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HEAT STRESS RELATED SYMPTOMS AND PULMONARY FUNCTION IN OIL SPILL RESPONSE AND CLEANUP WORKERS FOLLOWING THE DEEPWATER HORIZON DISASTER

YIYAO LI

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HEAT STRESS RELATED SYMPTOMS AND PULMONARY FUNCTION IN OIL SPILL
RESPONSE AND CLEANUP WORKERS FOLLOWING THE DEEPWATER HORIZON
DISASTER

by

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2020

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CLEANUP WORKERS FOLLOWING THE DEEPWATER HORIZON DISASTER

by

YIYAO LI

MPH, LOUISIANA STATE UNIVERSITY HEALTH SCIENCE CENTER, 2015

Presented to the Faculty of The University of Texas

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HEAT STRESS RELATED SYMPTOMS AND PULMONARY FUNCTION IN OIL SPILL CLEANUP WORKERS FOLLOWING THE DEEPWATER HORIZON DISASTER

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Objective: The objective of this study was to estimate the relationship between heat stress and pulmonary function among OSRC workers following the *Deepwater Horizon* (*DWH*) disaster. Methods: Pulmonary function test results were analyzed from a cohort of oil spill response and cleanup workers 1-3 years following the *DWH* disaster (N=5,131). Proxies for heat stress was employed by using information on heat stress-related symptoms as well as a questionnaire on stopping work due to heat reported during a structured telephone enrollment questionnaire. Associations between heat stress proxies and lung function were estimated using multivariable linear models and binomial logistic regression models while adjusting for potential confounders including oil spill chemicals. Results: A suggestive inverse relationship was observed between having experienced any type of heat stress-related symptom at the time of the oil spill and the FEV₁/FVC% ratio (beta: -0.17%; 95% CI: -0.54 to 0.21) among workers with acceptable quality scores on spirometry tests and complete exposure and covariate information. Conclusions: Workers with pre-spill hypertension or other cardiometabolic conditions may be at increased risk of reduced pulmonary function due to heat stress.

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BACKGROUND

Literature Review

Following the 2010 *Deepwater Horizon* disaster, oil spill response and cleanup (OSRC) workers were exposed to high temperatures (often exceeded 90°F to 100°F) and high relative humidity (52%-77%) (CDC, 2018; King & Gibbons, 2011; Singleton et al., 2015). OSRC workers participated in a range of outdoor activities that may have exposed them to high ambient temperatures including drilling relief wells, burning oil, cleaning the waters, marshes, beaches, and shoreline structures, decontaminating vessels and other equipment, and providing support to operations in multiple locations on and off the water (Stewart et al., 2018). During work site visits, the National Institute of Occupational Safety and Health (NIOSH) highlighted heat stress as a primary risk to worker safety and health and identified multiple cases of hospital-induced heat stress (King & Gibbons, 2011).

Heat stress is defined as the cumulative imbalance between heat generation and heat dissipation (Cramer & Jay, 2016) and is induced by a combination of the effects of the environment (measured as wet bulb globe temperature), metabolic rate (measured as workload), and protective clothing (i.e. full body coveralls and protective gloves and boots) (Havenith, 1999; King & Gibbons, 2011; Tustin et al., 2018). Heat stress also induces a range of neurological symptoms such as severe headaches, nausea, dizziness, and fatigue/extreme tiredness (CDC, 2018). Serious cases of heat stress can lead to cramps, rhabdomyolysis, and stroke (CDC, 2018). In addition to neurological symptoms, heat stress may adversely affect respiratory health.

The relationship between heat stress and respiratory health is unclear. Although no prior occupational study has reported significant associations between heat stress and respiratory conditions or pulmonary function, some studies have linked heat stress with adverse respiratory health outcomes among vulnerable subpopulations (Jehn et al., 2014; Lepeule et al., 2018; McCormack et al., 2016; Soneja et al., 2016). Among individuals with chronic obstructive pulmonary disease (COPD), a rise in ambient temperature is correlated with increases in COPD-related symptoms such as breathlessness, coughing, and sputum after accounting for air pollution (McCormack et al., 2016). During the summertime, extreme heat exposure is correlated with a rise in the number of hospitalizations for asthma (Soneja et al., 2016). A recent study reported increases in ambient temperatures and relative humidity were associated with decreased pulmonary function among the elderly (Lepeule et al., 2018). For individuals with pulmonary arterial hypertension, exposure to high temperatures ($> 77^{\circ}\text{F}$) exhibited significantly more adverse symptoms compared to those exhibited during normal ambient conditions (Jehn et al., 2014).

Animal studies on the effects of heat stress on pulmonary function are also inconsistent. Rats exposed to heat stress are protected against mechanical ventilator-induced lung dysfunction (Ribeiro et al. 2014) as heat shock proteins can adopt a cytoprotective role during lung inflammation and injury (Wheeler et al. 2014). Heat stress induces cellular heat shock responses and protects cells from delayed injury stimulation such as ischemia/reperfusion or oxidative injury though the inhibition of apoptosis of lipopolysaccharide-induced pulmonary microvascular endothelial cells (Liu et al., 2016) whereas other heat-exposed mice have

exhibited pathological changes in lungs including the lung matrix, the alveolar space, and epithelial cells (Liu et al., 2011).

Little is known about the impact of chronic heat exposure on the pulmonary function of oil spill response and cleanup workers. Only one study investigated heat exposures in OSRC workers following the 2010 *Deepwater Horizon (DWH)* disaster and reported a positive association between wet bulb globe temperatures (wet bulb globe temperature range: 82.4°F - 93.2°F) and the risk for exertional heat illness and acute injury (Garzon-Villalba et al., 2016). Given the importance of heat exposure as a risk factor for OSRC workers and the dearth of knowledge regarding the impacts of heat on lung function, it becomes necessary to estimate the relationship between heat stress and pulmonary function among OSRC workers following the *Deepwater Horizon* disaster.

Public Health Significance

A major gap in knowledge exists in understanding the effects of heat stress-related symptoms on pulmonary function (e.g. FEV₁, FVC, and FEV₁/FVC), particularly among workers with pre-existing illnesses. Therefore, findings from this research study may provide additional insight for policy development personnel to increase efforts in the protection of susceptible heat-exposed workers.

Rationale, Research Question, Hypothesis, Objectives

Rationale

According to the National Institute for Occupational Safety and Health (NIOSH), exposure to extreme heat may induce a variety of adverse occupational illnesses such as heat exhaustion, cramps, skin rashes, and even heat stroke in more vulnerable workers (CDC, 2018).

Moreover, the risk for occupational injuries is also higher among workers who are exposed to extreme heat or excessively hot environments (CDC, 2018). Certain sociodemographic and health-related personal/lifestyle risk factors for heat stress include age, body mass index (BMI), hydration status, pregnancy status, smoking/alcohol statuses, and pre-existing medical conditions such as high blood pressure, diabetes, asthma/bronchitis, and/or cardiovascular disease (OSHA). Environmental risk factors include higher ambient temperatures, higher relative humidity, lower wind speed, time of day, and lack of shade or cloud cover (OSHA). Occupation-specific risk factors include excessive physical exertion and use of heavy clothing such as those used as personal protective equipment (OSHA).

In the aftermath of the 2010 *Deepwater Horizon* disaster, oil spill response and cleanup (OSRC) workers and volunteers were exposed to extreme outdoor heat and were at greater risk of experiencing heat stress-related symptoms as well as developing adverse heat-related illnesses (Goldstein et al., 2011). Furthermore, prolonged exposure to heat and tropospheric ozone may exacerbate respiratory symptoms among OSRC workers with pre-existing respiratory conditions such as asthma and bronchitis (Asthma and Allergy Foundation of America, 2016). Findings from this research study may provide additional insight for policy development personnel to increase efforts in the protection of susceptible heat-exposed workers.

Research Question

This research study aimed to estimate the relationship between heat stress and pulmonary function among OSRC workers following the *Deepwater Horizon (DWH)* disaster.

Hypothesis

OSRC workers with heat stress-related symptoms during the time of work are at higher risk of lower pulmonary function (e.g. reduced FEV₁/FVC) compared to workers who did not experience heat stress-related symptoms.

Objectives

- 1) To develop a measure or measures of heat stress including self-reported heat stress-related symptoms and other indicators collected during enrollment in the GuLF STUDY.
- 2) To elucidate the relationship between heat stress-related symptoms or other measures of heat stress and pulmonary function while accounting for sociodemographic, health-related risk factors, and other oil spill chemical exposures.

METHODS

Data Collection: Study Design, Setting, and Participants Recruitment

Data was collected from the Gulf Long-term Follow-up Study (GuLF STUDY), a large prospective cohort study of adults who worked on the oil spill response effort or who received safety training but were not hired (Kwok et al., 2017). This study enrolled persons who participated in the oil spill response and cleanup work (workers) and others who were not hired (nonworkers) through a telephone interview that sought information on oil spill jobs and tasks, demographics, lifestyle, and health. Among the 25,304 eligible participants who spoke English or Spanish and resided in Alabama, Florida, Louisiana, Mississippi, and eastern Texas, a total of 11,193 enrolled participants completed home visits between May 2011 and May 2013 that involved pulmonary function testing. The analysis was restricted to workers with a pulmonary function test that met the American Thoracic Society/European Respiratory Society (ATS/ERS)

acceptability and reproducibility criteria and complete exposure and covariate information (n=5,131).

Heat Stress Related Symptoms

All heat-related symptoms were defined utilizing NIOSH-based definitions (National Institute for Occupational Safety & Health, 2018 #27). According to NIOSH, symptoms of heat exhaustion include headache, nausea, dizziness, weakness, irritability, thirst, heavy sweating, elevated body temperature, and decreased urine output (National Institute for Occupational Safety & Health, 2018 #27). A structured interview at enrollment was utilized to collect information on heat exposure. Specifically, participants were asked about how often they experienced specific symptoms at the time of the oil spill such as “sweating heavily for no reason”, “experienced severe headaches”, “experienced nausea”, “experienced dizziness”, “experienced fatigue”, and “experienced problems with urination”. Responses included “All the time”, “Most of the time”, “Sometimes”, “Rarely”, and “Never”. Participants were classified as exposed if they responded positively to having experienced a heat stress-related symptom “All the time” or “Most of the time” at the time of the oil spill. Due to the greater number of symptoms that corresponded with heat exhaustion, this specific heat-related illness was categorized based on the following criterion “experienced at least four symptoms or fewer than four symptoms related to heat exhaustion” The rationale underlying the selection of the most suitable number of heat exhaustion symptoms was due to the reason that experiencing at least four symptoms corresponded to the minimum number of symptoms that could be considered as possibly experiencing heat exhaustion. Furthermore, another heat exposure variable, “experienced any heat stress-related symptom”, was created to provide insight on a broader

scale. Additionally, another relevant heat exposure variable, "stopped work due to heat", was created to provide evidence that the individual symptoms were correlated with heat stress.

Pulmonary Function

Trained examiners at the home visit administered spirometry utilizing a portable ultrasound transit time-based spirometer (Easy On-PC; ndd Medical Technologies, Andover, MA) following 2005 ATS/ERS guidelines (Gam et al., 2018; Miller et al., 2005). Among home visit participants (n=11,193), some did not complete a spirometry test due to refusal (n=110), early home visit termination (n=75), or a technical problem (n=74). Others were not eligible for spirometry due to an American Thoracic Society or study-specific medical exclusion (n=716). The reason for missing spirometry test data was not recorded for a small sample of participants (n=178). For those home visit participants who completed spirometry tests, 8,055 participants had complete over-read data.

To assess pulmonary function among home visit participants who had passed the spirometry tests with valid quality scores, the forced expiratory volume in 1 second (FEV₁; milliliters), forced vital capacity (FVC; milliliters) and the ratio of FEV₁:FVC (FEV₁/FVC, %) were analyzed. Following a standard approach, we derived the FEV₁/FVC ratio by utilizing the best FEV₁ and best FVC measures regardless of the maneuver from which they originated (Miller et al., 2005).

Confounders Assessment

Covariates were selected for adjusted models using a minimally sufficient adjusted set as determined by a directed acyclic graph (Hernan, 2018). Demographic, socioeconomic, chemical exposures, and health-related data collected at enrollment included age (years), gender (male,

female), race (White, Black, Other). Hispanic ethnicity (Hispanic, Non-Hispanic), educational attainment (less than high school, high school equivalent, some college, 4 years college or greater), employment at enrollment (employed, looking for work, other), marital status (married/living with partner, not married/not living with partner), maximum ordinal total hydrocarbon (THC) level (≤ 0.29 ppm, 0.3 ppm – 0.9 ppm, 1.0 ppm – 2.99 ppm, ≥ 3 ppm), potentially for exposure to burning/flaring oil and natural gas (none, low/medium, high), potential for exposure to dispersants (yes, no), smoking status (heavy current [≥ 20 cigarettes per day], light current [< 20 cigarettes per day], former, never), previous lung disease (yes, no), diagnosis of hypertension (diagnosis before spill, diagnosis after spill, diagnosis [timing unknown], no diagnosis, diagnosis in same year as spill), and diagnosis of diabetes (diagnosis before spill, diagnosis after spill, diagnosis [timing unknown], no diagnosis, diagnosis in same year as spill). Examiners also measured standing height (inches) and weight (pounds); the mean of three measurements was used in statistical analyses. Additionally, examiners assessed the duration of clean-up among OSRC workers.

Statistical Analysis

Multivariable linear regression was employed to estimate the adjusted relationship between heat stress-related symptoms and pulmonary function among oil spill response and cleanup workers. Pulmonary function measures (FEV₁, FVC, and FEV₁/FVC ratio) were treated as separate continuous measures. Multivariable linear regression models were created to estimate the mean differences and 95% confidence intervals (CIs) in pulmonary function measures by individual heat stress-related symptom. Additionally, univariate binomial adjusted logistic regression models were employed to compare the significances of individual heat stress-related

symptoms between individuals with normal pulmonary function measures and those with abnormal measures with significances from the multivariable linear regression models. Statistical Analysis Software version 9.4 (SAS, Cary, NC) was used to conduct statistical analyses.

Sensitivity Analysis

To assess the impact of heat stress-related symptoms on pulmonary function among subgroups, analyses were stratified into the following subgroups: (1) pre-spill hypertension (n=930), (2) pre-spill diabetes (n=268), (3) pre-spill asthma (n=523), (4) stopped work due to heat (n=2105), and (5) sought medical assistance for having experienced any heat stress-related symptoms at the time of the oil spill disaster (n=1111), (6) type of job worked during the oil spill cleanup and response (n=898), and (7) time of home visit closest to the time of the oil spill disaster (n=679).

Ethical Considerations

This research study was approved by the Institutional Review Board of the National Institute of Environmental Health Sciences. Written informed consent was collected for all participants who completed a home visit.

RESULTS

Workers who had stopped work due to heat were slightly younger than workers who had not stopped work due to heat (42 vs. 44 years of age; Table 1). A higher proportion of workers who had not stopped work due to heat than workers who had stopped work due to heat were men (84% vs. 74%) and were of Caucasian descent (64% vs. 45%). Only a slightly higher proportion of workers who had not stopped work due to heat than workers who had stopped work due to heat were Hispanic (7.2% vs. 5.2%). Also, a higher proportion of workers who had not stopped

work due to heat than workers who had stopped work due to heat had 4 or more years of higher education (16% vs. 8.8%) and were employed at the time of enrollment (62% vs. 52%).

Moreover, a higher proportion of workers who had not stopped work due to heat than workers who had stopped work due to heat were married or living with a partner (55% vs. 45%).

Contrarily, a slightly higher proportion of workers who had stopped work due to heat than workers who had not stopped work due to heat were exposed to a maximum THC level of ≥ 3 ppm (18% vs. 13%) and were potentially exposed to high levels of burning or flaring (1.2% vs. 0.93%) as well as dispersant(s) (15% vs. 7.7%). Interestingly, approximately identical proportions of workers who had stopped work due to heat and workers who had not stopped work due to heat were heavy smokers at the time of enrollment (13% vs. 13%).

With regard to chronic conditions, a slightly higher proportion of workers who had stopped work due to heat than workers who had not stopped work due to heat had been diagnosed with lung disease (17% vs. 14%). However, a slightly higher proportion of workers who had not stopped work due to heat than workers who had stopped work due to heat had been diagnosed with hypertension (19% vs. 17%) and diabetes (5.7% vs. 4.5%) prior to the oil spill.

Adjusted pulmonary function measurements by heat stress-related exposures as well as sociodemographic, chemical, and lifestyle exposures are shown in Table 2. Among workers with acceptable quality scores on spirometry tests and complete exposure and covariate information, a suggestive positive relationship was observed between having stopped work due to heat and the FEV₁/FVC% ratio (beta: 0.18%; 95% CI: -0.20 to 0.55), whereas a suggestive inverse relationship was observed between having experienced any type of heat stress-related symptom at the time of the oil spill and the FEV₁/FVC% ratio (beta: -0.17%; 95% CI: -0.54 to 0.21).

Likewise, a suggestive positive relationship was observed between having stopped work due to heat and the FEV₁/FVC% ratio (adjusted odds ratio: 1.3; 95% CI: 0.83 to 1.47) among workers with acceptable quality scores on spirometry tests and complete exposure and covariate information. Furthermore, a suggestive inverse relationship was observed between having experienced any type of heat stress-related symptom at the time of the oil spill and the FEV₁/FVC% ratio (adjusted odds ratio: -1.04; 95% CI: -1.26 to 1.08) among workers with acceptable quality scores on spirometry tests and complete exposure and covariate information.

Among workers with pre-spill hypertension (shown in Table 4), a statistically significant inverse relationship was observed between having experienced any problems with urination at the time of the oil spill and FEV₁ (beta: -212 mL; 95% CI: -360, -65) whereas a suggestive positive relationship was observed between having stopped work due to heat and the FEV₁/FVC% ratio (beta: 0.42%; 95% CI: -0.54 to 1.38). Among workers with pre-spill diabetes (shown in Table 5), statistically significant inverse relationships were observed between having experienced severe headaches at the time of the oil spill and the FEV₁/FVC% ratio (beta: -2.97%; 95% CI: -5.45 to -0.48) as well as between having experienced dizziness at the time of the oil spill and the FEV₁/FVC% ratio (beta: -3.86%; 95% CI: -6.84 to -0.89). Among workers with pre-spill asthma (shown in Table 6), a suggestive positive relationship was observed between having stopped work due to heat and FEV₁/FVC% ratio (beta: 1.18%; 95% CI: -0.17 to 2.52).

Among workers who had sought medical assistance at the time of the oil spill (shown in Table 7), a statistically significant positive relationship was observed between having experienced fatigue/extreme tiredness at the time of the oil spill and FVC (beta: 88 mL; 95% CI:

3 to 173). In addition, a suggestive positive relationship was observed between having experienced nausea at the time of the oil spill and the FEV₁/FVC% ratio (beta: 1.07%; 95% CI: -0.18 to 2.32). Among workers who had conducted cleanup activities on land (shown in Table 8), statistically significant inverse relationships were observed between having stopped work due to heat and FEV₁ (beta: -77 mL; 95% CI: -152 to -1.59) as well as between having experienced nausea at the time of the oil spill and FEV₁ (beta: -148 mL; 95% CI: -295 to -0.80). Moreover, a statistically significant inverse relationship was also observed between having stopped work due to heat and FVC (beta: -90 mL; 95% CI: -179 to -0.77). Additionally, a suggestive positive relationship was observed between having experienced problems with urination at the time of the oil spill and the FEV₁/FVC% ratio (beta: 1.89%; 95% CI: -0.03 to 3.81).

Among workers who had completed a home visit closest to the time of the oil spill (shown in Table 9), a suggestive positive relationship was observed between having experienced dizziness at the time of the oil spill and FEV₁ (beta: 157 mL; 95% CI: -7 to 320). Moreover, a statistically significant positive relationship was observed between having experienced dizziness at the time of the oil spill and FVC (beta: 288 mL; 95% CI: -90 to 487). Furthermore, statistically significant inverse relationships were observed between having experienced nausea at the time of the oil spill and the FEV₁/FVC% ratio (beta: -3.21%; 95% CI: -5.49 to -0.93) as well as between having experienced any type of heat stress-related symptom at the time of the oil spill and the FEV₁/FVC% ratio (beta: -1.42%; 95% CI: -2.51 to -0.34).

Table 1. Characteristics of GuLF STUDY Home Visit Participants with Acceptable Pulmonary Function Test Quality Scores by Stopped Work Due to Heat (n = 5,131)

Characteristics	Stopped Work Due to Heat	Did not Stop Work Due to Heat
	(n = 2,105)	(n = 3,026)
	Mean (SD)	Mean (SD)
Age (yrs)	42.0 (11.9)	44.5 (13.1)
Height (inches)	68.6 (4.1)	69.1 (4.0)
Weight (lbs)	195.0 (43.8)	197.9 (43.6)
Duration of Clean-up (days)	152.2 (144.1)	136.5 (138.2)
	n (%)	n (%)
Gender		
Male	1561 (74)	2532 (84)
Female	544 (26)	494 (16)
Race		
Caucasian	956 (45)	1927 (64)
African American	975 (46)	753 (25)
Other	174 (8.3)	346 (11)
Ethnicity		
Hispanic	110 (5.2)	212 (7.0)
Non-Hispanic	1995 (95)	2814 (93)
Education		
Less than High School/Equivalent	453 (21)	573 (19)
High School Diploma/GED	784 (37)	1013 (33)
Some College/2-yr Degree	683 (32)	956 (32)
4-yr College Graduate or Higher	185 (8.8)	484 (16)
Employment		
Working Now	1090 (52)	1890 (62)
Looking for Work or Unemployed	704 (33)	683 (23)
Other	311 (15)	453 (15)
Marital Status		
Married/Living with Partner	941 (45)	1663 (55)
Not Married/Not Living with Partner	1164 (55)	1363 (45)
Maximum THC Level		
≤ 0.29 ppm	186 (8.8)	386 (13)
0.3 ppm – 0.9 ppm	844 (40)	1144 (38)
1.0 ppm – 2.99 ppm	688 (33)	1105 (36)
≥ 3 ppm	387 (18)	391 (13)

Potential for Exposure to Burning/Flaring		
No Burning/Flaring	1875 (89)	2779 (92)
Low/Medium Burning/Flaring	205 (9.7)	219 (7.2)
High Burning/Flaring	25 (1.2)	28 (0.93)
Potential for Exposure to Dispersant(s)		
Yes	311 (15)	233 (7.7)
No	1794 (85)	2793 (92)
Smoking Status		
Heavy Current Smoker	275 (13)	387 (13)
Light Current Smoker	624 (30)	658 (22)
Former Smoker	363 (17)	679 (22)
Never Smoker	843 (40)	1302 (43)
Previous Lung Disease		
Yes	364 (17)	425 (14)
No	1741 (83)	2601 (86)
Diagnosis of Hypertension		
Diagnosis Before Spill	365 (17)	571 (19)
Diagnosis After Spill	284 (13)	224 (7.4)
Diagnosis, Timing Unknown	25 (1.2)	52 (1.7)
No Diagnosis	1401 (67)	2142 (71)
Diagnosis in Same Year as Spill	30 (1.4)	37 (1.2)
Diagnosis of Diabetes		
Diagnosis Before Spill	95 (4.5)	173 (5.7)
Diagnosis After Spill	50 (2.4)	59 (1.9)
Diagnosis, Timing Unknown	4 (0.19)	10 (0.33)
No Diagnosis	1955 (93)	2774 (92)
Diagnosis in Same Year as Spill	1 (0.05)	10 (0.33)
GULF STUDY, Gulf Long-term Follow-up Study.		

Table 2. Heat Stress-Related Symptoms and Pulmonary Function
Among Workers with Acceptable Spirometry Quality Scores (n = 5,131)

Exposure Status		n	Linear/Logistic Regression Beta (95% CI) ^a OR (95% CI) ^b
FEV ₁ (mL)			
Stopped work due to heat			
	Yes	2105	8 (-25, 41)
	No	3026	Referent
Profuse sweating			
	Yes	868	0.43 (-41.86, 42.73)
	No	4263	Referent
Severe headaches			
	Yes	981	-11 (-52, 29)
	No	4150	Referent
Nausea			
	Yes	357	-17 (-78, 45)
	No	4774	Referent
Dizziness			
	Yes	538	6 (-46, 58)
	No	4593	Referent
Fatigue/Extreme tiredness			
	Yes	1321	0.74 (-35, 37)
	No	3810	Referent
Problems with urination			
	Yes	341	-41 (-104, 21)
	No	4790	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	324	4 (-61, 68)
	No	4807	Referent
Experienced any heat stress-related symptoms			
	Yes	2141	-23 (-55, 10)
	No	2990	Referent
FVC (mL)			
Stopped work due to heat			
	Yes	2105	5 (-34, 44)
	No	3026	Referent

Profuse sweating	Yes	868	4 (-46, 54)
	No	4263	Referent
Severe headaches	Yes	981	0.83 (-47, 49)
	No	4150	Referent
Nausea	Yes	357	-10 (-83, 63)
	No	4774	Referent
Dizziness	Yes	538	16 (-46, 78)
	No	4593	Referent
Fatigue/Extreme tiredness	Yes	1321	14 (-28, 57)
	No	3810	Referent
Problems with urination	Yes	341	-33 (-107, 40)
	No	4790	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	324	-0.57 (-77, 76)
	No	4807	Referent
Experienced any heat stress-related symptoms	Yes	2141	-14 (-53, 25)
	No	2990	Referent
FEV ₁ /FVC%			
Stopped work due to heat	Yes	2105	0.18 (-0.20, 0.55)/1.3 (0.83, 1.47)
	No	3026	Referent
Profuse sweating	Yes	868	0.002 (-0.48, 0.49)
	No	4263	Referent
Severe headaches	Yes	981	-0.09 (-0.56, 0.37)
	No	4150	Referent
Nausea	Yes	357	-0.11 (-0.82, 0.59)
	No	4774	Referent

Dizziness	Yes	538	-0.002 (-0.60, 0.59)
	No	4593	Referent
Fatigue/Extreme tiredness	Yes	1321	-0.18 (-0.59, 0.24)
	No	3810	Referent
Problems with urination	Yes	341	-0.36 (-1.07, 0.35)
	No	4790	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	324	0.21 (-0.53, 0.95)
	No	4807	Referent
Experienced any heat stress-related symptoms	Yes	2141	-0.17 (-0.54, 0.21)/-1.04 (-1.26, 1.08)
	No	2990	Referent
*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of cleanup efforts, previous lung disease, hypertension diagnosis, and diabetes diagnosis.			

Table 3. Heat Stress-Related Symptoms and Pulmonary Function
Among Workers Who Had Stopped Work Due to Heat (n = 2,105)

Exposure Status		n	Linear Regression Beta (95% CI) ^a
FEV ₁ (mL)			
Profuse sweating			
	Yes	558	19 (-36, 73)
	No	1547	Referent
Severe headaches			
	Yes	604	-16 (-69, 38)
	No	1501	Referent
Nausea			
	Yes	243	-20 (-95, 54)
	No	1862	Referent
Dizziness			
	Yes	392	-3 (-66, 59)
	No	1713	Referent
Fatigue/Extreme tiredness			
	Yes	821	-4.9 (-54, 44)
	No	1284	Referent
Problems with urination			
	Yes	218	-42 (-120, 36)
	No	1887	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	241	-8 (-83, 68)
	No	1864	Referent
Experienced any heat stress-related symptoms			
	Yes	1258	-22 (-71, 27)
	No	847	Referent
FVC (mL)			
Profuse sweating			
	Yes	558	26 (-39, 90)
	No	1547	Referent
Severe headaches			
	Yes	604	-3 (-67, 60)
	No	1501	Referent

Nausea	Yes	243	-24 (-112, 65)
	No	1862	Referent
Dizziness	Yes	392	-3 (-78, 71)
	No	1713	Referent
Fatigue/Extreme tiredness	Yes	821	15 (-43, 72)
	No	1284	Referent
Problems with urination	Yes	218	-35 (-128, 57)
	No	1887	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	241	-0.61 (-90, 89)
	No	1864	Referent
Experienced any heat stress-related symptoms	Yes	1258	-12 (-70, 47)
	No	847	Referent
FEV ₁ /FVC%			
Profuse sweating	Yes	558	-0.04 (-0.68, 0.60)
	No	1547	Referent
Severe headaches	Yes	604	-0.12 (-0.76, 0.52)
	No	1501	Referent
Nausea	Yes	243	-0.11 (-0.99, 0.77)
	No	1862	Referent
Dizziness	Yes	392	0.10 (-0.64, 0.84)
	No	1713	Referent
Fatigue/Extreme tiredness	Yes	821	-0.33 (-0.91, 0.25)
	No	1284	Referent
Problems with urination	Yes	218	-0.48 (-1.40, 0.44)
	No	1887	Referent

Heat exhaustion categorized by
 ≥ 4 symptoms or < 4 symptoms

Yes	241	-0.11 (-1.00, 0.78)
No	1864	Referent

Experienced any heat stress-related
symptoms

Yes	1258	-0.21 (-0.80, 0.37)
No	847	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of cleanup efforts, previous lung disease, hypertension diagnosis, and diabetes diagnosis.

Table 4. Heat Stress-Related Symptoms and Pulmonary Function
Among Workers with Pre-Spill Hypertension (n = 930)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped Work Due to Heat			
	Yes	365	-11 (-88, 67)
	No	565	Referent
Profuse sweating			
	Yes	158	-7.4 (-106, 91)
	No	772	Referent
Severe headaches			
	Yes	149	5.6 (-101, 112)
	No	781	Referent
Nausea			
	Yes	61	-129 (-279, 21)
	No	869	Referent
Dizziness			
	Yes	102	29 (-94, 151)
	No	828	Referent
Fatigue/Extreme tiredness			
	Yes	220	12 (-75, 100)
	No	710	Referent
Problems with urination			
	Yes	61	-212 (-360, -65)
	No	869	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	59	-79 (-234, 75)
	No	871	Referent
Experienced any heat stress-related symptoms			
	Yes	363	-42 (-121, 36)
	No	567	Referent
FVC (mL)			
Stopped Work Due to Heat			
	Yes	365	-29 (-121, 62)
	No	565	Referent

Profuse sweating	Yes	158	-22 (-138, 94)
	No	772	Referent
Severe headaches	Yes	149	63 (-62, 188)
	No	781	Referent
Nausea	Yes	61	-168 (-345, 8.9)
	No	869	Referent
Dizziness	Yes	102	54 (-90, 199)
	No	828	Referent
Fatigue/Extreme tiredness	Yes	220	63 (-40, 167)
	No	710	Referent
Problems with urination	Yes	61	-208 (-382, -34)
	No	869	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	59	-115 (-298, 67)
	No	871	Referent
Experienced any heat stress-related symptoms	Yes	363	-16 (-108, 77)
	No	567	Referent
FEV ₁ /FVC%			
Stopped Work Due to Heat	Yes	365	0.42 (-0.54, 1.38)
	No	565	Referent
Profuse sweating	Yes	158	0.26 (-0.95, 1.48)
	No	772	Referent
Severe headaches	Yes	149	-0.82 (-2.13, 0.49)
	No	781	Referent
Nausea	Yes	61	-0.06 (-1.92, 1.80)
	No	869	Referent

Dizziness	Yes	102	-0.30 (-1.82, 1.21)
	No	828	Referent
Fatigue/Extreme tiredness	Yes	220	-0.81 (-1.89, 0.28)
	No	710	Referent
Problems with urination	Yes	61	-1.56 (-3.38, 0.27)
	No	869	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	59	0.35 (-1.56, 2.26)
	No	871	Referent
Experienced any heat stress-related symptoms	Yes	363	-0.67 (-1.64, 0.30)
	No	567	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, previous lung disease, and diabetes diagnosis.

Table 5. Heat Stress-Related Symptoms and Pulmonary Function Among Workers with Pre-Spill Diabetes (n = 268)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped Work Due to Heat			
	Yes	95	109 (-26, 245)
	No	173	Referent
Profuse sweating			
	Yes	40	-2.6 (-181, 176)
	No	228	Referent
Severe headaches			
	Yes	44	-106 (-291, 79)
	No	224	Referent
Nausea			
	Yes	16	-33 (-306, 240)
	No	252	Referent
Dizziness			
	Yes	28	12 (-210, 234)
	No	240	Referent
Fatigue/Extreme tiredness			
	Yes	67	-42 (-196, 111)
	No	201	Referent
Problems with urination			
	Yes	18	99 (-157, 356)
	No	250	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	15	36 (-255, 326)
	No	253	Referent
Experienced any heat stress-related symptoms			
	Yes	104	-81 (-220, 58)
	No	164	Referent
FVC (mL)			
Stopped Work Due to Heat			
	Yes	95	111 (-52, 274)
	No	173	Referent

Profuse sweating	Yes	40	0.20 (-215, 215)
	No	228	Referent
Severe headaches	Yes	44	-13 (-236, 210)
	No	224	Referent
Nausea	Yes	16	-5.3 (-334, 323)
	No	252	Referent
Dizziness	Yes	28	175 (-91, 441)
	No	240	Referent
Fatigue/Extreme tiredness	Yes	67	-8.7 (-194, 176)
	No	201	Referent
Problems with urination	Yes	18	230 (-78, 538)
	No	250	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	15	133 (-216, 482)
	No	253	Referent
Experienced any heat stress-related symptoms	Yes	104	-78 (-246, 89)
	No	164	Referent
FEV ₁ /FVC%			
Stopped Work Due to Heat	Yes	95	0.41 (-1.44, 2.26)
	No	173	Referent
Profuse sweating	Yes	40	-0.08 (-2.51, 2.35)
	No	228	Referent
Severe headaches	Yes	44	-2.97 (-5.45, -0.48)
	No	224	Referent
Nausea	Yes	16	-0.84 (-4.55, 2.86)
	No	252	Referent

Dizziness	Yes	28	-3.86 (-6.84, -0.89)
	No	240	Referent
Fatigue/Extreme tiredness	Yes	67	-1.18 (-3.26, 0.91)
	No	201	Referent
Problems with urination	Yes	18	-2.47 (-5.95, 1.00)
	No	250	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	15	-2.18 (-6.11, 1.75)
	No	253	Referent
Experienced any heat stress-related symptoms	Yes	104	-0.78 (-2.68, 1.11)
	No	164	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, previous lung disease, and hypertension diagnosis.

Table 6. Heat Stress-Related Symptoms and Pulmonary Function
Among Workers with Pre-Spill Asthma (n = 523)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped Work Due to Heat			
	Yes	247	59 (-48, 166)
	No	276	Referent
Profuse sweating			
	Yes	88	-17 (-155, 120)
	No	435	Referent
Severe headaches			
	Yes	106	39 (-95, 174)
	No	417	Referent
Nausea			
	Yes	34	-100 (-311, 111)
	No	489	Referent
Dizziness			
	Yes	57	80 (-92, 251)
	No	466	Referent
Fatigue/Extreme tiredness			
	Yes	134	-67 (-185, 51)
	No	389	Referent
Problems with urination			
	Yes	25	150 (-88, 387)
	No	498	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	30	72 (-154, 298)
	No	493	Referent
Experienced any heat stress-related symptoms			
	Yes	226	-79 (-185, 26)
	No	297	Referent
FVC (mL)			
Stopped Work Due to Heat			
	Yes	247	20 (-106, 146)
	No	276	Referent

Profuse sweating	Yes	88	-52 (-215, 110)
	No	435	Referent
Severe headaches	Yes	106	100 (-58, 258)
	No	417	Referent
Nausea	Yes	34	-124 (-372, 125)
	No	489	Referent
Dizziness	Yes	57	133 (-69, 335)
	No	466	Referent
Fatigue/Extreme tiredness	Yes	134	-44 (-183, 95)
	No	389	Referent
Problems with urination	Yes	25	65 (-216, 345)
	No	498	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	30	93 (-173, 359)
	No	493	Referent
Experienced any heat stress-related symptoms	Yes	226	-50 (-175, 74)
	No	297	Referent
FEV ₁ /FVC%			
Stopped Work Due to Heat	Yes	247	1.18 (-0.17, 2.52)
	No	276	Referent
Profuse sweating	Yes	88	0.97 (-0.76, 2.71)
	No	435	Referent
Severe headaches	Yes	106	-0.51 (-2.20, 1.19)
	No	417	Referent
Nausea	Yes	34	0.29 (-2.38, 2.95)
	No	489	Referent

Dizziness	Yes	57	-0.33 (-2.50, 1.83)
	No	466	Referent
Fatigue/Extreme tiredness	Yes	134	-0.77 (-2.26, 0.71)
	No	389	Referent
Problems with urination	Yes	25	2.31 (-0.68, 5.30)
	No	498	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	30	0.32 (-2.52, 3.17)
	No	493	Referent
Experienced any heat stress-related symptoms	Yes	226	-0.71 (-2.04, 0.62)
	No	297	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, hypertension diagnosis, and diabetes diagnosis.

Table 7. Heat Stress-Related Symptoms and Pulmonary Function Among Workers Who Had Sought Medical Assistance at the Time of the Oil Spill (n = 1,111)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped work due to heat			
	Yes	649	-19 (-90, 53)
	No	462	Referent
Profuse sweating			
	Yes	277	21 (-60, 103)
	No	834	Referent
Severe headaches			
	Yes	378	11 (-63, 86)
	No	733	Referent
Nausea			
	Yes	140	-19 (-123, 86)
	No	971	Referent
Dizziness			
	Yes	211	54 (-36, 143)
	No	900	Referent
Fatigue/Extreme tiredness			
	Yes	419	58 (-14, 129)
	No	692	Referent
Problems with urination			
	Yes	117	-82 (-194, 31)
	No	994	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	141	-47 (-152, 58)
	No	970	Referent
Experienced any heat stress-related symptoms			
	Yes	667	24 (-49, 97)
	No	444	Referent
FVC (mL)			
Stopped work due to heat			
	Yes	649	13 (-72, 98)
	No	462	Referent

Profuse sweating	Yes	277	33 (-64, 129)
	No	834	Referent
Severe headaches	Yes	378	-9 (-98, 80)
	No	733	Referent
Nausea	Yes	140	-85 (-208, 39)
	No	971	Referent
Dizziness	Yes	211	56 (-50, 162)
	No	900	Referent
Fatigue/Extreme tiredness	Yes	419	88 (3, 173)
	No	692	Referent
Problems with urination	Yes	117	-91 (-225, 42)
	No	994	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	141	-70 (-194, 54)
	No	970	Referent
Experienced any heat stress-related symptoms	Yes	667	18 (-68, 105)
	No	444	Referent
FEV ₁ /FVC%			
Stopped work due to heat	Yes	649	-0.54 (-1.40, 0.31)
	No	462	Referent
Profuse sweating	Yes	277	0.02 (-0.96, 0.99)
	No	834	Referent
Severe headaches	Yes	378	0.69 (-0.20, 1.59)
	No	733	Referent
Nausea	Yes	140	1.07 (-0.18, 2.32)
	No	971	Referent

Dizziness	Yes	211	0.23 (-0.85, 1.30)
	No	900	Referent
Fatigue/Extreme tiredness	Yes	419	-0.15 (-1.01, 0.71)
	No	692	Referent
Problems with urination	Yes	117	-0.53 (-1.88, 0.82)
	No	994	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	141	0.26 (-1.00, 1.52)
	No	970	Referent
Experienced any heat stress-related symptoms	Yes	667	0.41 (-0.46, 1.29)
	No	444	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, previous lung disease, hypertension diagnosis, and diabetes diagnosis.

Table 8. Heat Stress-Related Symptoms and Pulmonary Function
Among Workers Who Conducted Cleanup Activities on Land (n = 898)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped Work Due to Heat			
	Yes	347	-77 (-152, -1.59)
	No	551	Referent
Profuse sweating			
	Yes	126	-17 (-120, 85)
	No	772	Referent
Severe headaches			
	Yes	168	-35 (-128, 58)
	No	730	Referent
Nausea			
	Yes	54	-148 (-295, -0.80)
	No	844	Referent
Dizziness			
	Yes	86	4.16 (-117, 125)
	No	812	Referent
Fatigue/Extreme tiredness			
	Yes	204	58 (-28, 144)
	No	694	Referent
Problems with urination			
	Yes	46	44 (-115, 203)
	No	852	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	40	-100 (-269, 68)
	No	858	Referent
Experienced any heat stress-related symptoms			
	Yes	345	15 (-60, 91)
	No	553	Referent
FVC (mL)			
Stopped Work Due to Heat			
	Yes	347	-90 (-179, -0.77)
	No	551	Referent

Profuse sweating	Yes	126	-27 (-149, 94)
	No	772	Referent
Severe headaches	Yes	168	-62 (-173, 49)
	No	730	Referent
Nausea	Yes	54	-141 (-316, 34)
	No	844	Referent
Dizziness	Yes	86	-22 (-166, 121)
	No	812	Referent
Fatigue/Extreme tiredness	Yes	204	79 (-23, 182)
	No	694	Referent
Problems with urination	Yes	46	-44 (-233, 145)
	No	852	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	40	-106 (-306, 94)
	No	858	Referent
Experienced any heat stress-related symptoms	Yes	345	5.76 (-84, 95)
	No	553	Referent
FEV ₁ /FVC%			
Stopped Work Due to Heat	Yes	347	-0.16 (-1.07, 0.75)
	No	551	Referent
Profuse sweating	Yes	126	-0.04 (-1.27, 1.20)
	No	772	Referent
Severe headaches	Yes	168	0.59 (-0.54, 1.72)
	No	730	Referent
Nausea	Yes	54	-0.75 (-2.54, 1.04)
	No	844	Referent

Dizziness	Yes	86	0.61 (-0.87, 2.07)
	No	812	Referent
Fatigue/Extreme tiredness	Yes	204	0.15 (-0.89, 1.20)
	No	694	Referent
Problems with urination	Yes	46	1.89 (-0.03, 3.81)
	No	852	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	40	-0.41 (-2.46, 1.63)
	No	858	Referent
Experienced any heat stress-related symptoms	Yes	345	0.52 (-0.39, 1.44)
	No	553	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, previous lung disease, hypertension diagnosis, and diabetes diagnosis.

Table 9. Heat Stress-Related Symptoms and Pulmonary Function Among Workers Who Had Completed a Home Visit Closest to Time of Oil Spill (n = 679)

Exposure Status		n	Linear Regression
			Beta (95% CI) ^a
FEV ₁ (mL)			
Stopped Work Due to Heat			
	Yes	246	-8 (-103, 87)
	No	433	Referent
Profuse sweating			
	Yes	95	69 (-64, 203)
	No	584	Referent
Severe headaches			
	Yes	106	-98 (-223, 28)
	No	573	Referent
Nausea			
	Yes	36	-131 (-331, 69)
	No	643	Referent
Dizziness			
	Yes	56	157 (-7, 320)
	No	623	Referent
Fatigue/Extreme tiredness			
	Yes	178	-34 (-138, 70)
	No	501	Referent
Problems with urination			
	Yes	35	-45 (-250, 160)
	No	644	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms			
	Yes	26	-27 (-206, 207)
	No	653	Referent
Experienced any heat stress-related symptoms			
	Yes	286	-60 (-155, 36)
	No	393	Referent
FVC (mL)			
Stopped Work Due to Heat			
	Yes	246	-19 (-135, 97)
	No	433	Referent

Profuse sweating	Yes	95	108 (-54, 271)
	No	584	Referent
Severe headaches	Yes	106	-69 (-222, 83)
	No	573	Referent
Nausea	Yes	36	7 (-236, 251)
	No	643	Referent
Dizziness	Yes	56	288 (90, 487)
	No	623	Referent
Fatigue/Extreme tiredness	Yes	178	-11 (-138, 116)
	No	501	Referent
Problems with urination	Yes	35	-51 (-300, 199)
	No	644	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	26	-55 (-339, 229)
	No	653	Referent
Experienced any heat stress-related symptoms	Yes	286	-4 (-120, 112)
	No	393	Referent
FEV ₁ /FVC%			
Stopped Work Due to Heat	Yes	246	-0.02 (-1.11, 1.07)
	No	433	Referent
Profuse sweating	Yes	95	-0.26 (-1.79, 1.27)
	No	584	Referent
Severe headaches	Yes	106	-1.11 (-2.55, 0.32)
	No	573	Referent
Nausea	Yes	36	-3.21 (-5.49, -0.93)
	No	643	Referent

Dizziness	Yes	56	-1.09 (-2.97, 0.78)
	No	623	Referent
Fatigue/Extreme tiredness	Yes	178	-0.73 (-1.92, 0.46)
	No	501	Referent
Problems with urination	Yes	35	0.62 (-2.96, 1.72)
	No	644	Referent
Heat exhaustion categorized by ≥ 4 symptoms or < 4 symptoms	Yes	26	-0.11 (-2.78, 2.56)
	No	653	Referent
Experienced any heat stress-related symptoms	Yes	286	-1.42 (-2.51, -0.34)
	No	393	Referent

*Adjusted for: age, gender, race, ethnicity, height, height-squared, weight, level of education, employment status, marital status, maximum ordinal THC level, potentially exposed to burning/flaring, worked with dispersants, smoking status, duration of clean-up efforts, previous lung disease, hypertension diagnosis, and diabetes diagnosis.

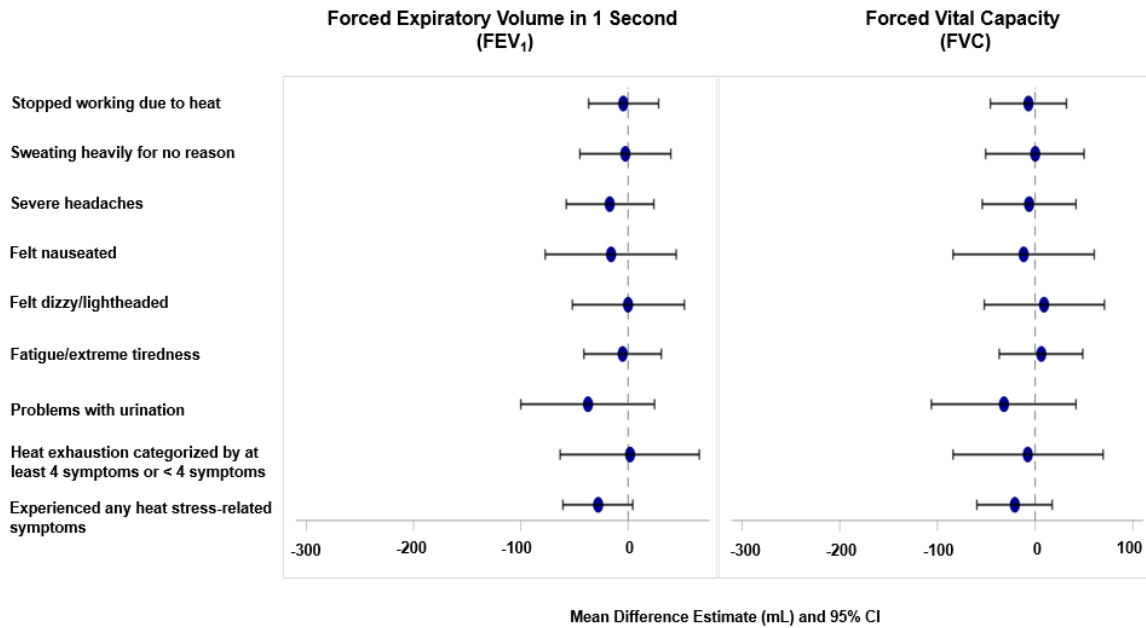


Figure 1. No clear associations between heat stress-related symptoms and pulmonary function among cleanup workers overall (N=5,131)

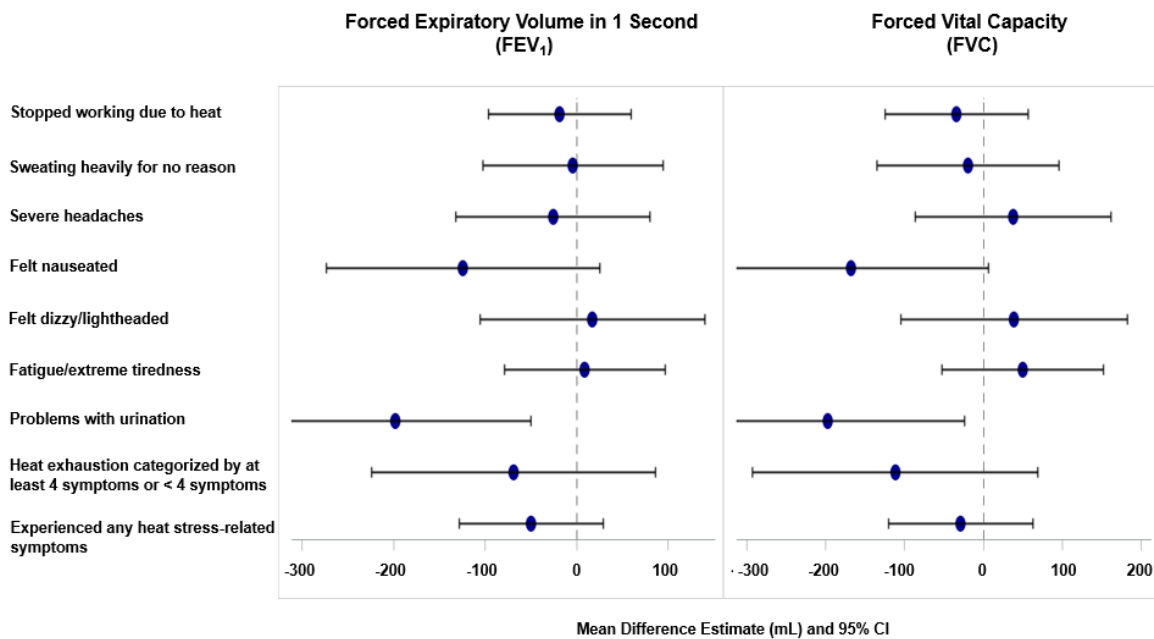


Figure 2. Problems with urination all or most of the time inversely associated with pulmonary function among oil spill cleanup workers with pre-spill hypertension (N=930)

DISCUSSION

In the subgroup that included participants with pre-spill hypertension, it was generally observed that having experienced any problems with urination at the time of the oil spill may have resulted in reduced pulmonary function. In the subgroup of participants with pre-spill diabetes, it was generally observed that having experienced severe headaches and dizziness at the time of the oil spill may have resulted in decreased pulmonary function. In the subgroup that included participants who had sought medical assistance at the time of the oil spill, it was generally observed that having experienced fatigue/extreme tiredness at the time of the oil spill may have resulted in an improvement in pulmonary function. In the subgroup of participants who had conducted cleanup activities on land, it was generally observed that having stopped work due to heat may have resulted in reduced pulmonary function. In the subgroup that included participants who had completed a home visit closest to the time of the oil spill, it was generally observed that having experienced dizziness at the time of the oil spill may have resulted in an improvement in pulmonary function. Nevertheless, it was also observed that having experienced nausea and any type of heat stress-related symptom at the time of the oil spill may have resulted in decreased pulmonary function.

To the best of my knowledge, the underlying biological mechanisms responsible for the observed associations are unclear at the current state of research. Although it has been elucidated that high humidity conditions suppress the evaporation associated with perspiration (Lepeule et al., 2018), the general impacts on pulmonary function have been quite understudied. Nevertheless, researchers have suggested that thermoregulatory mechanisms may be impaired under high ambient heat conditions, particularly among vulnerable subgroups such as individuals

with pre-existing conditions. The dysfunction in thermoregulatory mechanisms may result in decreases in cardiac output and ultimately reduced cutaneous blood flow and respiratory rate (Lepeule et al., 2018).

Individuals with a chronic form of a less prevalent type of hypertension (known as pulmonary hypertension) are highly susceptible to ambient heat conditions due to the reason that the arteries that carry blood from the right side of the heart to the lungs stiffen (bronchoconstriction) and thicken or develop blood clots upon exposure to high temperatures and relative humidity (Harvard Heart Letter). Moreover, the stimulus for this particular type of bronchoconstriction (EIB) is the loss of water by humidifying large volumes of air during physical exertion (Anderson & Kippelen, 2010). Furthermore, the mechanism for EIB is related to both the thermal and osmotic effects of water loss (Anderson & Kippelen, 2010). The thermal theory proposes that EIB is a vascular event comprising of vasoconstriction during physical exertion followed by rapid rewarming and a reactive hyperemia at the end of physical exertion (Anderson & Kippelen, 2010). Contrarily, the osmotic theory proposes that water loss induces an increase in osmolarity in the airways, which subsequently causes the release of mediators that cause bronchial smooth muscle to contract (Anderson & Kippelen, 2010).

Several limitations are present in this study that impede the feasible interpretation of the findings. One of the major limitations of is that only one-time measurements of pulmonary function were collected approximately 1 to 3 years following the oil spill disaster. A second limitation is that exposure variables only serve as proxies for heat stress and heat exposure. In other words, individual metabolic rates and average hourly wet bulb globe temperatures were not measured. Despite these limitations, this is the first study to examine the associations between

heat stress and pulmonary function among the workers who were engaged in cleanup efforts following the 2010 *Deepwater Horizon* oil spill disaster. Furthermore, future studies are necessary to further investigate this research topic by linking external web bulb globe temperature data as well as exploring the impacts of the effect modifications with different types of potential chemical and biological oil spill exposures.

CONCLUSIONS

Based on the overall findings, it is rather evident that workers with pre-spill conditions may experience an exacerbation of their symptoms under conditions consisting of both high ambient temperatures and relative humidity. Therefore, it is reasonable to conclude that workers with pre-spill hypertension or other cardiometabolic conditions may be at increased risk of reduced pulmonary function due to heat stress.

APPENDICES

- Appendix A: [Study Protocol](#)
- Appendix B: [Telephone Enrollment Questionnaire](#)
- Appendix C: [Home Visit Questionnaire](#)
- Appendix D: [Exposure Monitoring Questionnaire](#)
- Appendix E: [Follow-up Telephone Questionnaire](#)
- Appendix F: [Follow-up Mental Health Questionnaire](#)
- Appendix G: [Clinical Exam-Health Questionnaire](#)
- Appendix H: [Clinical Exam-Mental Health Questionnaire](#)
- Appendix I: [Clinical Exam-Mental Health Referral Questionnaire](#)
- Appendix J: [Clinical Exam-Substance Abuse Questionnaire](#)
- Appendix K: [Clinical Exam-Saliva Questionnaire](#)

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