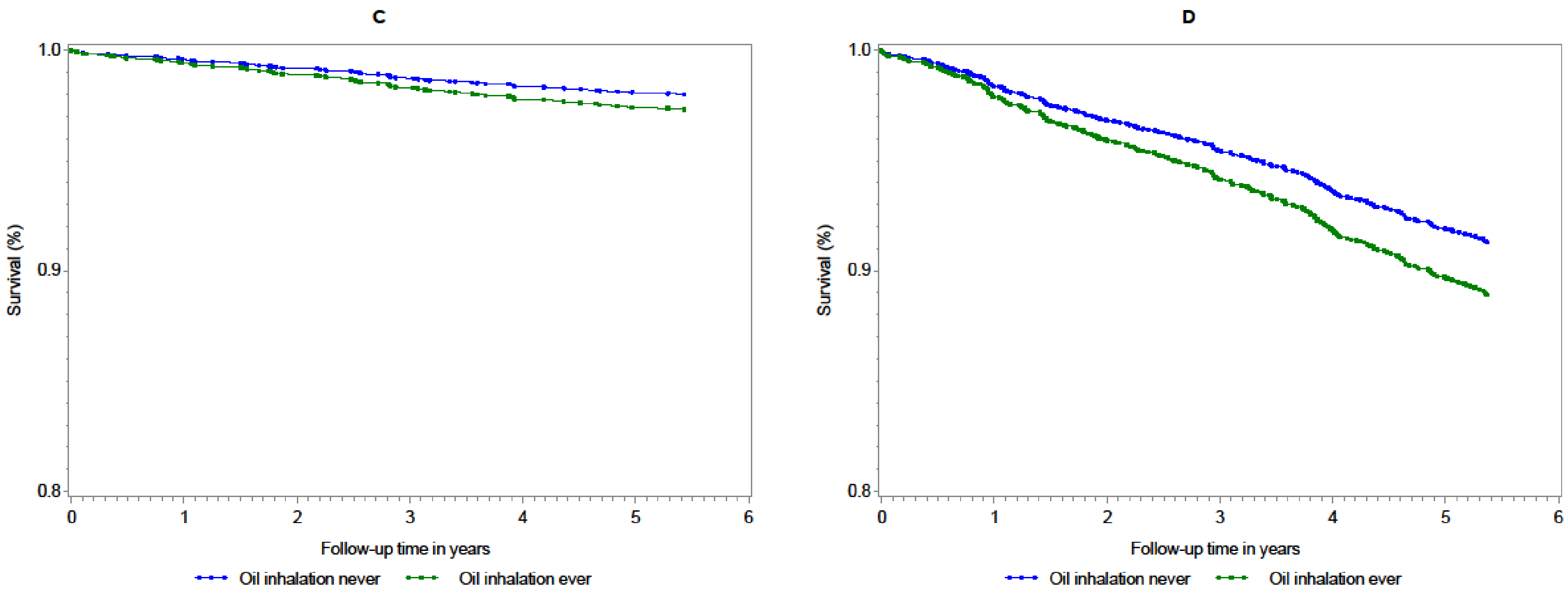


Figure 2 (A-D). Survival plots adjusted for age, sex, and smoking for incident A) *chronic sinusitis*, B) *COPD and Other Allied Conditions,* C) *asthma*, and D) *dyspnea and respiratory abnormalities* by crude oil inhalation exposure

Table 5. Risk of respiratory conditions among active duty DWH U.S. Coast Guard responders exposed to crude oil, but not oil dispersant or crude oil and oil dispersant vs. neither; MDR data 2010-2015, ICD 9 diagnostic codes in any position

	No Oil or Dispersant Exposure[1] (N=1,282)			Oil Exposure, No Dispersant[1] (N=1,351)				Oil and Dispersant Exposure[1] (N=448)			
Condition (ICD 9 code)	**N**	**Person Years**	**IR[2]**	**N**	**Person Years**	**IR[2]**	**HR[3,4] 95% CI**	**N**	**Person Years**	**IR[2]**	**HR[3,4] 95% CI**
Chronic respiratory conditions (472.0, 473, 477.9, 490-496)	225	5,150	43.69	198	4,786	41.37	1.12 (0.92-1.38)	61	1,656	36.82	1.03 (0.77-1.38)
Chronic rhinitis (472.0)	31	6,399	4.84	23	6,059	3.80	0.84 (0.48-1.47)	2	-	-	--
Chronic Sinusitis (473)	67	6,191	10.82	65	5,791	11.22	1.11 (0.78-1.58)	13	1,954	6.65	0.63 (0.34-1.15)
Unspecified chronic sinusitis (473.9)	56	6,235	8.98	59	5,802	10.17	1.21 (0.83-1.77)	9	-	-	-
Allergic rhinitis, cause unspecified (477.9)	150	5,704	26.30	105	5,382	19.51	0.93 (0.71-1.22)	35	1,855	18.87	0.92 (0.63-1.35)
COPD and Other Allied Conditions (490-496)	51	6,244	8.17	51	5,853	8.71	1.16 (0.77-1.74)	16	1,962	8.15	1.21 (0.68-2.18)
All Bronchitis (490,491)	30	6,369	4.71	16	6,045	2.65	0.55 (0.30-1.03)	9	-	-	--
Bronchitis, not specified as acute or chronic (490)	28	6,378	4.39	16	6,045	2.65	0.60 (0.32-1.12)	7	-	-	--
Asthma (493)	24	6,404	3.75	29	5,988	4.84	1.44 (0.81-2.56)	9	-	-	--
Symptoms involving the respiratory system											

and other chest symptoms (786)	233	5,376	43.34	222	5,014	44.27	1.08 (0.89-1.31)	69	1,728	39.92	1.00 (0.76-1.32)
Dyspnea and respiratory abnormalities (786.0)	94	6,166	15.25	120	5,726	20.96	1.37 (1.03-1.81)	36	1,928	18.67	1.26 (0.85-1.87)
Shortness of breath (786.05)	19	6,457	2.94	23	6,053	3.80	1.23 (0.66-2.27)	13	2,007	6.48	2.24 (1.09-4.64)
Wheezing (786.07)	6	-	-	7	-	-	--	1	-	-	-
Cough (786.2)	77	6,198	12.42	59	5,844	10.10	0.90 (0.63-1.29)	15	1,947	7.70	0.69 (0.39-1.21)
Asthma and reactive airway diseases (472.0, 477.9, 493, 786.05, 786.07, 786.2)	263	5,134	51.23	216	4,759	45.39	1.07 (0.88-1.30)	69	1,679	41.09	0.97 (0.74-1.29)

[1] No oil or Dispersant exposure combines "Never" exposure to crude oil via any route and "Never" or "Rarely" exposure to dispersant from Survey 2; Oil exposure, No dispersant combines "Ever" exposure to crude oil via any route and "Never" or "Rarely" exposure to dispersant from Survey 2;

Oil and Dispersant Exposure combines "Ever" exposure to crude oil via any route and "Sometimes", "Most of the time" and "All of the time" exposure to dispersant from Survey 2;

[2]Incidence Rate per 1,000; [3]All models adjusted for age (years), sex (male, female) and smoking status (never, former, current, unknown);

[4] All Schoenfeld residual p-values >0.05, indicating proportionality of hazard.