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Exposures to the Kuwait Oil Fires and Their Association with Asthma and Bronchitis among Gulf War Veterans

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Military personnel deployed to the Persian Gulf War have reported a variety of symptoms attributed to their exposures. We examined relationships between symptoms of respiratory illness present 5 years after the war and both self-reported and modeled exposures to oil-fire smoke that occurred during deployment. Exposure and symptom information was obtained by structured telephone interview in a population-based sample of 1,560 veterans who served in the Gulf War. Modeled exposures were exhaustively developed using a geographic information system to integrate spatial and temporal records of smoke concentrations with troop movements ascertained from global positioning systems records. For the oil-fire period, there were 600,000 modeled data points with solar absorbance used to represent smoke concentrations to a 15-km resolution. Outcomes included respiratory symptoms (asthma, bronchitis) and control outcomes (major depression, injury). Approximately 94% of the study cohort were still in the gulf theater during the time of the oil-well fires, and 21% remained there more than 100 days during the fires. There was modest correlation between self-reported and modeled exposures ($r = 0.48$, $p < 0.05$). Odds ratios for asthma, bronchitis, and major depression increased with increasing self-reported exposure. In contrast, there was no association between the modeled exposure and any of the outcomes. These findings do not support speculation that exposures to oil-fire smoke caused respiratory symptoms among veterans. ***Key words:*** **air pollution, asthma, chronic bronchitis, exposure modeling, geographical information systems, oil-well fires, Persian Gulf War.** ***Environ Health Perspect*** **110:1141–1146 (2002). [Online 25 September 2002]**
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The media, Gulf War veterans, and some scientists have suggested that illnesses observed among veterans after the war are attributable to deployment-related exposures (*1*). Gulf War veterans have reported a higher prevalence of symptoms than contemporaneous soldiers not deployed to the war for many illnesses, including bronchitis and asthma (*2–10*). Principal respiratory exposures that occurred during the war include combustion products, chemical agent-resistant coating paint, sand, and smoke emanating from oil-well fires within Kuwait. The oil-fire smoke came from some 600 burning wells that were ignited in February 1991 by Iraqi forces as they retreated. These burning wells produced a composite smoke plume of gaseous constituents, acid aerosols, volatile organic compounds, metal compounds, polycyclic aromatic hydrocarbons, and particulate matter that was visible over a large area of southwest Asia (*11*). Gaseous constituents were predominantly carbon dioxide and sulfur dioxide; the particulate matter mostly consisted of salts, organic compounds, soot (elemental carbon), and sulfates. The particle diameters were in the respirable range, mostly between 0.1 µm and 0.8 µm (*12*).

Relatively few data have been available regarding the impact of oil-fire smoke on the subsequent health of the veterans. During the fires, veterans who reported the closest proximity to the fires reported the greatest number of respiratory symptoms (*13*). However, there was little measurable evidence of adverse effects in exposed animals. Cats captured in proximity to oil fires had little indication of histologic effects in their airway respiratory epithelium (*14*). Hamsters instilled with particles from the fires showed no signs of acute toxicity (*15*). Risk assessment methodology suggests minimal potential for adverse health effects among veterans who were located in the smoke plume (*16*).

Epidemiologic study of the exposure to oil-fire smoke, like most other exposures of the Gulf War, has been limited by availability of objective exposure information. In this analysis, we hypothesized that self-reported symptoms of respiratory illnesses after the war may have been related to modeled and self-reported exposures to the oil-fire smoke. The self-reported exposure and illnesses came from a well-designed, population-based study of Gulf War veterans originally from Iowa at enlistment (*5*). These veterans were interviewed by telephone 5 years after the war to assess exposures, current symptoms, prevalent conditions, and health status. Modeled exposures were developed using a geographic information system to integrate spatial and temporal records of both smoke concentrations, which were modeled upon atmospheric data and satellite imagery, and of military units, which were collected using global positioning systems.

Methods

Study population and survey methods. All human subjects protocols were reviewed and approved by the University of Iowa Investigative Review Board. The study population (*5*) included all individuals identified from military records maintained by the Defense Manpower Data Center (Monterey, CA) who met three criteria: *a*) any military service between 2 August 1990 and 31 July 1991, *b*) Iowa listed as the "home state of record," and *c*) military service within the Gulf War theater (i.e., Iraq, Kuwait, Saudi Arabia, Oman, Bahrain, Qatar, United Arab Emirates, Persian Gulf, Red Sea, and the Gulf of Oman). Of the 8,089 individuals who met these criteria, a stratified random sample of 2,421 subjects was selected and contacted for study participation. The response rate was 78.3% ($n = 1,896$).

Structured telephone interviews conducted 5 years after the war were used to collect demographics, exposures, and health information from each study participant (*5*). Demographic data included sex, age at deployment, race (white, black/other), military rank (enlisted/officer), type of service (Reserve or Guard, Active duty), smoking status (never, former, or current), and level of preparedness for the war. Self-reported exposure was assessed using the question "While you were in the Persian Gulf, were you

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exposed to [smoke from oil well fires]?" (Yes, No, Don't know). Those who answered "yes" were further queried about duration of exposure: "About how many days were you exposed? Consider any part of a day as 1, so we would like to know the total days you were exposed. Would you say 5 days or less, 6 to 30 days, or 31 days or more?"

Using information gained in interviews with key informants, we developed a measure of predeployment military preparedness based on responses to six questions. These questions addressed how well the veteran's training and fitness prepared him or her for accomplishing assigned tasks. The number of positive responses to these six items indicated the veteran's level of preparedness. An individual having four or fewer positive responses was classified as having a low level of preparedness; all other individuals were classified as having a high level of preparedness. The items used for this variable were the following:

> In August, 1990 had you *a*) passed your last physical training test? *b*) met the weight standards for your height? (Yes, No, Don't Know). Given what the military expected of you during August 1990 to July 1991, did you feel that *c*) you were qualified in your common tasks? *d*) you were adequately trained for your specialty? *e*) your physical condition was adequate for your specialty? *f*) you were prepared to deal with the combination of challenges associated with your military service? (Yes, No, Don't Know).

Measures of health included symptoms of asthma and of bronchitis assessed using questions from the American Thoracic Society Questionnaire (*17*). Injury and symptoms of major depression, measures that have little or no biologically plausible relationship to oil-fire exposure, were included to serve as control health outcomes. Subjects were asked whether symptoms bothered them not at all, a little, moderately, quite a bit, or extremely.

A case of asthma symptoms was defined *a priori* as a response of moderately or greater to at least one of the following symptoms in the past month:

> *a*) Has your chest sounded wheezy or whistling when you did not have a cold or flu? *b*) Have you had an attack of wheezing that has made you feel short of breath? *c*) Has there been an occasion when you had tightness of the chest when walking up stairs or running or walking quickly on flat ground?

A case of bronchitis symptoms was defined *a priori* as a response of moderately or greater to both of the following symptoms in the past month:

> *a*) Have you been bothered by a cough when you did not have a cold or flu? *b*) Have you been congested or did you bring up mucous or phlegm when you did not have a cold or flu?

We screened for the outcome of major depression using questions from the PRIME MD (*18*). A case with symptoms of major depression was defined using a previously validated definition of at least one of the following two problems nearly every day for the past 2 weeks:

> *a*) Having had either little interest or pleasure in doing things, *or b*) feeling down, depressed, or hopeless and reporting of at least five of the following symptoms nearly every day for the past 2 weeks: feeling tired; lacking in energy; trouble falling asleep; difficulty in concentrating; poor appetite; moving or speaking so slowly that other people have noticed; feeling bad about yourself; fidgety more than usual; or feeling like hurting yourself.

An injury case was defined as an individual who reported sustaining an injury in the past 3 months that was serious enough to seek medical advice or to cut down on usual activities for more than half a day (*19*). The injury questions were derived from the planned revisions to the National Health Interview Survey (*20*).

Exposure modeling. Modeling each individual's exposure to oil-fire smoke was a multistep process that included identifying the potential exposure period for each individual; identifying the military unit to which each individual was assigned; identifying the daily locations of each unit; identifying the daily locations and concentrations of smoke plumes; and integrating military unit and smoke concentration locations. Self-reported dates of Gulf War service and the duration of the oil fires (10 February 1991–15 October 1991) were used to define the potential exposure period for each individual. Subjects without known dates of war service were excluded ($n = 9$).

Military records of unit assignments (≈ 120 personnel per unit) were maintained by the Defense Manpower Data Center and came from two data collection mechanisms: regular submissions and last submissions. Regular submissions were established for peacetime operations and reflect assignments on the first day of each month. Last submissions were generated by a postwar collaboration of military representatives. They reflect assignments immediately before departure from the war. We used these records to identify a single unit to which each individual was assigned during his or her potential exposure period. For most (85%) individuals, both submission types were in agreement. For submission types not in agreement, we used the last submission. Individuals without a known unit were excluded ($n = 54$).

Military records of unit locations came from a post-war effort of the Armed Services Center for Research of Unit Records (Fort Belvoir, VA). They organized and digitized handwritten records of locations that were ascertained from global positioning devices during the war. We used these records to obtain a single daily location for each unit. Units with multiple locations on a given day were split into subgroups or assumed to be in transit. Subgroups were identified by the presence of the same multiple locations on at least 3 consecutive days for a given unit. Modeled exposures were calculated for each subgroup. The subgroup with the highest exposure was used for the entire unit if the coefficient of variation (100% × standard deviation/mean) for all exposures was less than 20%. If the coefficient of variation exceeded 20%, all individuals in the unit were excluded ($n = 63$). We used the previous known location of a unit for those days that were missing location data (16.5% of data) because this generally meant that the unit was stationary. Individuals in units missing more than 50% of daily locations were excluded ($n = 210$).

For quality assurance of our assumptions and record processing, the daily locations for a 10% random sample of units (24,893) were mapped and visually examined to ensure data completeness and to identify anomalous locations. Locations were considered anomalous if they were inconsistent with known military activities of the period (e.g., pre-war preparation, ground war, and troop departure). Only 11 of the 24,893 locations examined were identified as anomalous.

The daily (24-hr average) concentration of oil-fire smoke at all locations were modeled by the National Oceanic and Atmospheric Administration Air Resources Laboratory (Silver Spring, MD) to 15-km resolution (*21,22*). Briefly, a hybrid, single-particle Lagrangian integrated trajectories model was used to predict the atmospheric advection and diffusion of the smoke based on the average number of burning wells, the initial height of smoke release, and daily meteorology. Model building was validated with satellite imagery and by atmospheric and ground-based measurements. Smoke concentrations were a representation of the solar absorbance (natural log [solar energy at earth surface/maximum solar energy available]) between 2 and 4,000 m due to the smoke. For the oil-fire period, there were 600,000 modeled data points with solar absorbance values ranging from 0.01 to 4.0. We used these data points to categorize exposure using two approaches: number of days above a low threshold of smoke concentration and number of days above a high threshold of smoke concentration. The threshold levels were set without available precedent and without intuition regarding a level that would adequately balance sensitivity and specificity. Thus, we selected *a priori* threshold levels including the 50th percentile value of all data points (i.e., absorbance ≥ 0.032), and the 95th percentile value of all data points (i.e., absorbance ≥ 0.77).

We used a geographic information system to assign exposure values to individuals in

three steps. First, a map of the Gulf War theater was divided into 15-km square grid boxes; next, locations of military units and of smoke concentrations for each day were placed on this map; then if a military unit and a smoke concentration shared a grid box, that smoke concentration was attributed to individuals of the unit (Figure 1). Software packages used included Oracle (version 7; Oracle Corporation, 1996, Redwood Shores, CA) for data set management; MicroStation95 (version 5; Bentley Systems Inc., 1995, Exton, PA) for cartographic output; Relation Interface System Shared Component (version 5; Intergraph Corporation, 1996, Huntsville, AL) to link the data set and cartographic output; and Modular GIS Environment (version 6, Intergraph) to perform the geographic analysis.

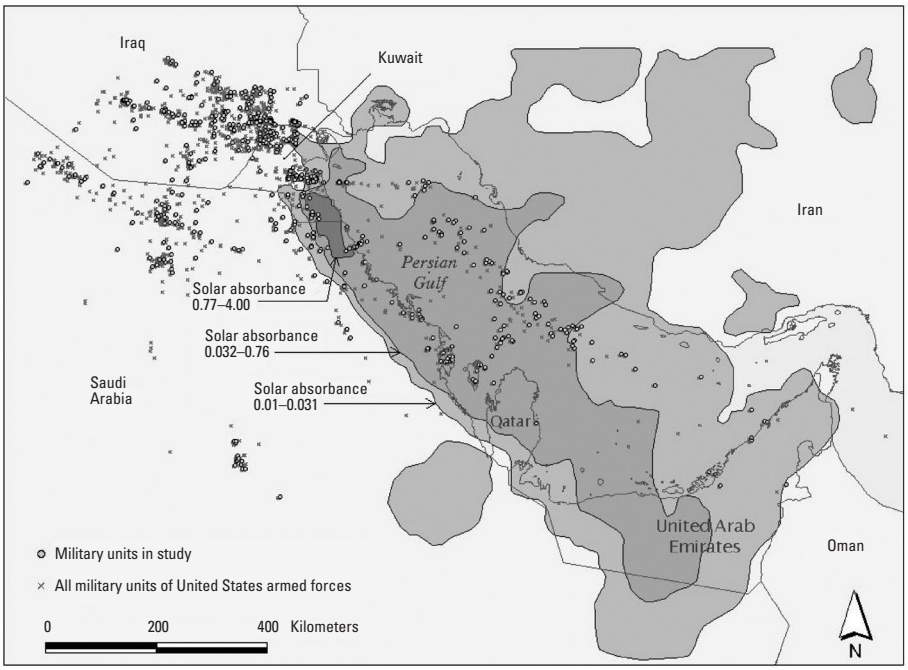

Figure 1. Map of the Gulf War theater demonstrating the method of exposure assessment for a single day, 31 March 1991. The shaded areas show the gradation of smoke concentration of the oil-fire plumes. Locations of soldiers in our study on that day are indicated by circles; X indicates locations of all military units.

Table 1. Prevalence of symptoms for illness outcomes among Gulf War-deployed veterans in the Iowa Gulf War Study (n = 1,560) 5 years post-conflict on the basis of the stratification variables, smoking status, and level of preparedness.

		Illness outcomes (%)			
Characteristic	No.	Asthma	Bronchitis	Injury	Major depression
All	1,560	8.3	4.7	24.4	8.6
Sex					
Men	1,455	8.3	4.7	24.7	8.5
Women	105	8.6	3.8	19.0	9.5
Age in war (years)					
≤ 25	880	7.4	4.1	26.1	8.6
> 25	680	9.6	5.4	22.1	8.5
Race					
White	1,499	8.4	4.8	24.3	8.3
Other	61	6.6	1.6	26.2	14.8
Military rank					
Enlisted	132	8.7	4.9	24.4	9.0
Officer	1,428	4.5	2.3	23.5	3.8
Smoking history					
Never	689	4.9	3.0	21.8	7.4
Former	345	7.5	5.5	25.8	9.6
Current	526	13.3	6.3	26.8	9.5
Military service					
Guard or reserve	769	9.6	6.2	24.8	9.4
Active duty	791	7.1	3.2	23.9	7.8
Level of preparedness					
Low[a]	236	11.9	10.2	28.0	21.2
High	1,324	7.7	3.7	23.7	6.3

[a]Score of 0–4 out of 6 points possible for the six questions on level of preparedness prior to deployment, assessed at the time of the interview, 1995–1996.

Analysis. We used Spearman correlation (SAS version 8; SAS Institute, Cary, NC) to assess the relationship between modeled and self-reported measures of exposure. The α-level was set at 0.05, and all p-values are two tailed. Multivariate logistic regression models were used to assess the relationships between exposures and health outcomes while accounting for demographic covariates. Backward stepwise elimination of covariates was used to create parsimonious models. For regression models that included self-reported exposure, we used the four percentiles of the response exposure levels (none, 1–5 days, 6–30 days, ≥ 31 days). For regression models that included modeled exposure, exposure data were categorized into quartiles.

Results

The prevalence of self-reported symptoms among the study population (n = 1,560) of veterans 5 years after the Gulf War was 8.3% for asthma, 4.7% for bronchitis, 24.7% for injury, and 8.6% for major depression. Of the demographic and behavioral characteristics examined, smoking history and level of preparedness for the war were the characteristics most related to symptoms for respiratory illnesses (Table 1). Current smokers had more than twice the prevalence of symptoms of asthma and of bronchitis than never-smokers. Veterans with a low level of preparedness for the war had a 50% higher prevalence of symptoms of asthma and had nearly triple the prevalence of symptoms of bronchitis than veterans with a high level of preparedness for the war.

There was a wide range in the amount of exposure to oil-fire smoke across the study population (Table 2). Nearly 6% of the deployed sample left the Gulf War theater before the fires began. Conversely, 21% of the sample was in the Gulf War theater more than 100 days during the fires. For the modeled exposure measure, the interquartile ranges (i.e., 25th and 75th percentiles) of exposures were 8 and 28 days exceeding the low threshold concentration and were 0 and 6 days above the high threshold. One-fourth of the sample reported no oil-well fire exposure and one-fourth reported more than 31 days of exposure. Of the demographic and behavioral characteristics examined, military rank (officers > enlisted) and service (reserve or guard > active duty) were the characteristics most related to self-reported level of exposure (Table 2).

There was moderate correlation (Spearman r between 0.40 and 0.48, $p < 0.05$) between the self-reported exposure and the low and high threshold (respectively) modeled

measures of exposure to oil-well fire smoke. The correlation was linear (every increase in self-reported exposure corresponded to an increase in modeled exposure) but was not homogeneous (there was a wide distribution of individual modeled exposures per level of self-reported exposure; Figure 2).

There was no evidence of any association between the modeled measure of exposure to oil-fire smoke and symptoms of either asthma or bronchitis (Figure 3). Results were similar for modeled measures at high and low thresholds; however, only the high threshold is shown. The risk of illness did not increase with magnitude of exposure. Compared to the sample quartile having the lowest exposure, the other three quartiles of greater exposure had similar (all odds ratios near 1.0, range 0.77–1.26) risk of asthma and bronchitis symptoms. Also, any differences in risk between the quartiles were not statistically significant (all 95% confidence intervals overlapped 1.0). Additionally, the risk of asthma and bronchitis symptoms across the quartiles paralleled the risk for the two outcome measures, injury and major depression, that served as negative controls (Figure 3).

In contrast to the modeled exposures, there was a significant association between the self-reported measure of exposure to oil-fire smoke and symptoms of both asthma and bronchitis (Figure 3). The risk of these outcomes increased with increasing magnitude of exposure. Compared to the sample percentile having the lowest exposure, subjects with greater exposure had higher risk for symptoms of asthma (range of odds ratios, 1.77–2.83) and of bronchitis (range of odds ratios, 2.14–4.78). Most of these differences were statistically significant (i.e., the lower bounds of the 95% confidence interval exceeded 1.0). However, the risk also increased with greater magnitude of exposure for injury and for major depression, the two control outcomes (Figure 3).

Discussion

We previously reported that Gulf War veterans had a greater prevalence of self-reported symptoms of asthma (2.3 more cases per 100) and of bronchitis (2.3 more cases per 100) than comparable contemporaneous military personnel who did not serve in the war (*5*). The difference in prevalence between those with and without Gulf War service may be explained, in part, by observations in the current study. We observed statistically significant associations between the prevalence of self-reported symptoms for respiratory illnesses and self-reported exposure to oil-fire smoke within a population-based sample of Gulf War veterans. However, these symptoms were not associated with exposures estimated from the integration of subject location data and oil-fire smoke plume data. We postulate that associations observed between self-reported exposures and respiratory health outcomes may be due to recall bias (i.e., unequal reporting of exposure between sick and healthy people). Recall bias may also explain the observation of a significant relationship between the self-reported exposures to oil-fire smoke and major depression (Figure 3); a relationship with little biologic plausibility. Most soldiers who had direct engagement with the enemy were in Iraq and in regions upwind of the oil-fire plumes most of the time (Figure 1). Thus, smoke-exposed individuals were less likely to have experienced psychologically traumatic situations. One explanation for the relationship between smoke exposure and depression is that those meeting the case definition for major depression may have been prone to symptom reporting and reporting of higher exposures due to somatization or personality factors. Supporting this explanation is evidence of an apparent "media effect" in studies of factors influencing participation in Gulf War Registries (*7*). Because of the strong possibility of recall bias, significant relationships between self-reported exposure and the respiratory illnesses may be without clinical relevance.

It is noteworthy that those soldiers with a low level of military preparedness more frequently reported asthma, bronchitis, injury, and major depression. They also reported more days of exposure to oil-fire smoke. However, exposure modeling revealed no difference in exposure between those with high and low levels of military preparedness. This was also true for guard/reserve compared to

Table 2. Days of exposure above the modeled threshold level and prevalence of self-reported exposure to smoke from the oil-well fires among Gulf War veterans in the Iowa Gulf War Study (n = 1,560).

	Modeled exposure (days above threshold)[a]		Self-reported exposure (%)			
Characteristic	High	Low	None	1–5 days	6–30 days	≥ 31 days
All	1 (0–6)	15 (8–28)	27.3	16.9	30.0	25.7
Sex						
Men	1 (0–6)	15 (8–29)	27.1	16.9	30.6	25.4
Women	0 (0–5)	14 (8–23)	30.5	17.1	22.9	29.5
Age in war (years)						
≤ 25	0 (0–6)	17 (8–30)	29.3	17.5	29.2	24.0
> 25	1 (0–5)	14 (7–23)	24.8	16.2	31.2	27.9
Race						
White	1 (0–5)	15 (8–28)	27.4	16.8	29.9	25.8
Other	3 (0–10)	23 (12–34)	24.6	19.7	32.8	23.0
Military rank						
Enlisted	0 (0–5)	15 (8–28)	28.0	16.9	30.0	25.1
Officer	1 (0–7)	18 (8–30)	19.7	17.4	30.3	32.6
Smoking history						
Never	1 (0–6)	16 (8–29)	26.8	18.8	29.3	25.1
Former	1 (0–7)	16 (8–27)	24.9	14.4	29.0	31.7
Current	0 (0–4)	13 (6–28)	29.6	16.1	31.7	22.6
Military service						
Guard or reserve	3 (0–10)	16 (9–29)	13.5	19.9	32.3	34.3
Active duty	0 (0–3)	15 (2–27)	40.8	14.0	27.8	17.4
Level of preparedness						
Low[b]	1 (0–6)	16 (8–28)	24.8	13.2	31.6	30.3
High	1 (0–5)	15 (8–28)	27.8	17.6	29.8	24.9

[a]Median (25th–75th percentile). The low threshold of smoke concentration (solar absorbance ≥ 0.032) was the 50th percentile value of all data points. The high threshold (solar absorbance ≥ 0.77) was the 95th percentile value of all data points. The exposure variable was days of exposure to conditions of attenuation of solar energy due to oil-fire smoke between 2 and 4,000 m altitude. [b]Score of 0–4 out of 6 points possible for the six questions on level of preparedness prior to deployment, assessed at the time of the interview, 1995–1996.

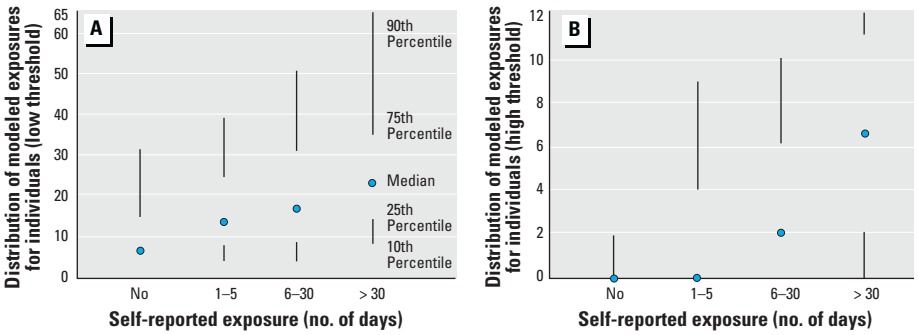

Figure 2. Correlation between self-reported and modeled measures of exposure to oil-fire smoke for (*A*) the low smoke concentration threshold (solar absorbance ≥ 0.032; r = 0.40, p < 0.05) and (*B*) the high threshold (solar absorbance ≥ 0.077; r = 0.48, p < 0.05). Bars above and below the median points indicate percentiles of the distribution of modeled exposures for all subjects with the indicated self-reported exposure.

active duty service. A soldier who is physically less well prepared for war may have had a greater concern for smoke exposure, and this may have been reflected as an exaggerated recall of exposures.

Although modeled exposures were not subject to recall bias, they were subject to measurement error. Errors in modeled exposures were likely to be inherited from the different types of source data (i.e., unit locations, meteorology, and military attributes) collected for purposes other than modeling of smoke exposure. These secondary data came from the effort of literally thousands of people who used unknown levels of quality assurance. Another likely source of error in the modeled exposures were assumptions made in modeling. One major assumption was that an individual remained with his or her unit (i.e., the level of exposure assessment) for the entire exposure period. Unfortunately, no data are available with which to validate this assumption. The effect of errors from the source data and assumptions is likely to be nondifferential misclassification (i.e., the amount of misclassified exposure does not depend on disease status), which usually biases results toward the null hypothesis (*23*). Hence, the observation of no relationship between modeled exposure and respiratory illnesses (Figure 3) could be attributed to nondifferential misclassification. Despite potential errors in both the modeled and self-reported measures of exposure, the two measures were, at least to some extent, reflective of a true measure of exposure. There are no available criteria to directly measure the amount of error in our measures of exposure. However, there was modest correlation observed between these two independent measures of exposure (Figure 2).

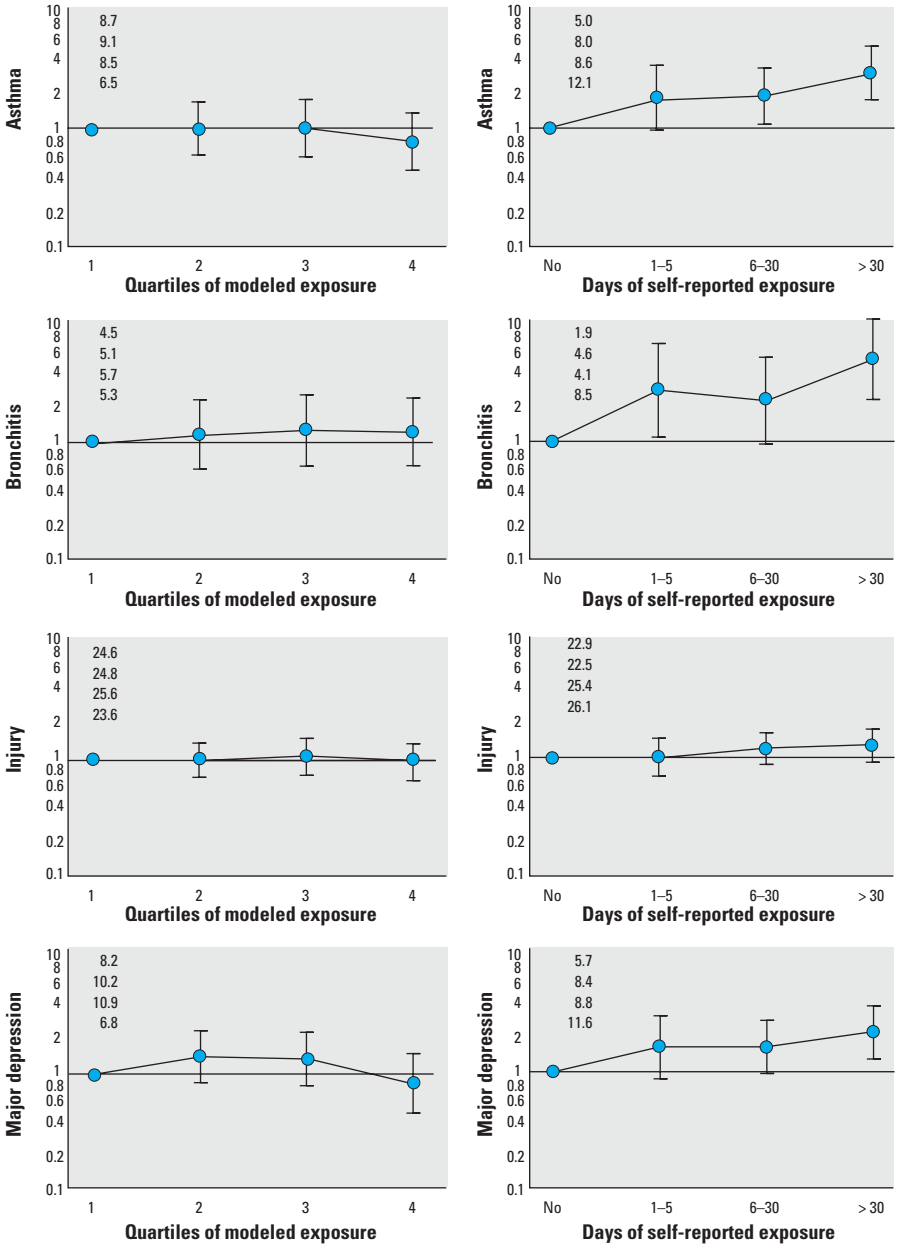

Figure 3. Association between increasing magnitude of exposure to oil-fire smoke (modeled, left column; self-reported, right column) and illness outcomes including asthma, bronchitis, and control outcomes of injury and major depression. Odds ratios are adjusted for sex, age, race, military rank, smoking history, military service, and level of preparedness for war (see text). The lowest magnitude of exposure is the referent group. Crude prevalence rates for each of the data points are provided in the upper left of each plot. Bars indicate 95% confidence intervals.

Potential errors in the classification of disease status were an additional concern. A recent nested case–control study was conducted on our study population to assess the validity of the self-reports of asthma used in this study (*24*). This study compared asthma symptoms, pulmonary function, and bronchial hyperresponsiveness among three groups of veterans (n = 97): Gulf War veterans who self-reported asthma, Gulf War veterans who did not self-report asthma, and veterans not serving in the Gulf War who self-reported asthma. This study served to validate the self-reporting of asthma in the original survey with objective measures of respiratory health. However, this conclusion is complicated by the fact that there was a significantly higher rate of current or past smoking in the asthma group with Gulf War service versus the nonasthma controls.

The exposures in this sample of 1,560 Gulf War veterans are likely to be generalizable to the nearly 700,000 personnel that were deployed to the Persian Gulf. As illustrated in Figure 1, the locations of individuals in our study within the Gulf War theater were representative of the entire military. There was no evidence of a location bias, and the distribution of exposures among this study population is similar to the distribution of all Gulf War veterans who served during the period when the oil wells were burning. Additionally, there were similar self-reports of exposures between this sample and veterans in the VA National Study of Gulf War veterans (*25*).

The use of satellite sensing data and geographic information systems for retrospective exposure modeling is novel. Thus, we sought evidence to further validate this approach. Ground-based area samples of total suspended particulate matter and sulfur dioxide were taken at the time of oil-well fires and compared to the modeled concentrations (*21*). These samples were taken near industrial sites as part of routine air pollution monitoring programs. Ground-level measurements of sulfur dioxide near the industrial sites showed reasonable agreement with the modeled concentrations when the background from the industrial

sources was subtracted (*21*). Area sampling was conducted for particulate matter with a 50% cut-off efficiency at an aerodynamic diameter of 10 µm (PM_{10}) at various troop encampments by the U.S. Army Environmental Hygiene Agency (*16*). The level of carbon within a relatively small number of particulate matter samples was identified. The median fraction of the mass that was carbon was 13%, and the range was 3–47%. Much of the particulate matter was thought to be windblown sand. This variation in the carbon content of the PM_{10} precluded meaningful comparison between modeled exposures and these ground-based samples.

The modeled solar absorbance measures reflect the aerosol concentrations in the column from 2 to 4,000 m and not just those at breathing height where the exposures occur. For this reason the model incorporated the effects of vertical mixing on concentration (*21*). The model was also used to generate measures of exposure for a host of pollutants at 2 m (total suspended particulates, criteria pollutants, and elements such as vanadium that were being released from the burning oil wells) and for the solar absorbance between 2 and 4,000 m. We chose the solar absorbance to be representative of all available modeled exposures. Solar absorbance was highly correlated the other modeled exposures. For example, the correlation between solar absorbance and cumulative total suspended particulates at 2 m was $r = 0.94$. The solar absorbance variable is logarithmic. Thus, the high threshold that was used in this analysis (absorbance > 0.77) is well above the 0.01 value observed before the fires or in areas outside the plume.

Among the 1,560 Gulf War veterans in this study, the prevalence of symptoms of asthma was 9.6% for guard or reserve and 7.1% for active duty. These are slightly higher values than reported for the overall Iowa Gulf War Study ($n = 1{,}896$; guard or reserve = 9.4%; active duty = 6.7%) (*5*). The prevalence of symptoms of bronchitis was 6.2% for guard or reserve and 3.2% for active duty, the same as our overall deployed group. Data from the 1996 National Health Interview Survey representing the U.S. civilian population provided prevalence estimates of 5.7% for physician-diagnosed asthma and 4.5% for chronic bronchitis among person 18–44 years of age (*26*). Although these are lower than the prevalence estimates in our study sample, direct comparisons are difficult because the case definitions were different.

In conclusion, assessment of the relationship between exposure to the oil-fire smoke and symptoms of respiratory illnesses 5 years later among Gulf War veterans is made difficult by limitations inherent to retrospective exposure assessment. The two independent measures of exposure, self-reported and modeled, were moderately correlated. Notably, we found no association of any outcomes with modeled exposure and an association for a control outcome of major depression with self-reported exposure. These findings taken together do not support speculation that exposures to oil-fire smoke have led to respiratory symptoms among Gulf War veterans.

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